Supporting Information

Proceedings of the 2018 Laboratory Safety Workshop: Hazard & Risk Management in the Laboratory

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Appendix A: Poster Abstracts

**Tool for the Integrated Assessment of Health, Safety and Environmental Protection Management in High School Laboratories. The Case of Mexico**


We developed an instrument for the diagnosis of health, safety, and environmental protection management in high school science laboratories based on aspects of occupational health, civil and environmental protection, educational infrastructure, and expert recommendations. The instrument evaluates and compares the state of this management in a comprehensive and flexible way through a composite indicator called the health, safety, and environmental protection management (IHSE) indicator, which includes four sub-indicators: health, safety, and environmental policies (iPHSE); integrated management of chemicals (iMCH); facilities, safety, and emergency equipment (iFSEE); and staff training (iTr). These sub-indicators can also be evaluated and compared independently. This instrument was used in a case study of 62 high schools incorporated into the University of Sonora in Mexico, located both inside and outside the capital. The results showed that the IHSE level was medium in the capital schools and low in the external schools. The iPHSE level was medium in the capital schools and high in the external schools, while the iMCH level was low in both groups. The iFSEE and iTr levels were medium in the capital schools and low in the external schools. Statistically significant differences were found in the IHSE, iFSEE, and iTr. This study fills a gap in the existence of instruments for evaluating the state of health, safety, and environmental protection management, and it identifies specific improvement opportunities in Mexican high schools. The instrument can be used in other regions because its content is basic and can be generalized to high schools of any region.

**Hazard Assessment for the Multi-Step Organic Syntheses**

Jacob Kochurani, Research Safety, University of Alabama at Birmingham

Multi-step syntheses are regularly used in academic laboratories for synthesizing natural products and their analogues of biological interest. Such syntheses can involve 10 to 40 steps to generate the final product in milligram to gram quantities for the subsequent structure and biological activity determinations of the molecule. Numerous techniques and hazardous chemicals are manipulated at different scales in various steps. Though the precursors and reagents are manipulated at lower scales, however physical and chemical hazards are often present. Use of pyrophoric, strong oxidizers, shock sensitive, reducers, and toxic chemicals can pose significant risks if an appropriate technique or method is not used. Understanding and mitigation of hazards at various stages is a critical part of the syntheses, and this process can be time-consuming. As an example, the complete synthesis of spore photoproduct (Scheme 1) is carried out in 18-20 steps, and the precursors, bromo-substrate and protected dihydrothymidine are generally prepared in 5 steps in 5-10 g scales. Many chemical transformations are repetitive at various stages to generate precursors and intermediates; therefore, a quick hazard assessment for the critical steps where hazardous chemicals are involved is important to complete the
syntheses safely. In this study, we will discuss a quick and time-effective hazard assessment for multi-step organic syntheses.

Scheme 1:

Reagents and Conditions:
(i) LDA, THF, -78 °C (ii) Formic acid: MeOH, rt. 75-85% (iii) DMTrCl, triethylamine, pyridine, 10-12 h, 70-80% (iv) 2-Chlorophenyl dichlorophosphate, 1,2,4-triazole, THF, 95% (v) TBAF, THF, 2 h, 86% (vi) MSNT, pyridine, rt, 50-60% (vii) acetic anhydride, pyridine, rt, 6 h, 95-98% (viii) SnCl₄, methylene chloride, 2 h, 70-76% (ix) ammonium hydroxide, rt, 36 h, 80%.

Example: Hazard Assessment LAH reduction (What if strategy)

<table>
<thead>
<tr>
<th>What if?</th>
<th>Answer</th>
<th>Probability</th>
<th>Consequences</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction flask size is not enough to hold the reaction volume in the event of excess LAH addition</td>
<td>Discharge of reaction mixture from the vessel</td>
<td>high</td>
<td>Fire and chemical exposures</td>
<td>Use a slightly larger size flask even for a small-scale reaction in order to contain the contents for excess heat formation. All LAH reduction should be carried out inside a properly functional chemical fume hood.</td>
</tr>
<tr>
<td>Oxygen is present inside reaction vessel</td>
<td>Formation of explosive environment</td>
<td>high</td>
<td>Fire/explosion</td>
<td>Make sure reaction set-up is free from oxygen</td>
</tr>
<tr>
<td>Magnetic bar is insufficient to stir the reaction mixture</td>
<td>Inadequate reaction mass stirring and cooling</td>
<td>medium</td>
<td>Incomplete conversion, uncontrolled heat formation</td>
<td>Use an appropriate oval shape magnetic bar to stir the reaction mixture</td>
</tr>
<tr>
<td>Reaction assembly is pressured</td>
<td>Pressure</td>
<td>high</td>
<td>Fire and explosion</td>
<td>Properly vent the reaction mixture</td>
</tr>
</tbody>
</table>
Department: Chemistry/Biochemistry

