RSC Sustainability

PAPER

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Cite this: *RSC Sustainability*, 2026, **4**, 2211

Instructional laboratory personnel's views about practices of chemical safety and security: implications for professional learning and global sustainability

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Received 11th November 2025
Accepted 8th April 2026

DOI: 10.1039/d5su00857c

rsc.li/rscsus

Although chemical safety and security fall under chemical risk management, research has shown that knowledge about chemical safety is more prevalent at post-secondary institutions than chemical security knowledge. Historically, chemical safety has mainly focused on preventing laboratory accidents and health hazards. However, in response to the Sustainable Development Goals (SDGs) launched by the United Nations in 2015, there have been calls to promote a sustainable chemistry education, research and development. This qualitative study aimed at exploring laboratory personnel's views of chemical safety and security as well as their daily safety and security practices employed in their chemistry laboratories. Face-to-face semi-structured interviews probing for the laboratory personnel's beliefs, knowledge, and understanding of chemical safety and security practices employed in their laboratories were conducted. Thematic analysis was used for data analysis. Findings revealed that laboratory personnel hold a strong understanding of chemical safety, with many participants demonstrating limited knowledge, or unfamiliarity with the term chemical security. However, both concepts are essential and should be mandatory to protect the health of students and staff. A critical absence of chemical inventory control systems across all surveyed laboratories was revealed, leaving the institution vulnerable to undetected internal theft and the diversion of high-risk precursors like acetic anhydride for illicit drug manufacturing. Exploring the laboratory personnel's views about chemical safety and security practices, elucidated the breadth and depth of their knowledge pertaining chemical safety and security as well as its impact on their daily laboratory practice. The views gathered have been found to be useful in informing and guiding the mandate of universities in equipping and improving the laboratory personnel's knowledge including awareness raising necessary to promote global sustainability.

Sustainability spotlight

Our interest was to explore laboratory personnel's views on chemical safety and security, as well as the daily safety and security practices they employ in their chemistry laboratories. Our exploration revealed a gap in laboratory personnel's knowledge of chemical safety and security, as well as in their daily laboratory practices. Our work emphasizes the need to expose laboratory personnel to green chemistry education through chemical safety and security training workshops to help bridge the gap and raise awareness of the impact of their daily laboratory practices on the environment and human health. The following UN sustainable development goals are relevant to and emphasized in our study: good health and well-being, SDG 3, and clean water and sanitation, SDG 6.

Introduction

Several universities worldwide have implemented various methods to manage laboratory safety at universities. For example, in the United States of America (USA), universities use the Environmental Health and Safety system as the basis for managing laboratory safety, whereas universities in Japan have safety and environmental protection management institutions.[1] Historically, chemical safety has mainly focused on preventing laboratory accidents and health hazards. However, in response to the Sustainable Development Goals (SDGs) launched by the United Nations in 2015, there have been calls to promote a sustainable chemistry education, research and development.[2] One way to promote sustainability is through chemical safety. According to the American Chemical Society (ACS), incorporating sustainability in laboratory chemical safety practices offers new solutions towards the reduction of pollution and its

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impacts on human health and the environment, SDG-3, and ensuring waste management practices that promote better chemical waste practices, SDG-6 (https://www.acs.org/green-chemistry-sustainability/education/chemistry-sustainable-development-goals.html). Besides chemical safety, chemical security is also essential as it aids in the prevention and protection against theft and the intentional misuse of chemicals.[3,4] There is a worldwide outbreak of the misuse of dual-use chemicals and as a result, chemical security has become a threat since it leads to the misuse of chemicals to produce drugs such as methamphetamine and improvised chemical weapons[3,5–7] negatively impacting world peace (SDG 16) and human health and wellbeing (SDG 3).

Understanding of sustainability concepts by students, laboratory personnel and teaching staff and incorporating these concepts and green chemistry into instructional laboratory practices and professional learning opportunities is essential for global sustainability.[8] Green chemistry places the safety of both humans and the environment at the center of chemistry research and application.[9] The twelve principles of green chemistry serve as guidelines for reducing or eliminating the use and generation of hazardous chemical substances with the aim of minimizing negative impacts on the environment and people. The principles cover aspects such as waste prevention, maximizing atom economy, using less hazardous substances, designing safer chemicals, and increasing energy efficiency.

