Chemical Laboratory Safety: A Neglected Topic in Science Curriculum Design

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Introduction and Background Information

The basic human survival needs include oxygen, water, food, sleep, and safety. Scientific research results have a profound impact on the modern world and changed lifestyles. Chemicals and chemical reactions are indispensable in a highly technical society of 21st century. It is essential for people to work in humane and safe conditions in all the scientific laboratories as it is one of the defining pillars of scientific growth. The professionals must have their awareness of the sociological implications of their research and development work and observe a code of conduct to protect our environment for a better future. The societal and technological transformation, funding availability for the proper maintenance of laboratory facilities, training of safety personnel, and the recruitment of safety officers have driven the improvement in the practice of laboratory safety during the last three decades (Amburgey-Peters, 2002). The statistical data on laboratory incidents form a vital component in the quest to achieve safer scientific laboratories worldwide. But the safety survey on workplace conducted in 2013 indicates the significant laboratory risks causing minor to severe injury for the research scholars and the employers should ensure the safety of the lab participants (Noorden, 2013).

We have to understand the factors causing lab accidents supported by scientific facts and by eliminating the cause/s one can limit the prospect of an incident and protect ourselves from potential dangers. The causes of laboratory accidents include the lack of experience or working understanding of hazards, improper or unintended use of equipment, distractions or lack of attention to task, the use of broken, damaged glassware or equipment, and carelessness. These parameters can be traced back to the fundamental lack of necessary chemical background and failure to make connections between the academic concepts and laboratory safety (NRC, 2014). Academic lab accidents can result in loss of life, and multiple injuries, economic loss, property destruction, and harm to the environment. It is essential to identify the cause or causes, and by eliminating the causes, accidents will be reduced.

The safety extension from laboratory scale to pilot plant to industrial scale comes with scale up operations involving several chemical plants, products and processes (AICE, 1990; ICE, 1983). An unhealthy work environment such as hazardous chemicals, chemical waste, biological species, noise, metal fumes and monotonous nature of work in the industries are known to cause disabilities and diseases (Freeman & Whitehead, 1982). Industrial safety has not received the required attention and importance, especially in

small and medium scale undertakings. If we take suitable steps to promote safety in an industrial setup most of the accidents are preventable, thus helping with the healthy growth of the community (Kharbanda & Stallworthy, 1988).

The changes to transform chemical laboratory safety begins with the course of trying to review the current situation. Some undergraduate colleges do not have proper laboratories, training in safety aspects, a chemical safety plan for instruction, and quality control mechanism. It is extremely important to develop the sense of rights and the responsibilities of a learner, researcher, or professional worker in these laboratories. There is an increasing need to have an active educational program on safety to bring attitudinal change among all the stakeholders to enable them to contribute immensely to the overall safety through a series of efforts. The education on safety will help the learner to unlearn certain misperceptions, misconceptions, misunderstandings, incorrect assumptions, and help understand the real concepts and broader understanding of many other factors related to safety. We have to become conscious of the value of safe procedures and develop a proper mental attitude to promote safety in the laboratory. Proper education about laboratory safety has to be accorded on a priority basis to change the attitude towards safety to a large extent (Schroder et al., 2016).

The various circumstances of the contemporary lab settings lead us to consider the fine line between safety and risk and open the door to a new vision of a unique rapid reaction world expecting the unexpected. Advances in the chemical sciences with the help of modern technology have resulted in an explosion of knowledge about safety. The advances in the transient techniques have allowed us to understand certain realities of reaction dynamics. Some unexpected instantaneous incidents remind us that the past, present, and future are linked by concerted or stepwise mechanism. The existence of a well-established reaction mechanism for the solution of safety issues will enable a suitable action to what might otherwise end in danger. Laboratory safety research has become more important in the last decade as indicated by the increasing number of published papers in the field and their extreme relevance for human security. The research journals on different safety topics include the Journal of Safety Research, Biosafety, Structural Safety, Safety Science, Fire Safety Journal, Applied Biosafety, Journal of Chemical Education, Journal of Laboratory Chemical Education, and Journal of Chemical Health and Safety. The journal 'Loss Prevention Bulletin' published by the IChem, UK publishes various process safety case studies related to laboratory and industrial safety including near miss cases.