Description of Operation: Use of LAH for organic syntheses

By: Review Team Date XX/XX/20XX

<table>
<thead>
<tr>
<th>What if?</th>
<th>Answer</th>
<th>Probability</th>
<th>Consequences</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>not vented properly</td>
<td>build-up</td>
<td></td>
<td>explosion</td>
<td>using a calcium chloride guard tube or using a Schlenk line port.</td>
</tr>
</tbody>
</table>

References
https://www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/hazard-assessment.html


How Low Can You Go: Reducing Flow, Increasing Savings
Paul Lueth, EHS, Iowa State University

Fume hoods must operate continually to ensure a safe laboratory work environment. This safety requisite constitutes an increased energy load and higher ventilation requirements. As a result, laboratory buildings containing fume hoods consume a substantial amount of energy. In academic institutions, laboratory buildings consume anywhere from 300-800% more energy than other building types and may account for up to 50% of total energy consumed on a university campus. Of the total energy used, close to 50% is related directly to ventilation. Institutions seeking to reduce overall energy costs, may find a direct and immediate savings by reducing air flow through building ventilation and exhaust systems. This is especially true, in older buildings which house fume hoods containing constant volume (CV) designs that exhaust a constant volume of air.

Established in 1858 and with over 36,000 students, Iowa State University is the most student-centered public research university and the largest university in the state of Iowa. At Iowa State University, there are over 1200 fume hoods. We identified 242 fume hoods with extremely high face velocities ( > 125 (f.p.m.) feet per minute), directly related to high air flow in five buildings.

Fume hoods with face velocities above 125 f.p.m. expend more energy, are less efficient, decrease equipment lifespan, and pose a laboratory safety hazard by creating turbulence, allowing for contaminants to escape the hood potentially increasing worker exposure. Reducing air flow of exhaust systems in five buildings at I.S.U. decreased fume hood air velocity, saved energy, and enhanced laboratory safety, by mitigating the potential exposure to contaminants in 20% of the fume hoods used on campus. This initiative resulted in a total energy savings of about $450/year per fume hood, potentially leading to $108,900 in annual energy savings.

Graduate Student-Led Safety Team: An Approach to Engage Researchers in Laboratory Safety
Xiaodi Wang, Agnes Thorarinsdottir, Research Safety Student Initiative (RSSI), Northwestern University
In response to several fatal laboratory accidents in the past decade, there has been an increasing emphasis on research safety in academic laboratories. Parallel to the top-down approach that most academic institutions have adopted in promoting a stronger culture of safety, a number of student-initiated organizations have emerged since the formation of the Joint Safety Team (JST) at the University of Minnesota in 2012. Here we describe the effort of such a student group at Northwestern University - Research Safety Student Initiative (RSSI), which was formed following a trip to Dow Chemical Company in Fall 2017. In collaboration with Dow and the Office for Research Safety (ORS) at Northwestern, this group of students launched the inaugural weeklong event - Safety Awareness Week, to introduce their effort in developing and promoting a stronger culture of safety at Northwestern. More than a hundred researchers, including principal investigators, postdoctoral associates, graduate students, and research specialists attended the opening reception while an average of seventy people stopped daily by the RSSI safety booth throughout the week to learn about different aspects of safety. Subsequent initiatives include introduction of Safety Minutes during research meetings, Safety Designate Training, and Laboratory Safety Walk-throughs.