Much of the research at the intersection of green chemistry education and laboratory safety and security has shifted the focus from mere compliance to a proactive culture.[10] Albalawi and team, in their conceptual paper, argue that it is possible to integrate green chemistry and chemical security into laboratory culture through a systems-thinking approach,[11] which employs DOZN 2.0, a green chemistry metric that students can use to numerically evaluate the safety and sustainability of a chemical reaction, promoting a "systems thinking" approach.[11] Increasingly, scholarly work advocates a "Safety-by-Design" approach, using the 12 principles of Green Chemistry as a framework for risk mitigation.[12] Researchers have demonstrated that replacing hazardous reagents with benign alternatives and implementing microscale chemistry techniques can significantly reduce laboratory risk profiles.[13] Another development in the field is the alignment of green chemistry with the RAMP framework (recognise hazards, assess risks, minimise risks, prepare for emergencies). Studies have highlighted green chemistry as providing the "Minimise" component of RAMP.[14] While chemical safety focuses on accidental harm, scholarly work in chemical security addresses the intentional misuse of chemicals, especially the hazardous ones.[15] Research by the American Chemical Society (ACS) and various safety consortia suggests that reducing the inventory of toxic, explosive, or precursor chemicals makes laboratories less attractive targets for theft or diversion.[16] Another interesting research focus in the field highlights a psychological shift in learners when safety is framed through the lens of green chemistry, reporting observed higher levels of 'safety agency' in learners.[17]

Literature has focused on green chemistry education as it relates to students and classroom practice, leaving a paucity on its importance for laboratory personnel training and professional learning.[9,18] Engagement in green chemistry education concepts through chemical safety and security training can provide laboratory personnel with connections between their chemical handling and disposal in the laboratory and their impact on the environment and human health. Institutions of higher education are in the fortunate position to raise awareness about laboratory chemical security and chemical sustainability in students as future chemists who may find themselves working in commercial or instructional laboratory settings as chemists, researchers or laboratory personnel. There is, therefore, a need for institutions of higher education to be deliberate in not only educating students about foundational chemical concepts but also investing in a curriculum that teaches them about the potential harm created by the lack of systems that safeguard the deliberate release of toxic chemicals as well as mitigation strategies when the harmful chemicals have been released and the application of green and sustainable chemistry that can help reduce hazardous chemical pollution. This training and awareness can begin with laboratory personnel primarily responsible for facilitating laboratory instruction, health, safety, and security. Thus, the current paper shares findings obtained in a study aimed at exploring laboratory personnel's views of chemical safety and security as well as their daily safety and security practices employed in their chemistry laboratories. Exploring the laboratory personnel's views about chemical safety and security practices, elucidated the breadth and depth of their knowledge pertaining chemical safety and security as well as its impact on their daily laboratory practice. The views gathered have been found to be useful in informing and guiding the mandate of universities in equipping and improving the laboratory personnel's knowledge including awareness raising necessary to promote global sustainability. To address the aim, the following research questions were addressed: (i) What are the laboratory personnel's views on chemical safety and security? (ii) According to the laboratory personnel, what chemical safety and security practices are employed in their laboratories? (iii) What are the laboratory personnel's suggestions regarding how the current chemical safety and security practices could be improved?.

Context

The study was conducted at a research-intensive university in South Africa. Data was only collected from chemistry laboratory personnel as individuals dealing mostly with chemical substances. Although the university has five campuses, data was collected from the main and the education campuses which are the only campuses with chemistry laboratories. Laboratory personnel at these campuses are required to attend laboratory safety training workshops once a year. At these workshops, they are expected to learn about chemical safety and security practices to implement in their laboratories, however, these workshops only concentrate on chemical safety. Since chemical safety and security fall under chemical risk management, exposing laboratory personnel to both practices is essential because chemical safety protects students and workers from chemicals. In contrast, chemical security prevents the misuse of chemicals.[4] Improving chemical security awareness and competency is critical.[19] Therefore, this study aimed to learn more about chemistry laboratory personnel's views about the chemical safety and security practices implemented in their laboratories. The study was purposively conducted with laboratory personnel because safety and security practices are core to their profession and practice and they are tasked with keeping their laboratories compliant, ensuring that safety and security requirements are adhered to by anyone accessing and/or using the laboratories including students. Furthermore, knowing the laboratory personnel's views about chemical safety and security practices employed in their laboratories, was key in informing us about the knowledge they have pertaining chemical safety and security.

Theoretical framework

Narratology[20,21] was considered relevant for framing the study. The narrative approach involves an inquiry directed at narratives of human experiences or inquiry that produces data in a narrative form; it examines human lives through the lens of a narrative, honoring lived experiences as a source of knowledge and understanding.[22–25] Narratology on the other hand, aids the researcher in learning more about the narrator's culture, historical experiences, identity, and lifestyle.[20,21,25] In this study, narratology was relevant because it allowed us to report stories about the chemical safety and security culture employed in the laboratories of the participating laboratory personnel. The advantage of using the narrative approach is that humans are natural storytellers, and as such, it is easy to obtain stories: gathering in-depth data is easily accomplished as narratives usually provide thick descriptions, and it is possible to gather in-depth meaning as participants usually reveal themselves in their stories.[22,23,26] Since narratology is an invaluable tool to understand how people's stories and ability to self-narrate reflect the human experience, it was relevant to the current study because it allowed us to gather stories from the laboratory personnel that revealed the personnel's views about chemical safety and security practices employed in their laboratories.