Humans have prepared, found or used over 50 million unique chemicals, each with a distinct chemical composition, and chemical industry archives contain more than 62,000 commercial chemicals.[3)] From the soft baby foods to the powerful destructive bombs, many products are manufactured worldwide for a multitude of purposes. Many

companies are introducing innovative products to meet specific needs of customers in addition to standardized products. It is indeed a difficult task to collect, analyze and assess the safety aspects of each of these products and find out protection methods for a safe laboratory experience. The principle danger exists in ignorance of specific hazards and negligence during working and experiments with chemicals need to be looked at closely with caution (Fig. 1.) The lack of available data on lab incidents and injuries may be due in part to an out-of-court settlement in many legal cases, and it is not mandatory to report such accidents to concerned people or media in certain organizations. It is our responsibility towards the scientific community to report such accidents and to suggest preventive actions be taken to reinforce laboratory participants to follow safety principles regularly. There is a need to provide safety education that enables scientific understanding of issues, the primary reasons and deduce solutions to various safety issues, including readiness to cope with an emergency. A systematic research study of various safety aspects with a molecular level perspective and the development of chemistry associated with them will reveal some unknown properties of certain chemicals and unpredictable reactions. The discussion above establishes the importance of the study of safety in science curricula and for the conduct of chemical education. The basic safety skills can be cultivated and developed by practice, but often neglected in curriculum.

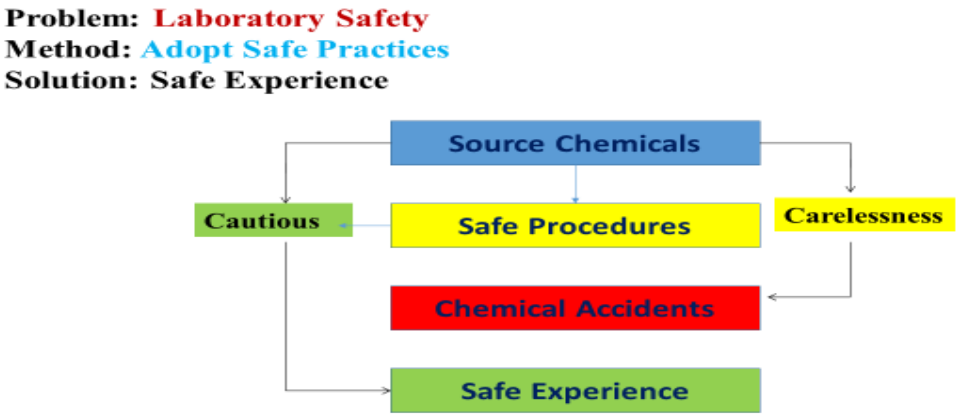

Figure 1. Flowchart Depicting Linked Steps in the Overall Safety Net.

The purpose of this paper is to draw the attention of general readers to the chemical laboratory safety aspects and impacts as one of the neglected topics in curriculum design. Our concern is to upgrade the academic laboratory safety infrastructure and follow the standard best practices to reconnect with the real reader in a more extended manner to think about the unintended consequences. This article is intended to promote safety awareness and encourage safe working practices in the chemical laboratory and to anticipate, evaluate and recognize hazards that may occur during laboratory operation. It attempts to explain briefly the nature of the safety issues and general line of control and preparation for emergencies. The discerning reader can get a complete picture or additional details through numerous cross references of original work, review

articles, books or monographs. The text is divided into sections concerned with a brief history of laboratory accidents, understanding the safety aspects, enhancing laboratory safety, professional development approaches, towards a safer world of a laboratory, and conclusions and future directions. An academic laboratory safety course is included in the appendix A concerning the needs of the modern scientific practice. A subdisciplinary content on 'Academic Laboratory Safety Course' is presented in a dedicated unit, and the syllabus itself does have value. The idea is to fully explore the immense possibilities within the purview of the scientific facts and choose a better course of action in any given set of circumstances, which has severe consequences for the future of safe laboratory practices. The genuine spirit of creating a thinking framework allows people to imagine different risk possibilities and re-engineer all aspects of safety through the knowledge of chemical sciences. In addition to the understanding the general and specific safety issues, tracking the distinctly different trajectories at the molecular level is paramount to reduce specific risks involved. The content of the paper is useful to audiences such as laboratory instructors, workers, teachers, and students. It will be of interest to the non-specialist readers, research scholars, educational advisers, curriculum writers, consultants, graduate level students as well as some research-minded scientists in government laboratories and industry.