Principles of Lab Safety Advocacy
Dan Kuespert, Whiting School of Engineering, Johns Hopkins University

One of the key principles for leading any organization is to manage risk, for failure to do so is a threat to the existence of the organization. In the research university setting, the health and safety of those working in the lab is a primary risk. Unfortunately, lab safety is often seen as a legal matter: compliance with safety regulations is equated to achieving a safe environment. This is not necessarily so. Within many organizations, the unmet need to address lab safety risks can be fulfilled through advocacy of lab safety, not as a replacement for compliance but as a complement to it. In this poster, we give five principles for effective lab safety advocacy, along with illustrative examples of the application of each principle:

1. We, not you: Develop partnerships with stakeholders rather than dictating procedures;
2. Resources, not rules: Be a source of solutions rather than instructions;
3. Education, not training: Teach the researcher to think in a safer manner;
4. Flexibility, not rigidity: Actively promote alternative safety solutions;
5. Behavior, not conditions: Link hazardous conditions in lab to researcher behaviors and depersonalize the discussion by focusing on cognitive biases and failures.

These principles are essential for effective advocacy. The end goal of safety advocacy is to turn all laboratory researchers into laboratory safety advocates. We conclude with advice for designing a “laboratory safety advocate” position similar to that used at Johns Hopkins.

The UC Irvine Graduate Safety Fellowship
Alex Reath, Department of Chemistry, UC Irvine

The Graduate Safety Fellowship is an award given out by the University of California,
Irvine to chemistry graduate students as an initiative to promote lab safety on campus and provide an immersive training program for its recipients. The fellowship provides funding to a graduate student for one year, sponsored jointly by the Department of Chemistry and the Department of Environmental Health and Safety. The general responsibilities of the Graduate Safety Fellow are broad and include collaborating with EH&S as a representative of the graduate student body, participating in accident analysis, and working with professors to introduce safety fundamentals into undergraduate lab courses. Another duty of the Graduate Safety Fellow is to serve as the group leader of the Graduate Safety Team (GST). The GST is a student formed organization that is working towards improving and maintaining lab safety culture on campus. The team works to plan seminars and promote lab safety through newsletters and other public outreach methods, and also coordinates student lead walkthroughs of research labs to gather compliance data. By getting graduate students involved in the conversation of lab safety, it is hoped that a robust culture of safety will continue to develop over time at the University of California, Irvine.

“Risk and the Researcher”; Finding Paths towards Embedding Safety into Everyday Lab Culture
Representative(s) of the study’s participating UCI graduate students with the help of Professor Kimberley Edwards, Department of Chemistry (UCI), John Palmer and Larry Wong (UCOP), UC Irvine

The poster will describe progress on a multipart investigational program by and with UCI graduate researchers aimed at identifying creative and “more easily applied” risk assessment methods, tools, and resources. The (eventual) goal is embedding risk assessment technology and instruction in the very fabric of everyday research activity. Where enhanced tools or resources are desired, this program hopes to describe why those augmentations are needed, and to suggest path(s) to those improvements.

Many models of risk assessment exist. Several were evaluated in an American Chemical Society (ACS) sponsored resource titled “Identifying and Evaluating Hazards in Research Laboratories” which was developed in response to a specific US Chemical Safety Board (CSB - 2012) request to the Society. Those examples of risk assessment methodologies, and others, constituted the stepping off point for our group’s investigational program. After organizing a dozen graduate level researchers and briefly reviewing the findings of several recent reports and studies signifying that a new emphasis or approach to improving “safety culture” was needed [especially in academic research laboratories] we touched on, as a group, examples of serious laboratory incidents over the last 10-15 years, and we then applied some focused hindsight to guide our efforts at shifting the rote behaviors of laboratory research towards a more fundamental inclusion of safety.

Our efforts at identifying and then adapting various versions of risk assessment tools [to everyday research efforts in working academic research laboratories] will be reported along with our suggestions for needed enhancements of those tools and informational resources.