Methods

Study setting, participants and recruitment

Eleven chemistry laboratory personnel were invited to participate in the study; however, only ten gave consent. Table 1 below summarizes the participants' education level, and work experience. The participants included three laboratory managers and seven laboratory assistants working in teaching laboratories. Of the three managers, two worked in first-year general chemistry laboratories, whereas one worked in second and third-year inorganic and organic chemistry laboratories. Of the seven laboratory assistants, four worked in first-year general chemistry laboratories, two in second- and third-year physical and analytical chemistry laboratories, and one in second- and third-year inorganic and organic chemistry laboratories. Recruitment of participants was done *via* email and the aim and benefits of the study were stipulated in the mail. Laboratory personnel who agreed to participate signed the consent forms. Since the interest was in knowing the laboratory personnel's views regarding the chemical safety and security practices employed in their laboratories, purposeful sampling[27,28] was used because the interest was specifically in collecting data from laboratory personnel that work at the university at which the study was conducted. Pseudonyms were used to protect the identity of participants. Before commencing the study, a letter of ethical approval was obtained from the relevant Faculty's Ethics Committee (reference number: NAS376/2022).

Data collection and analysis

Semi-structured face-to-face interviews were used to probe laboratory personnel's knowledge and understanding of chemical safety and security practices in their laboratories. Since narratology framed the study, face-to-face semi-structured interviews were relevant as they allowed us to collect participants' stories that informed us about their views of chemical safety and security practices in their laboratories. Face-to-face interviews enabled us to gain participants' cooperation by establishing rapport with them and facilitating the production of in-depth and rich responses. All participants were asked questions about chemical safety and security practices in their laboratories. The interview protocol and questions can be found in the SI. The questions asked during the interviews were intended to address the study's research questions. Therefore, to address research question 1, two questions probed laboratory personnel's knowledge of and understanding of chemical safety and security. To address research question 2, two questions probed for the chemical safety and security practices employed in the participants' laboratories, whereas to address research question 3, two questions probed for the laboratory personnel's views on improving chemical safety and security practices currently employed in their laboratories.

Thematic analysis,[27–29] was used to analyze data as it aligns with narratological analysis. The focus when analyzing data was on identifying different laboratory personnel's views about chemical safety and security and related practices. The first step during data analysis was to become familiar with the raw data,[19,20] and that was achieved by thoroughly reading and re-reading the raw and transcribed data and understanding the responses from the participants. After being familiar with the data, the second step was to generate preliminary codes from the data that reflected the laboratory personnel's understanding of and knowledge of chemical safety and security practices in their laboratories. Preliminary codes were generated using words from the data (*in vivo* coding) and from the researcher's mind.[28] Codes were constantly compared with each other and their supporting data; this resulted in merging some codes. After the generation of preliminary codes was completed, all the statements within each code were pulled and re-analyzed. Through constant comparison, similar codes were merged to form categories and, in some cases, codes were renamed. After the development of categories, similar categories were then merged to form themes. After developing themes, they were

Table 1 Participants' demographic data

Educational level	Educational level of laboratories supervising	Work experience (Years)
Ph.D. chemistry	2nd & 3rd years	10
BSc biochemistry	2nd & 3rd years	2
BSc biochemistry	2nd & 3rd years	4
BSc biochemistry	2nd & 3rd years	1.6
Diploma microbiology	1st & 2nd years	3
Ph.D. chemistry	1st years	10
BSc chemistry	1st years	1.6
BSc chemistry (Hons)	1st years	1.6
BSc physics	1st & 2nd years	10
Diploma analytical chemistry	1st years	16

reviewed, and through this process, themes that were not in line with the research questions were discarded.[27] Since narratology was used as the theoretical framework, the aim was to gather stories from the laboratory personnel that informed us about their understanding and knowledge of chemical safety and security practices in their laboratories. Therefore, during analysis, laboratory personnel stories were combined into common themes that provide information about the state of chemical safety and security practices from the laboratory personnel's point of view. After completing the data analysis process, the analyzed data was sent to two chemistry education qualitative experts for peer debriefing.