Understanding the Safety Aspects

It is necessary to provide a safe working environment at your workplace to promote science, engineering, and technology.[4, 5] In this context, a proper study of safety related broader issues and facilitating sharing of scientific knowledge about safety management practice in the classroom and laboratory demonstrations of concepts of safety becomes critical. Interdisciplinary approaches to laboratory safety have become paramount in addressing a broad range of safety issues at both local and global levels. Most of the industrialized nations have taken action to reduce the frequency of laboratory accidents and teach the students how to handle chemicals safely, how to avoid accidents and what to do in the event of an accident. It is now common to see laboratory spaces completely separated from offices in the layout of modern science laboratories. In the Indian context, the understanding of laboratory safety and its significance becomes very critical when we consider the significant increase in the number of higher education institutions and universities in the recent past.[6] There is an acute shortage of necessary infrastructure and insufficient and inadequate safety devices except for a few established laboratories. Lack of adequately trained personnel as a result of a failure of safety management and planning also contributes to the problem. Further, many undergraduate students now take part in research activities, and this could involve risks with consequences such as physiological injury (disability and death), damage to standard equipment, financial loss, psychological impairment

and other long-term implications. Moreover, the disposal of toxic acids, solvents and other chemicals of unknown toxicity would have a direct impact on air, water and soil quality, posing environmental issues **(**NRC, 1995**).**

The awareness about laboratory safety is less due to the lack of interest in students and the administration and incredible diversity of solution chemistry. There are inherent engineering challenges to overcome safety issues in several industrial processes and find out the best methods to manufacture products or extracting certain metals from their ores (Sax & Lewis, 1988). The mainstream media need to improve their presentation of safety matters written by journalists with specialized scientific knowledge and soft communication skills. A journalist's efforts should be aimed at arousing safety awareness among the readers and making them conscious of their responsibilities towards safe experimentation to obtain practical knowledge. The safety message in forceful, clear terms from a magazine or newspaper can make the readers act intelligently and promptly to prevent laboratory accidents. The laboratory safety is necessary to prevent the adverse health effects of exposure to chemicals, personal injury or injury to fellow workers, laboratory equipment hazards - if not maintained properly, and damage to equipment. As there is increasing concern about the academic laboratory safety in the recent past, prudent practices in the laboratory provides a sense of confidence and social responsibility (NRC, 1981).

The government should support for basic safety measures, frame protection policy to promote safety in scientific laboratories and monitor the proper adoption of sustainable safety practices. Regular cleaning activities within the laboratories in all higher education organizations should become a part of the educational program involving the practical components. Sustainable strategies for safety management include educating laboratory users to get aware of safety rules and regulations through posters, slide shows, awareness notes, banners, safety quizzes, and workshops, among others (Author, 2006). Other learning resources on safety in the form of audio books or video are impactful in education. It is crucial to read the fine details on the label carefully to find out the summary of product characteristics and the critical safety information of the chemical that we are about to use. In addition to having safety rules and regulations and extensive safety support systems, there has to be a massive safety sensitization program to bring an attitudinal change among all stakeholders. Participation of multiple participants is essential for effective safety management. A new perspective involving safety mission, detail orientation, and making intelligent decisions based on scientific evidence, observations, case histories and knowledge will help in addressing various safety challenges and concerns in our professional lives everyday (Sanders, 2005). Depending on the nature of the safety problem, we have to decide what is the best course of action that can be safely be used and should be followed. Users often waste

precious time and by doing so may allow a controllable process to a harder to control stage (Cote & Wells, 1991).