Creating a Collaborative Relationship with Safety Since 2015
Meghan J. Seltzer, PhD, RBP; Jennifer Goodnight, ASP; Joshua Russell, CSP; Ashok Gopala-Rao; and Samantha Koob, Howard Hughes Medical Institute, Janelia Research Campus
In lieu of a “traditional” laboratory inspection or audit program, HHMI’s Janelia Research Campus instituted a new system in 2015: The Annual Laboratory Safety Evaluation and Training (AL-SET) program. The program involves a visit to each laboratory which includes an annual safety training and a walk-through of the laboratory’s spaces. All researchers (including the Laboratory Head) are required to attend this training. Safety specialists attend AL-SETs for laboratories working with hazards which fall under their respective programs. Annual trainings are tailored to the work a laboratory performs and also includes a review of the emergency response procedures and changes to applicable policies/procedures. The walk-through involves a review of the hazards with which a laboratory works and a walk-through of all laboratory spaces accompanied by the researchers who use the spaces. Following the visit, Janelia EH&S/C works collaboratively with the researchers to address any concerns or issues noted and takes primary responsibility for ensuring that all issues are addressed.

During the first three iterations of this program, researchers have increasingly reached out to EH&S/C proactively before beginning work or when they have a concern. We have also noticed that researchers are more willing to raise concerns with us during the walk-through and are engaged in the process.

Our poster will share the following:

- Description of the evolution of the program from inception to its current version and projected changes for the 2018 cycle
- Sample materials
- Examples of how the program has improved collaboration with researchers and within the EH&S/C team
- Discussion of lessons learned from the implementation experience
Appendix B: APLU Guidelines as Implemented by Utah State University

1. The president committed publicly to safety.

2. The president designated a lead, McLellan, to devise and implement safety policies.

3. McLellan engaged in a campus-wide dialog involving all departments in shaping safety culture.

4. Over a course of a year, safety policies and procedures were written and agreed upon by all departments, known as USU policy 337. Safety policies were integrated throughout all departments and auxiliary facilities (such as dining services). Each unit now has their own safety group. Representatives from each safety group report to university committees. Every major policy is now reviewed and re-reviewed with faculty input.

5. USU policy 337 clearly defines roles and responsibilities with prescriptive accountability especially for administrative leadership and faculty.

6. Safety communication has to be documented.

7. Safety culture developments have to be documented.

8. Faculty have to perform risk/hazard assessments. They are required to know all hazards in their labs and communicate those effectively.
9. USU unified administrative reporting, wherein EH&S, Risk Management and Administration now take a holistic approach to reporting of problems and incidents.

10. USU’s administrative leadership empowered students to become engaged in safety activities.

11. EH&S formed a relationship with faculty that is based on EH&S serving as a resource and friend, and as enforcer only as last resort.

12. EH&S and administrative leadership formed a working relationship with First Responders.

13. Routine hazard analysis was integrated in graduate education.

14. A Near Misses reporting system was established.

15. Safety training was prioritized.

16. Safety was integrated in all curricula.

17. A self-assessment process was established to monitor the progress in improving safety culture.

18. EH&S and administrative leadership invite continuous feedback for improvement of their safety program.

19. They created a system of accountability by everyone including research departments and auxiliary facilities.

20. They formed partnerships with outside organizations to help the safety process.
Appendix C: Panel Suggestions to the Research Community

- When considering safety management, it is important to understand the human behavioral side.

- Managers and supervisors should model safety behavior rather than just talk about it.

- Organizations should have Safety Days devoted exclusively to safety; safety drills, demonstrations and lab cleanups could take place during this time; administrative leadership should show formal support.

- Safety takes less time and is more efficient if it is integrated into the research activities on an ongoing basis.

- A near miss reporting system provides important feedback on safety gaps; with improving safety culture employees generally feel more comfortable to report.

- An accident should always trigger a hazard and risk review.

- Safety training should be integrated into teaching new laboratory techniques.

- In academic institutions, safety should become a condition of employment – as part of a contract-resulting in disciplinary action for violations – similar to industry.
• Administrative leadership should sponsor safety experts embedded into certain departments to help with their safety challenges.

• Incentive suggestions for promoting lab safety include:
  
  o “Safe Lab” stickers placed on lab doors to signal a safe lab culture, which helps in recruiting new students.

  o Bonus money for conducting safe research paid from indemnification funds.

  o Award research labs for developing their own safety program.

  o Safety medals for outstanding researcher’s safety actions and publishing the winner list monthly.
Appendix D: Detailed Compilation of the Workgroup Session Outcomes

A. How can universities use hazard identification and risk assessment forms for research involving hazards?

Hazard identification and risk assessment are vital to safety management and should be part of every experimental design. Work group participants suggested that researchers should be proactive in identifying all potential hazards involved in experimental procedures and assess the risks associated with those hazards. Hazard identification and risk assessment forms should be generated by researchers for specific experimental protocols. A dichotomous key was generated by the workgroup participants to determine the assessment level when experimenting with hazardous materials (Figure 1). This model assumes job hazard analysis (JHA) is the assessment of choice.