Results

Research question 1: laboratory personnel's views of chemical safety and security

To learn more about laboratory personnel's views of chemical safety and security, they were asked to demonstrate their knowledge and understanding of chemical safety and security by (i) providing a definition of chemical safety, and chemical security, and (ii) explaining whether chemical safety and chemical security are important. All the ten participating laboratory personnel were familiar with the term "chemical safety" and defined it as the understanding, handling, and storage of chemicals including risk management in terms of exposure with the recurring theme highlighting knowledge and understanding of the MSDS [Table 2]. Safety was thus viewed not just as an action, but as an informed state of mind where the technician understands the specific properties of a chemical, such as its concentration, volatility, and reactivity. In practice, laboratory personnel highlighted the understanding of chemical safety as manifesting through strict application of chemical handling, storage protocols, and storage management.

Regarding chemical security, only four laboratory personnel provided the correct definition of chemical security; that is, they defined chemical security in terms of access control and storage of chemicals. Others, as shown in Table 2 indicated that they had never heard of the term "chemical security" and instead used chemical safety terminology to define chemical security.

Regarding the importance of chemical safety, the laboratory personnel provided different reasons as to why chemical safety is important, citing proper handling of chemicals, prevention of injuries and health hazards as shown by the selected quotations:

"[…] It's important to prevent injuries to a person dealing with the chemicals. And because chemicals can be dangerous. You've got corrosive chemicals, you've got chemicals which can affect your skin, eyes, or whatever. And even some chemicals are incompatible. It can cause explosions. So it's very important." Haley.

"[…] If people don't know about chemical safety, for example, in industry, even in the laboratory, if you don't know about chemical safety, we might throw chemicals down the drain and then they're going to contaminate the water, the environment. Yeah, it will eventually affect us humans and the environment if we don't know about chemical safety, so it is important." Molly.

"Ehh chemical safety is important in the sense that, the chemicals that you are using are, have a very high potential of damaging the environment, the students as well as staff. […] They can be harmful if they are not used properly." Kay.

Personnel viewed chemical safety as fundamentally essential for preventing immediate injuries such as skin burns from corrosive substances, eye damage, and the harmful effects of inhaling toxic fumes. Beyond these immediate dangers, the participants highlighted that safety protocols are vital for preventing catastrophic incidents like explosions caused by storing incompatible chemicals together. Furthermore, there is a recognition that the importance of safety extends to long-term health. A significant recurring theme in the personnel's views was that chemical safety is a communal and environmental obligation. Improper handling, such as disposing of heavy metals or other toxins down laboratory drains, was identified as a direct threat to water sources and the broader ecosystem.

Since majority of the laboratory personnel had never heard of chemical security, the researcher provided a literature informed definition of chemical security so the personnel could refer to the definition when answering questions related to chemical security. Therefore, once it became clear how chemical security differs from chemical safety, the personnel could provide appropriate responses with regards to the importance of chemical security. As shown in the quotations below, all the participating laboratory personnel indicated that chemical security is important:

Table 2 Laboratory personnels' definitions of chemical safety and security

Laboratory personnel's definition of chemical safety	
Themes	Examples of quotations
Knowledge & understanding of MSDS	"Yah, i would say is ehh, the safety precautions you have to take when working with chemicals in the lab." **Katy** "It's about handling chemicals in a safe manner and also storing them and stuff like that. Also, okay, handling chemicals and storing them and also knowing about their danger, precaution, just like MSDSs and stuff like that." **Molly** "I would say that the chemical safety is about the use or safety of using chemicals. Let's say as a lab technician you're doing preparation. And also, your students or lecturers are also going to use the chemicals, i think chemical safety is also around that scenario where the lab personnel, the lecturer and the student all use the chemicals." **Dandee**
Laboratory personnel's definition of chemical security	
Themes	Examples of quotations
Access control and storage	"I haven't but let me try (laughs) and elaborate it in my own view. I would say that chemical security is mainly based on, are we using chemicals in a proper way. What I mean by a proper way, i mean like people who are using chemicals to make drugs or are we using chemicals to sell them to people who are using them to do certain things for their own interest. Do we have the key that is controlled by a few? i think that's what I can say about chemical security." **Dandee** "Security i would understand that to mean are they put away somewhere, away from being stolen. Away from being stolen. So, we have storerooms inside the labs. We have storerooms outside the labs. So, because we're trying not to get them stolen, […]" **Lotto** "I think it should include putting chemicals in a place where people who are not familiar with chemicals should not be accessible to people who are not familiar with chemicals. I think we should put them in a safe place […]" **Haley**
Term unknown	"[…] No, it's always chemical safety, security, no never heard of it. So, yeah," **Molly** "I don't know what to do with it," **Mike** "Chemical security. Ahh i wouldn't say I do. No, i don't know chemical security," **Katy** "Basically, i'm not really sure specifically what it means by chemical security […]" **Paul** "[…] I've never thought about that," **Kay**

"Okay, i'll be repeating myself, but yeah chemical security is important so that we keep chemicals away from people who are going to misuse them. Basically, that's the reason why." Dolly.