It is essential to enhance our perception skills to go beyond the average human eye and train the brain to analyze more data in a much faster way to take proactive and immediate action of every aspect of safety including unexpected effects (Weiss, 1986; Windholz, 1976). There is a paucity of safety data available on new laboratory chemicals. The actual safety information on a diverse range of products should flow from suppliers (chemical manufacturers, importers, distributors) to employers and then to the workforce to ensure their safe handling under actual academic operating conditions with the professional operating ethos.[7)] The professional societies should provide a platform for the exchange and transfer of safety knowledge and information about research and development through their activities. A researcher should be made aware of various potential safety issues in instrument rooms with lasers, pressurized gas cylinders, cryogenic liquids and high pressure/temperature reactors, to improve overall safety. The interrelated safety aspects of lab practice such as prudent practices in practical work, precautionary measures in violent reactions, visual inspections of maintenance work, controlled conditions using safety devices, emergency techniques in fire accidents, first aid in physical injuries, professional help in health problems, and control mechanism in preventing environmental pollution are necessary to develop safety consciousness (LeFèvre & Shirley, 1997; Meyer, et al., 2007; NFPA, 2010). In the light of overall safety development, we have to blend the right benchmark principles of safety into laboratory practice by controlling our thoughts and actions in the right safety spirit. The safety is the fundamental requirement to overcome the investigation challenges that demonstrate our quest to understand and discover the world through various natural and artificial mediums, methods, materials, and scientific interpretations, assessments, analyses, and expressions (Girolalmi, et.al, 1999, Shriver & Drezdzon, 1986, Skoog et al., 1994).

Enhancing Laboratory Safety

The modern chemical laboratories are safer with all the safety measures in place, and proper precautions are taken for safety during experimentation phase. Proper laboratory safety and a chemical hygiene plan help in minimizing the risk of chemical exposure, reducing the danger of lab work-related injury and illness, lowering the risk to the environment, and comply with applicable regulations and standards. It is important to increase reporting of laboratory incidents, provide safety training to react swiftly and with sensitivity to victims, and have a worldwide awareness campaign to reignite core values and safety precautions to develop a real safety culture.[8)] The specific objective of safety program should be to achieve the four E's- education, expertise, experience, and exposure to a range of safety aspects and develop, implement and maintain a particular

standard of good laboratory practice. At the end of the safety program, the learner will be able to understand and employ safety knowledge and have strong safety ethics in laboratory practice. They should have the technical background and the ability to understand, analyze and explain the impact of laboratory safety-related incidents and suggest suitable safety measures in particular situations.

Each university should start a formal safety program development, depending on the need and requirements of local affiliated colleges and intense involvement of industry experts on safety will help to raise the bar on safety quality. There should be a robust linkage between the safety specialist in education institutes and those in industrial laboratories to strive for a stronger safety culture in an academic setting (Staehle et al., 2016). The primary emphasis is on bringing radical changes in the concerned departments and fixing accountability on higher education providers. Universal eligibility criteria for a safe scientific lab and high safety standards must be maintained as a step towards prevention of accidents. Conducting proper training and refresher courses by competent training authorities would help us to understand the nature and magnitude of the problem, the impact of safety measures, and the relationships between safe practices and the number of lab incidents. It is important to ensure enough human resources and other technical assistance to adhere to global safety standards to reduce unnecessary risk or the magnitude of the risks involved. Improving professional standards and commitment to ethical values along with an efficient safety management system to implement safety measures to a sufficient level will go a long way in addressing the problem of academic lab safety. National council for safety research and training can conduct meetings to reflect, discuss, and debate on thematic organization and presentation of topics in the safety course and arrive at a point to enhance the quality of learning activities and experiences. The laboratory activities must be consistent with the standard best practices followed by the top level universities for many years to achieve our safety goals (RSC, 1986).