![Figure 1. Example of a Job Hazard Analysis (JHA) to determine assessment level when experimenting with hazardous chemicals.](image)

As stated by participants, the goal of risk assessment tools used by universities is to:
1. Provide the right level of analysis for each type of research
2. Facilitate decision making by management, and keeping consistency in approach
3. Teach researchers to identify hazards and working safely by reinforcing best practices and good mitigation strategies
4. Be practical and useful. Should be visible (e.g. PPE assessment, job hazard summary)
5. Be owned by researchers and solicit feedback from safety experts
6. Include proficiency as a mitigation strategy
7. Assess non-routine or emergency conditions
8. Result in both learning and safe work

Participant suggested that hazard summaries should be visible, and include hazard statements, hazard codes and hazard class pictograms. The purpose of posting hazard summaries is to remind researchers the unique properties of the control-banded chemicals and other hazardous materials. This would allow researchers to identify and prevent potential hazards. Group participants also suggested researchers generate individual reaction forms that include the type of chemical reaction that it is in progress (e.g. reactants, solvent being used, conditions). Forms should include hazard class and useful information for emergency response. This type of forms would be particularly useful for unattended chemical reactions and should be posted at fume hoods or work bench.

Workgroup participants also identified some of the challenges and gaps in implementing some hazard identification tools or forms. These include:

1. Selecting the correct tool for the work process
2. Achieving a balance between ease of use and including all required information to perform a proper hazard assessment
3. The tools need to define boundaries
4. Risk assessment should reflect actual practice
5. Ensuring that the hazard mitigation strategies are feasible and effective for all members
6. Making sure that assessment is developed based on previous incidents
7. Ensuring the assessment provides sufficient information to make risk-based decisions. These should be approved or reassessed by PI/supervisor/EHS

B. What do PIs need to know to effectively manage hazard identification, risk assessment and safety culture?

In order to address this question, participants first described the concrete tasks that risk management should entail. These are 1) understand the difference between hazards and risks, 2) know how to conduct risk assessments which should include define roles and accountabilities, 3) be knowledgeable about the working environment, and identify risks and risks levels, and 4) provide risk assessment tools.

Workgroup participants discussed whether PIs should receive risk management training and the type of training that would be appropriate. As stated by participants, PIs should receive risk
management training that enables them to identify potential hazards and device mitigation strategies. In addition to providing PIs with hazard analysis and risk assessment techniques, risk management training should allow PIs to gain a broad overview of potential hazards including radiation, laser, chemical and biological. This is particularly important for PIs that conduct multidisciplinary research and those who are engaged in research collaborations or share space with other labs where different types of hazards are present. As stated by participants, risk management training should provide PIs with basic skills such as personnel management and help them determine what needs to be managed and how to prioritize. In addition, the objective of the risk management training should be for PIs to learn how to foster a good safety culture. In order to do this, PIs should encourage their researchers to take safety seriously, incentivize the reporting of near-misses, and recognize and manage mental health concerns. Participants indicated that emergency preparedness should also be part of the PI risk management training.

According to the group participants, one of the challenges for many PIs is to ensure that hazard recognition and risk control measures are implemented by their researchers. Therefore, it is important for PIs to maintain a physical presence in the lab. PIs should perform walk-throughs to identify potential hazards and discuss high risk activities with researchers. To ensure hazard recognition and risk control measures are implemented by researchers, PIs should maintain routine safety discussions with researchers. These can be in the form of safety moments at group meetings and safety talking points during research presentations. In addition, PIs could generate, in collaboration with EHS, safe operation cards that can be used by researchers to identify high risk activities and devise mitigation strategies. Workgroup participants recognize that PIs might require support to implement risk management. This includes safety training for researchers (students, postdocs) before they start to work independently in the lab. PIs should also have access to safety information and tools such as tailored lessons learned specific to research and hazard areas, and reporting mechanisms. PIs should be provided with a safety/EHS official that can assists them to incorporate hazard analysis and risk management into their research. In some instances, EHS funding might also be required to implement risk management as new safety procedures might require new equipment and safety gear. EHS could also assist new and existing PIs with practical drills and simulations to reinforce safety concepts. Participants indicated that at all levels, collaboration is important, therefore, faculty should have the opportunity to provide input into EHS processes, requirements, and decisions.