"Yeah, it's very important. Because suppose wrong people get access to that, then they get chemicals for illicit use, which is illegal of course. So, we avoid the illegal use of chemicals." Haley.

"Okay, it would have to be important, and it should be implemented in our labs as well, because some of the laboratory personnel, also steal this chemical, like they can order more than what is required in the laboratory and steal it for their personal use outside the labs, and yeah." Molly.

"Okay, that's the uses of the chemical itself. Because you can use it to make drugs. So they can't be selling anyone that chemical. You need to tell them why you need acetic anhydride." Mike.

Laboratory personnel characterised the importance of chemical security as a critical defence against the theft, diversion, and intentional misuse of hazardous substances. Although many participants initially struggled to define the term, often conflating it with chemical safety, they unanimously identified chemical security as a mandatory requirement once the distinction was clarified. The most prominent theme regarding chemical security is its role in preventing chemicals from being stolen for illegal purposes, specifically drug manufacturing. Personnel highlighted substances like acetic anhydride as high-risk materials that must be strictly secured because of their known use in the narcotics trade.

Overall, the data shows that laboratory personnel perceive chemical safety as a mandatory, knowledge-based framework essential for preventing physical injuries, environmental damage, and long-term health risks through strict adherence to handling and storage protocols. Once introduced to the concept of chemical security, participants indicated chemical security as a critical safeguard for preventing the theft or misuse of substances for illicit activities, such as drug manufacturing, and as a necessary barrier to protect against unauthorized access and catastrophic laboratory accidents.

Research question 2: chemical safety and security practices employed in their laboratories

To learn more about the chemical safety and security practices employed in their laboratories, laboratory personnel were provided with a list of chemical safety and security practices (SI) and asked to indicate the (i) practices maintained in their laboratories on a daily basis, as well as (ii) the practices they prioritized in their laboratories. Regarding chemical safety practices, laboratory personnel indicated that all the listed chemical safety practices are maintained in their laboratories; the only two practices not maintained are the inventory tracking of chemicals and procedures to follow in case of chemical spillage. The personnel pointed out that inventory tracking is not maintained daily, instead, chemicals are only checked during stock taking at the begin and end of the semester. Furthermore, the personnel stated that they did not have any guidelines detailing the procedures to follow in case of chemical spillage.

Regarding the chemical safety practices they prioritize, laboratory personnel indicated that they prioritize the proper handling of chemicals to avoid injuries as a result of chemical spillage on the skin (Table 3). Furthermore, laboratory personnel such as Haley, Molly, Dolly, Dandee, Kay, and Katy stipulated that they prioritize chemical labelling because labelling informs users what chemicals are contained in the bottles. In addition to chemical labelling, laboratory personnel such as Paul, Dolly, Treva, Dandee, and Kay, indicated that they also prioritize the proper use of personal protection equipment (PPE) to protect themselves from unplanned mistakes and accidents that might happen in the laboratory. Other chemical safety practices prioritized by individual laboratory personnel include the prohibition of eating and drinking in the laboratory so as to prevent students from drinking harmful chemicals (Mike), adequate ventilation to avoid dizziness and headaches as a result of inhaling chemicals (Paul), proper storage of chemicals based on their physical and chemical properties to prevent the development of fumes and explosions (Molly), and proper disposing of chemical waste to avoid environmental pollution (Kay and Molly).

In terms of chemical security practices maintained, all the ten laboratory personnel indicated that they maintain limited access to the laboratories, lock their laboratories when not in use, place chemicals of concern in locked cabinets, prohibit unauthorized use of laboratories and enforce equipment control by assigning asset numbers to laboratory apparatus and equipment. Only three personnel indicated that they have reported suspicious behaviour such as theft and vandalism, and eight indicated that they maintain the completion of chemical waste destruction to aid in the secure transportation of chemicals. As shown in Table 4, priority in terms of chemical security included limited laboratory access, locking away of "Chemicals of Concern (CoCs)" as well as chemical waste destruction.