Professional Development Approaches

The different common types of chemicals present or produced in the chemical laboratory include toxic compounds, reactive species, carcinogenic agents, compressed gasses, corrosive chemicals, irritant fumes, lachrymatory vapors, flammable liquids, explosive substances, shock-sensitive compounds, pyrophoric chemicals, radioactive materials, and peroxide-forming reagents.[9,10)] The various types of incidents include explosions due to mishandling, accidents during disposal of used chemicals, fire mishaps, injuries due to sharps, inhalation of toxic fumes, chemical/electrical/thermal burns, and UV/X-ray exposure (Luxon, 1992). There is a requirement to create a climate of safety for achieving distinct results, technological advances through educational professionalism and research work, which could be useful in the public interest, the institution, and

the nation. Safety education in the right perspective should be actively encouraged in universities to enable a learner to make a proper use of safety knowledge during the subsequent period of their scientific life while performing lab activities. The accidents caused by unsafe conditions can be improved by conducting regular safety audits and inspections, maintenance of equipment, encouraging reporting, and good housekeeping, whereas those due to unsafe acts can best be prevented from developing and establishing a better safety culture.[11] This culture can be drawn up by making conscious efforts in the direction of thoughts, actions, habits, character, and destiny, each of which reinforces the next.

The development of a safety culture includes personal, behavioral, and environmental factors that condition our mind to make the working environment safer and take steps to remedy unsafe situations. This transformation could involve changing perceptions and paradigm shift by overcoming deep-underlying thought patterns and major concerns at the subconscious level. The persons with a well-trained and organized mind can work more efficiently and effectively and will be able to use the brain power to think clearly, concentrate and to perform meaningful experiments without giving scope for accidents to happen. There is an urgent need for laboratory safety education and awareness activities at the undergraduate level that can indeed be an enabler and a driver of positive change (Hill, 2016). The study of safety and achievement of educational objectives depends upon the practical content, the way in which it is taught, rigorous follow-up and evaluation.[12,13] Higher educational organizations need to be sensitized, and colleges should include safety aspects and impacts in training curricula and enhance the industry-institution interface. Students with strong safety education should be preferred for industrial jobs or safety research groups to minimize the risks through an organized application of safety knowledge.

The educational objectives of integrated safety development drive should include the following; i) to increase the level of awareness of laboratory safety among learners by providing safety knowledge and safety ethics ii) to present recent developments that can help reduce the number of laboratory accidents leading to serious injury or death iii) to show that chemical reactions can be useful to find concrete solutions to many significant problems without injuries from chemical events iv) to share the right information about chemical principles and techniques, phenomena, fundamental concepts, and chemistry core ideas relevant to develop a sense of the kinds of chemical and other laboratory hazards one might encounter v) to develop a proper safety consciousness through selection of relevant scientific content and educational methods, vi) to establish a safety management system and to instil stronger safety practices in chemical research (Stuart & McEwen, 2016) and vii) to promote chemical science to young learners with safe practices to minimize the risks of hazards through proper mentor-learner relationship.

The formal safety course could be taught to regular students as a stand-alone course or as an integral part of the general science curriculum. It is important to activate and develop the right cerebral functioning with emphasis on logical thinking, scientific reasoning, problem-solving ability and creativity skills. Teaching lab safety for faculty members and other technical staff as a formal safety education is important to minimize risks (Hall, 1993). The systematic safety education approach must be outcome based or impact driven by innovative ideas, management skills, and efficiency. The educational outcome could be measured by formal learning assessment modules involving objective type questions, very short answer, short answer or long answer type questions on different aspects and impacts of academic laboratory safety. The questions must consist of a well-balanced composition involving easy, moderate and challenging questions (E, M, and D in ~ 60, 30, & 10 %). This structure will enable a vast majority of students to answer the easy ones without much difficulty. The questions with an increased degree of difficulty should be such that only above average students can provide conclusive answers to these. The remaining questions should be such that the students who can apply knowledge learned in the regular class right in the examination hall can only respond to these. The proposed safety syllabus has been used before as a comprehensive material in a unique and educational way in classes of average strength fifteen using PowerPoint presentation methods and handouts distributed as supplementary materials to promote active learning. The response of students to the interpretation of particular aspects of safety was excellent as reflected in their active participation in classroom activities as well as their best performance in examinations.