Furthermore, positive recognition of good safety behavior might have a positive impact on risk management. Positive recognition could be in the form of incentives (e.g. additional funding, space) for PIs for promoting safe research. In addition, safety aspects could be incorporated into tenure package evaluations. PIs should also positively acknowledge, and support lab managers and safety champions.

C. What do students, postdoctoral fellows and research staff need to know to effectively implement hazard identification and risk assessment?

To answer this question, group participants first highlighted some of the challenges that prevent staff and trainees from implementing risk management. These include:

- Time and access to resources
- Highly variable safety training
- Lack of risk assessment knowledge and experience
- Mindset and attitude
- Interdisciplinary research

As stated by group participants, implementing hazard identification and risk assessment would not only reduce the frequency of injuries and incidents, but would also enhance reproducibility and efficiency of research. Risk assessment processes can assist in thinking through an experiment and might lead to increased efficiency which in turn can make a lab more productive (i.e. more publications). Hazard identification can also lead to the protection of equipment and minimize downtime that results from incidents.

According to workgroup participants, in order for staff and trainees to identify hazards and assess risks involved in their research, they need to be taught the theoretical aspects of hazard identification, and risk assessment and mitigation. In addition, immersive learning should be incorporated into lab safety trainings in which staff and trainees are taught skills and techniques that are relevant to their lab equipment, hazards and experimental procedures. Participants indicated that it is important for staff and trainees to have access to resources that facilitate risk assessments including safety manuals, SOPs and SDS sheets. All these can be used to generate formal forms for risk assessments. This type of forms should be succinct, relevant, and should be structured to guide and prompt safety thinking. In addition, it is imperative that PIs promote safety practices such as hazard identification, and risk assessment and mitigation among their staff and trainees. PIs should acknowledge lab safety practices and provide positive and consistent feedback to staff and trainees. Participants suggested that PIs should be sensitive to cultural differences, discipline-specific knowledge, power dynamics, and gender dynamics which can influence understanding or willingness to admit lack of hazard identification and risk assessment knowledge.

Furthermore, safety professionals can aid researchers to assess hazards and mitigate risks. Safety professionals should be aware of the language they use to describe programs and policies. They should work with researchers to make systems and policies that are simple, effective and logical. Participants suggested safety professionals should consider themselves as a resource to researchers and adapt a customer service mindset. They should also understand the constrains faced by researchers (e.g. cost, space limitations, time). Safety departments could also aid researchers by developing grass roots programs where the work is done by the students, post-docs and research staff (e.g. UCLA lab ENGAGE program).

**D. Improving the culture of safety: How can universities expand the focus from compliance towards active engagement in safety management?**

Participants began the discussion by describing the limitations of focusing mostly on compliance. As stated by participants, compliance is generally regarded as meeting the minimum requirements. Researchers often have the sense that safety standards are met once compliance have been achieved. However, researchers need to be aware that risks might persist (e.g. low frequency risks) even if compliance has been accomplished. Participants indicated several barriers need to be overcome in order to move from compliance towards active engagement.
These include:

- Lack of organizational commitment to safety
- Perception of EHS
- Lack of a positive relationship between EHS and researchers
- Lack of communication
- Insufficient applicable and valued safety training
- Attitudes (e.g. complacency)
- Power differentials and group dynamics
- Time and funding
- Lack of tools utilized to communicate at all levels of knowledge
- Interdisciplinary direction of current research, which introduces challenges for subject matter experts and PIs
- Absence of safety procedures in research project objectives

In order to overcome some of these barriers, group participants suggested that researchers (PIs, staff and trainees), safety officials and administrative leaders should be encouraged to take ownership of safety as everyone has a role in ensuring a safe environment for all. Building positive attitudes toward safety requires continual reinforcement of the importance of safety by individuals in leadership positions. PIs and safety departments should also empower students and reinforce their safety practices. Active engagement might be improved by providing an incentive to students who design and implement safety programs (e.g. UCLA lab ENGAGE program). This type of programs has the potential to improve group dynamics, safety attitudes, perception of EHS, and communication among peers. Individuals involved in these programs should be positively acknowledged by PIs and research safety departments. For example, EHS could design a “best lab award” per semester and academic department. Some participants argued that lab specific safety programs may only improve the safety culture within a lab, and that they have a narrow window of influence. The effectiveness of such of programs might only be measured by compliance.