Research question 3: laboratory personnel's suggestions regarding how their current chemical safety and security practices could be improved

To learn more about the laboratory personnel's suggestions regarding how the current chemical safety and security practices they implement in their laboratories could be improved, laboratory personnel were asked to (i) explain how the current chemical safety and security practices could be improved and, (ii) to state how chemical safety and security training workshops they had attended could be improved. As shown in Tables 5, 6 and 7, laboratory personnel proposed that continuous education and specialised workshops are the primary vehicles for improving chemical safety and security. Their suggestions include annual training sessions, the distribution of updated safety manuals, and the use of "PowerPoint presentation about chemical safety practices" before practical sessions to reinforce specific protocols. Personnel emphasised that these workshops should be comprehensive and exclusive to safety and security, incorporating practical training on fire drills, glassware handling, and the management of Liquid Petroleum (LP) gas. There is also a strong recommendation to include laboratory demonstrators in these educational sessions to ensure uniform knowledge across all levels of staff.

Improving physical infrastructure and technical systems is another key theme, with personnel advocating for the implementation of rigorous chemical inventory systems, which are currently noted as non-existent in their laboratories. To prevent hazardous reactions or explosions, they suggest increasing the number of storage cabinets to allow for better separation of chemicals based on their compatibility. Technical maintenance, specifically the regular inspection of fume hoods and the enhancement of ventilation systems, is viewed as vital for preventing the inhalation of toxic fumes.

Regarding security, the installation of additional surveillance cameras, including hidden ones in corridors and inside laboratories, is proposed to deter theft and monitor for unauthorized activities. Personnel also suggest stricter access control, recommending that lectures no longer be conducted within the laboratories to reduce unnecessary traffic and that regular audits of chemical stocks be performed. Finally, personnel argue that increasing the number of laboratory staff is essential to reduce individual workloads; this would allow technicians to focus on safety practices that might otherwise be bypassed due to time constraints or fatigue.

Discussion

In terms of laboratory personnel's understanding of chemical safety and security, the study's findings have revealed that laboratory personnel have a good understanding of chemical safety. However, the findings have shown that the laboratory personnel's knowledge of chemical security is limited, as most indicated it was their first time hearing of this concept. These findings align with the existing literature, which shows that students, academics, and laboratory personnel understand the laboratory chemical safety culture better than the chemical security culture.[3,4,30,31] The latter is

Table 3 Chemical safety practices prioritized

Practices prioritized	Examples of quotations	No. of participants
Proper handling of chemicals	"The proper handling of chemicals. Because, i mean, if chemicals are not handled properly, that can cause injury to oneself. Either physical or maybe even long-term health problems." **Haley** "If chemicals are handled properly that can eliminate accident in the lab." **Dolly** "Remember when handling chemicals, it can turn your skin itchy it can turn your skin to be hard and the whitish thing." Dandee	6
Chemical labelling	"The chemical labelling, because sometimes you find a bottle without labels. You dont know whether it's sulfuric acid, which is very hazardous. You dont know whether its water and all." **Haley** "Chemical labelling is very necessary so when, remember we use small containers, so if we don't label them, it's a mess. Even for us as well. We don't even know which chemical it's in there. And it will pose a threat or hazard to everyone who is in the lab." **Dolly** "I prioritise the labelling. Why? eeh the labelling, it tells you if you are working with cyanide. Cyanide is poisonous. So, you want to know that it's cyanide, so clearly, i prioritise the labelling. So, the rest come after." **Katy**	6
Appropriate use of PPE	"PPE is also a priority that will insure that even if there can be accidental spillage chemicals don't get to the skin." **Treva** "PPE also eeh remember, if a chemical can spill it can cause serious injuries." **Dandee**	5
Adequate ventilation	"Enough ventilation, because just a minute respiratory inhalation can cause headaches, dizziness, chances of dying are very high." **Paul** "And then if, we also see that those types of chemicals or reactions are very dangerous for them, we mostly prefer to do the reactions in the fume hoods to avoid inhalation." **Dandee**	2
Proper storage of chemicals based on their physical and chemical properties	"Chemicals have different properties, meaning they have to be stored accordingly. Things like environment temp, availability or absence of light and so on, needs to be considered to reduce the risks of fumes and explosions from developing." **Molly** "If you can store chemicals accordingly, it means you have the knowledge, which means already you are handling them well." **Kay**	2
Proper disposing of chemical waste	"By disposing chemicals correctly, you are avoiding pollution of the air, water, and soil, which can lead to a disaster like causing an explosion." **Molly** "By disposing chemicals correctly, you are avoiding pollution of the air, water, and soil, which can lead to a disaster like causing an explosion." **Kay**	2
Inventory tracking of chemicals	"Chemical inventory should be prioritized as well to a void theft." **Mike**	1
Eating and drinking in the laboratory must be prohibited	"Drinking, eating and drinking, i prioritize that one, students may drink harmful chemicals thinking that it is water." **Mike**	1