Further safety information can be obtained from the relevant literature survey, material safety data sheets (MSDS) available in CDs/printed version, the Merck Index, Chemical Laboratory Information Profile (CLIP) in J. Chem. Ed. (ACS), online databases, audiovisual materials, and CD read only memory products (CD-ROM form)[14-17]. A data bank of hazardous reactions was launched recently, and researchers can add their incident reports in this new chemical safety library service, helping to minimize dangerous reactions from being repeated.[18] In certain universities, the “Safety Quiz” has been introduced, and safety cell circulates ‘Caution Notes’ periodically for continual improvement. Surfing the internet sources to find some generic safety-related information (PDF or PPPs) and participating in global scientific conferences will allow us to switch between different themes in unconventional learning. The links to flashpoints, carcinogenic substances, MSDS data sheets, radioactive materials is included in the appendix B. Compiled information on various websites with their distinctive features along with detailed safety reports, interconnected conceptualized paintings, illustrative pictorializations and captured photographs can make a huge impact in scaling up learning levels. Further, audio-visual aids, cartoons, charts, diagrams, films, graphs, and models can be applied in the teaching-learning process that helps to see things

in a broader perspective. We have to look for factual safety information and ready to walk that extra mile to seek long-term solutions to safety problems (Haynes, 2017). The stages of safety-problem solving include recognizing that a problem exists, assembling information relevant to the problem and selecting and implementing the best solution. Most chemicals are toxic and dangerous chemical reactions include many more reactions than the reference library (Yoshida, 1987). If there is no published information on the hazardous properties of a chemical compound, this does not mean that no hazard exists (Saxena, 1984). It is better to keep track of the safety news to be aware of any dangerous properties and potential safety problems in our functional domains to enable us to make more informed judgments. Incorporation of safety data, including new guidelines and new policy matters in a laboratory information management system (LIMS) under analytical and managerial level tasks, would help address more immediate challenges and adapting to safety regulations.

The safety issue should be handled with extreme care while participating in various lab activities. The science, engineering and technology institutions take the lead in sensitizing the stakeholders about the various aspects of safety, reform their mindset, and educating them about safety culture is vital for the future. A regular theoretical training and practice sessions, including emergency action plan and response for the researchers to equip them with new skills required in safe laboratory operations and prudent practices, help in reducing the number of laboratory accidents. It is essential to develop strategies to an unblocked thought process and imagination to view things in their true relation or relative importance, with increasing concerns of environmental consciousness in the stakeholders. The scientific community should not allow workers to perform any potentially dangerous activities in an ordinary laboratory unless special safety requirements are met, and adequate risk management measures are in place (Sax & Lewis, 1987). The safety signs and symbols have become a core part of our communications, and the visual recognition carries profound significance. The forensic work for the investigative purpose could include establishing the cause of suspicious fires, academic hazard issues, hazardous equipment use and analyzing the presence or absence of various toxic substances in body fluids and tissues after the incident. The recruitment of safety management executive and recognition of safety teachers as scholarly practitioners at the university level will certainly boost the morale and confidence of those involved. The safety storage, waste disposal and emergency planning and response services have to be managed at the institutional level. The research activities related to safety problems are necessary to understand processes at the molecular level that cause them. Scientists and engineers have studied the spread of fire or gas inside the laboratories through computer simulations to find out practical solutions for several issues involving fire or toxic gases. Creating a trained, expert and motivated safety management task force in each university plays a pivotal role in the

process of promoting safety. A regular audit of laboratories for safety can alert us to accidents waiting to happen and taking certain precautions during lab activities help prevent many accidental injuries.