Table 4 Chemical security practices prioritized

Practice prioritizes	Examples of quotations	No. of participants
Limited laboratory access	"Because I mean, that one will… i think the major thing that will prevent people access to avoid theft." **Haley** "Access limitation will prevent people access and there would be no theft." **Dolly** "The access to the preparation room and the lab, access is the main key one because anyone can come and steal and sell the stuff, so that serves as a great risk." **Paul** "So, you avoid theft. […] Laboratories to be locked when not in use. For me, so you avoid theft." **Treva**	9
Chemicals of concern (COCs) should be locked	"It should be number five chemicals of concern, the one that I said not all of them, to avoid misuse of those chemicals for drug." **Lotto** "And the chemicals of concern also […]. There's no way you can steal them." **Treva**	2
Chemical waste destruction (CWDR)	"We prioritize that, because we don't want to be having explosions in the lab, or in the practicals. […] we prioritize that	1

because greater emphasis is placed on chemical safety education over chemical security education; hence, most published reports only concentrate on laboratory chemical safety culture. Furthermore, even the American Chemical Society's guidelines for undergraduate chemistry programs only concentrate on chemical safety education as it emphasizes the need for institutions, lecturers, and laboratory personnel to "understand their roles in educating students about safety and in supporting a culture of safety through shared responsibility." Both chemical safety and security fall under chemical risk management, which assesses and mitigates unacceptable consequences related to incidents arising from chemicals, chemical equipment, chemical processes, information about chemicals, and people working in chemical facilities.[4] Since chemical security falls under chemical risk

Table 5 Improvement of chemical safety practices

Themes	Examples of quotations	No. of participants
Safety training and workshops	"The university should have more trainings and workshops on chemicals safety." **Dolly** "Implementation of training on chemical safety once a year." **Dandee** "Okay. I think they can be improved by properly reminding ourselves of safety procedures. So, i mean, constant refreshing of safety protocols of using chemicals. I think that's the way to improve yeah, i think you put manuals and then keep on refreshing." **Haley** "Because sometimes we come across problems while we are experiencing problems. So I think it would be fair if maybe prior to practical sessions we just have maybe a PowerPoint presentation about chemical safety practices." **Paul**	4
Frequent maintenance of fume hoods and increased lab personnel	"Fume hoods should be well maintained and checked frequently and ventilation should be increased." **Katy** "By bringing more lab personnel so that they can be able to focus on safety practices that are being ignored due to workload." **Lotto**	2
Chemical inventory and storage cabinets	"Chemical inventory should be practiced as it is never done." **Treva** "There must be more chemical storage cabinets so that chemicals can be stored according to compatibility." **Mike** "Increasing chemical cabinets to lock away chemicals of concern." **Lotto**	2

Table 6 Improvement of chemical security practices

Themes	Examples of quotations	No of participants
Installation of more cameras	"Security practices… i think eh…, installing cameras where there are no cameras that would also include installing cameras inside the lab, even in the corridors, i think that will be enough." **Haley** "To add more cameras the one facing the lab and the other one facing the door, […]" **Molly** "Yeah, i think the cameras. Yeah, in as much as they can change the camera, at least the hidden cameras inside the lab where no one knows. Yeah, that there's a camera because maybe from the outside those ones they can shift them" **Treva** "Cameras to be installed in the labs" **Katy**	4
Improvement of access control and storage	"Access control, so maybe prior to a semester or after a semester, just go through the numbers again. Check on the chemicals and equipment if not stolen." **Paul** "Like access to be improved. […]" **Mike** "Access to the lab to be improved and lectures not to do teaching in the lab anymore." **Kay**	4
Frequent training on security practices	"Fume hoods should be well maintained and checked frequently and training on security practices should be introduced and done regularly." **Dolly** "Training on security practices should be done." **Dandee**	2

management, there is a need to promote a laboratory chemical security culture at the University level, as this will assist in improving laboratory personnel's understanding and knowledge of chemical security. In their suggestions, the laboratory personnel did indicate that more chemical safety and security training workshops and resources in the form of PowerPoint presentations and safety manuals should be provided as these will serve as reference materials and possibly assist in the awareness and literacy of chemical safety and security. As stated, providing training workshops is essential to address chemical safety and security barriers.[32]

Although the laboratory personnel indicated that chemical safety is essential and mandatory, it was surprising to learn that the personnel do not practice chemical inventory control in their laboratories. Chemical inventory control is one of the essential practices of chemical security because most of the chemicals used in chemistry laboratories can be misused by making narcotic drugs and chemical weapons.[3] Chemical inventory control is essential as it allows the laboratory personnel to track all chemicals in the lab and monitor who has access to them at all times.[30,33] Therefore, as suggested by the laboratory personnel, chemical inventory control has to be