Towards a Safer World of Laboratory

Depending on the stage of development of an institution and available resources, established laboratories (10 + years), young laboratories (5-10 years) and new laboratories (under five years) have to be considered for various safety development activities. The priority should be given to improving existing equipment, facilities and construction of new ones to support safety-related activities. Further, establishing the integrated safety facility by providing critical safety infrastructure would help in building bridges between institutes in proximity. Also, installing sophisticated surveillance systems can drastically transform the behavior of those working in the laboratories. An online, print, electronic and outdoor media campaign may be necessary to have strict safety measures in the workplace. Student poster competition and safety-related activities for students as well as conduct regular workshops or crash courses on the basics of safety in academic laboratories help in promoting a safe work environment. It will be more useful, relevant, intellectually stimulating, and more productive to have 'bridging the gap' course on safety in an undergraduate program in chemistry, chemical engineering, biotechnology, medical lab technology, microbiology, pharmacology, biomedical engineering, and materials science (ACS, 2017). Experimental studies at the interface of these subjects may encounter unexpected or new hazards. It is the responsibility of the authors to report any such hazards in safety notes while publishing the results of experimental work. We have to facilitate learning by providing supporting information in the form of student handout (PPT) on the topic, and instructor notes (PDF) and experimental protocol should be supervised by the experienced teachers. Also, it is essential to assess learner's knowledge, attitude and behavioral practices towards safe laboratory experimentation through a battery of tests. The safety curricula must be brought up to date continuously because of the rapid developments in the field. We have to meet the needs of the environment and contribute to finding processes that reduce environmental hazards and consumes less energy.

Online centralized safety management system by the university grants commission or the national safety council can also minimize the number of safety-related incidents in wet chemistry laboratories, but active participation of university officials, safety managers, researchers, activists, enthusiasts, and the academic community is essential. Starting a universal safety portal (USP) to record lab incidents and lessons to learn more about the academic lab safety, and helping the researchers with the much needed valuable data or analysis. There should be an electronic system to provide alerts, and automatic updates of advances in safety-related research activities around the globe

to face the new challenges. The way forward includes the government support in technology adoption and safety infrastructure development, optimal utilization of resources, engaging professional management, and promoting safety-related research activities. Promoting safety culture within an organization ensures a comfortable working environment and practical experimentation can be quite safe under carefully controlled conditions.

The area of chemical research holds the potential to produce many new compounds or elements, which has significant consequences for understanding safety under extraordinary conditions. The design of molecules with targeted chemical, electrical and optical properties for application in drugs, vaccines and those with mechanical, magnetic and thermal properties for application in materials science poses a significant risk of causing minor to severe injury. New research may reveal sudden, unexpected chemical process caused by the impact of nanoparticles leading to safety related issues. The discovery of new biological species, including pathogenic fungi, bacteria, and virus have far-reaching consequences in changing our safety knowledge. The global committee on lab safety (GCLS) has to be set up to act as a coordinating body for safety awareness activities throughout the world, and a newsletter can publish, review and promote the exchange of safety ideas and the dissemination of information on lab safety all over the world. The idea of universal basic safety (UBS) requires serious deliberation and subsequent implementation in the interest of every citizen of the country leading to improved work environment and productivity. The government and the private sector should jointly respond to the agenda of universal safety system through public-private partnership (PPP) models to support safety initiatives and to achieve an improved level of safety.

Conclusions and Future Directions

A brief history of laboratory accidents in the recent past indicates the gravity of the safety problem on multiple experimental platforms. The academic lab safety is a neglected topic in chemistry, chemical engineering, chemical technology related subject curricula and it is important to incorporate safety course in such programs. Knowing the sources and reasons of lab incidents is a definite aid to avoiding accidents by taking proper preventive actions. The article is concerned with and outlines the academic laboratory safety issues that exist in higher education institutions and highlights multiple analytical perspectives of safe lab practice. Laboratory safety is a significant aspect of every laboratory session that requires safe laboratory procedures and training for all users to develop safety-related skills, safety knowledge, and proactive attitudes. It is vital to prevent adverse health effects from exposure to chemicals, personal injury or injury to fellow workers, and damage to common equipment. It is important to recognize chemical hazards that may occur during laboratory operation and apply

controls to minimize the risks of these hazards and to significantly reduce the number of incidents. The difficulties in chemical safety are that each chemical has a different risk and the users usually cannot analyze the level of risks involved, and risks are not necessarily how they are perceived. A chemical may react violently with the evolution of heat or produce flammable/toxic products. It is a thinking and visualization about the eventuality and consequences with the reasons for the worst possible situation in laboratory operations and taking a quick and wise decision to favorable incident transformation in the direction of safety. The discussion on the roadmap for a paradigm shift through a change of mindset should occur at the user level, and safety should be at the forefront of our consciousness. A laboratory safety management plan (LSMP) should be designed as a baseline preventive model for teachers at tertiary level that can be replicated elsewhere in schools, colleges, and universities.