Table 7 Improvement of chemical safety and security training workshops

Themes	Examples of quotations	No. of participants
Detailed chemical safety and security workshops	"The university should also run those courses and allow the lab demis to also attend." **Haley** "They must do detailed training on chemical safety and security only not combined with other training like secretory." **Kay**	3
Operation of LP gas and handling of glassware	"Training on how to install the gas and place and controlling it by closing and opening the cylinder." **Mike** "They should include training about gases, how to use them, what type is being used, and how to store it. […] They should also include fire drill training." **Dandee** "It was mostly about safety. It was mostly about safety. Proper handling of chemicals should be improved, how to clean and dry used glassware of chemicals." **Lotto**	3

implemented at the University level to prevent theft and misuse of chemicals. This can be done using digital chemical inventory control systems such as the mobile-based QR code tag[33] and the LabCup.[30]

The findings regarding chemical safety and security provide a critical framework for laboratory management that directly aligns with several UN SDGs, particularly those focused on health, environment, and social justice. Laboratory personnel view chemical safety as a non-negotiable mandate essential for protecting human life. By strictly enforcing the use of PPE and fume hoods, laboratories mitigate acute physical injuries, such as chemical burns and respiratory distress caused by toxic fumes.

The findings highlight an educational imperative where safety is treated as a right for every student and staff member. Personnel suggest that chemical safety and security should be integrated through annual workshops, comprehensive safety manuals, and PowerPoint briefings prior to practical sessions. By advocating for the inclusion of laboratory demonstrators in these trainings, the findings support SDG 4 (Quality Education), ensuring that technical knowledge is effectively shared and that future scientists are equipped with the skills for safe and responsible research.

A primary environmental contribution of these findings is the prevention of ecosystem contamination.[34] Personnel identify improper disposal, specifically pouring heavy metals and other toxins down laboratory sinks, as a direct threat to local water sources. The implementation of chemical waste destruction protocols and non-drain disposal methods directly supports SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Consumption and Production). Additionally, proper storage based on chemical compatibility reduces the risk of accidental fires and explosions, thereby preventing catastrophic environmental disasters.[34]

Lastly, the findings link the importance of chemical security to the prevention of criminal activities and the preservation of institutional integrity. By securing "chemicals of concern," such as acetic anhydride, personnel prevent the diversion of university resources into the illicit drug trade, which they note "destroys our youth". This security-focused approach aligns with SDG 16 (Peace, Justice, and Strong Institutions) by mitigating social harm. Furthermore, suggestions for improved infrastructure, such as the installation of surveillance cameras and the development of rigorous chemical inventory systems, contribute to SDG 9 (Industry, Innovation, and Infrastructure) by building resilient and secure research facilities.

Conclusion and limitations

Although focused on laboratory personnel in instructional laboratory settings, the findings of the current study, are equally applicable to research and teaching laboratories. The study focused on laboratory personnel in one university and focused only on chemistry laboratory settings. The findings can therefore not be generalized. However, detailed descriptions of how the study was conducted have been shared enabling replication in other contexts. Future studies could be conducted nationally to determine the state of affairs in terms of preparedness and awareness of chemical safety and security considerations amongst laboratory personnel. These studies could inform institutional and national policy and practice, ensuring that laboratory facilities and personnel tasked with taking care of these facilities are adequately prepared. Environmental and human wellbeing sustainability remain vulnerable as long as attention is not given to how hazardous chemicals are handled and disposed. Laboratory personnel although a hidden profession, can contribute as agents of sustainable development and change and if well equipped with the requisite knowledge and skills.

Author contributions

Ms Francinah Futhane, who has just completed her MSc, was responsible for the investigation process; she conducted the research, collected and analyzed data, validated the results *via* peer debriefing, was involved in the writing, reviewing and editing of the original draft of the manuscript. She was also involved in the development of the methodology that was used to address the stated research questions. Dr Kgadi Mathabathe was the co-supervisor and was involved in the conceptualization of the project. She was also involved in project administration, supervision and the writing, reviewing and editing of the original draft of the manuscript. Dr Tekane was the supervisor and was involved in the conceptualization of the project. She was also involved in the supervision, project administration, provided any resources that were required for the project (*e.g.* audio recorders), and was involved in the peer debriefing process to validate the findings. Furthermore, she was involved in the funding acquisition.

Conflicts of interest

There are no conflicts to declare.

Data availability

Data was collected from the instructional laboratory personnel, therefore, due to ethical confidentiality requirements by the University, data cannot be made available.

Supplementary information (SI): (i) the interview protocol, (ii) list of chemical safety practices and (iii) the list of chemical security practices. See DOI: https://doi.org/10.1039/d5su00857c.

Acknowledgements

We would like to thank the University of Pretoria for funding this project through the Research Development Programme (RDP).

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