The research community should use common pool resources for safety related development activities and better resource management to safeguard lab user rights. The funds need to go into well-thought-out projects to make a visible impact. The chemical labs had to be housed in one place and redesigned wherever required, keeping in mind the major safety aspects and ecological impacts. Apart from the commitment to the safety of the university, it also requires a deep understanding of the challenges of the safety in academic laboratories to create a culture of safety. It is essential to take sufficient proactive steps during experimentation, including initial attention, closer inspection, keen observation, instant inference, empirical evidence, quicker recognition of potential danger, and taking immediate action applicable for tackling the emergency situations. The safety teachers have to become scholarly practitioners and professionals through the development of pedagogical content knowledge (PCK) and best practices (ACS, 2001). In the pre-laboratory session, elaborate instructions on the safety protocol, while performing the laboratory activities should be provided. In the post-laboratory experience, students should be asked to discuss appropriate safety measures taken to experiment safely and efficiently (Corwin, 1999; Grant & Meyer, 1996). It is essential to store the MSDS sheets of the common chemicals used in a particular laboratory electronically or in a filing cabinet. The recent trend of a lab on a chip (LOC) to scale down the size of the analytical or preparative platform would certainly help in addressing safety issues to some extent.

The electronic surveillance system by installing the closed circuit television (CCTV) camera network with enhanced surveillance features at various lab locations can have a significant impact on work life. A machine readable quick response (QR) code that contains safety information about the individual chemicals must be made available in all the chemical science laboratories. The scan-based image platform available on smartphones with Android and iOS operating systems will be a boon to laboratory

users. Tangible safety initiatives are essential to drive good candidates to promote talent, training, education, experience, dedication and delivery aspects of right decision making at the right time to enable them in performing physical experiments. Apart from the increased primary focus on infrastructural development, establishing a safety management system with integration of proper attitudes towards safety at the university level would have a direct impact on research. A joint research program on selected safety related topics may provide insights to bring about a change in current academic laboratory security scenario and provide opportunities for careers in safety science. An independent study of different safety characteristics of each chemical would throw light on possible physical risks, provide adequate information to foresee and prevent accidents by taking proper precautions for its safe handling.

It is time to set up the global level academic safety council and national level laboratory safety regulatory authority to frame safety policy, recommend improvements, monitoring safety standards, and incident reporting on scientific research/academic laboratories to foster growth and development in the area of fundamental and applied science, engineering, and technology. It is necessary to constitute a national academic safety council or safety enforcement directorate (SED) with safety experts to look into various aspects of laboratory safety and establishing a laboratory accident fund can cater to injury or death and provide appropriate compensation. Formation of safety resource center (SRC) with a national safety network with necessary knowledge, skills, and information about safety devices helps in the implementation of safety objectives. The department of safety policy and promotion at the university level should monitor the various organizations through lab safety and compliance program. Multidisciplinary safety committees at the institute level should strictly enforce a control in all science laboratories and demonstrate a new way of safety education and reward quality over quantity will transform the way the university functions. A planning and construction division can manage and monitor funds for development projects responsibly, and a resource center should be established in select universities to conduct regular refresher courses on safety. The extra and sustained efforts towards safety with the right intent and on a priority basis is the key to bringing in change. A sustained and systematic effort to nurture the safety culture by facilitating a favorable learning environment is required. It is important to share knowledge, skills and attitude aspects with chemical safety communities and implement regulations through safety officer/inspector and faculty resource and action initiative (FR & AI). Further, incentive award for institutions or individuals for their outstanding contribution in the safety field would encourage innovativeness. It remains to be seen if the detailed roadmap for the future would lead to getting significant results while we ultimately act in the general interest of society. We can hope to have a considerable impact on work life by further evolution in laboratory technology and practice resulting in enhanced safety culture and a decline

in the laboratory fatalities in the coming years.

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