In addition, providing more resources (e.g. funding safety programs and supplies) and improving communication from upper administration would also promote active engagement in managing risks, and improve the internal culture of safety. Other ideas proposed by participants to actively engage researchers in safety management is to build relationships within departments. This can be facilitated by hosting mixers, meet and greets, in-house poster sessions, and by creating student organizations that meet monthly to discuss safety issues. These types of activities might change peoples’ attitudes towards safety, improve communication and group dynamics.

Furthermore, group participants underlined the importance of integrating safety into the academic curriculum, and for EHS to provide highly qualified safety professionals to assist in research design and safety management.

E. What should be the professional expectations regarding safety for graduating scientists?

As stated by group participants, different disciplines introduce specific hazards and risks.
However, students pursuing scientific roles are expected to possess basic safety skills and values. Teaching students safety core values should be the joint responsibility of the university, mentors and peers. Using the ACS Employers Safety Awareness Expectations for new hires as a reference, participants generated a list of core expectations for undergraduates, master and doctoral students (Figure 2).

![Figure 2. Core Expectations for Graduating Scientists.](image)

To better prepare graduating scientists, group participants suggested that universities should emphasize more on safety by standardizing safety across departments and in research proposals. Other ways in which universities can better prepare their students include teaching students to recognize, assess and minimize the risks of hazards, and prepare for emergencies (RAMP). This can be done through case studies and leading by example. Universities should also propagate a culture of safety by encouraging students to lead safety initiatives, and by providing hands-on training for laboratory teaching assistants.

Universities should also establish collaborations with industry by inviting speakers, organizing field visits, and providing students with insights into industrial safety culture. This would be a good opportunity for hiring agencies to clearly communicate their safety expectations (Figure 3) to graduating scientists and potential job candidates.
F. Is current safety education in undergraduate instructional labs sufficient to train undergraduates in hazard identification and risk assessment?

To address how safety education in undergraduate instructional labs can be improved, group participants discussed different ways an institution, academic departments, and instructors can incorporate hazard identification and risk assessment in undergraduate instructional labs. As suggested by participants, leadership should be involved in the implementation of a safety curriculum in undergraduate education. For example, the provost of undergraduate education should mandate that academic departments incorporate hazard identification and risk assessment into the safety training for all laboratory courses. Experimental protocols used in teaching labs should be reviewed by researchers and EHS officials to ensure that risks are assessed, and a mitigation plan is in place.

Academic departments should also be engaged in promoting safety education. This can be done by creating an elective course on safety, which can become a catalyst for broader changes in safety culture. Individual departments could also generate safety assignment templates that can be used in instructional labs. In addition, participants highlighted the importance for instructors to engage undergraduate students in risk management. Instructors should integrate safety in lab and lecture curriculum, and actively involved undergraduate students in safety activities. Some of methods that can be used by instructors to engage students in risk management include:

- Require students to analyze their experimental protocols for hazards, and to develop a mitigation plan
- Instructors should incorporate safety case studies with real or hypothetical scenarios into lectures and lab discussions
- Encourage students to participate in safety teams that perform inspections of lab spaces
- Require students to lead pre-lab safety moments and safety discussions
- Encourage students to report near-misses
- Teach students how to use safety tools (e.g. SDS)
- Include a safety section in all lab reports and assignments

Furthermore, teaching assistants (TAs) play an important role in instructional labs and should be encouraged to incorporate safety into the curriculum. TAs should discuss risks and how these are mitigated during lab sessions. Participants agreed that instructors and TAs should collaborate with EHS to develop and deliver short safety training presentations to students. EHS should also provide PPE for advance lab classes (e.g. pyrophoric lab coats). Participants stated different ways in which teaching assistants can be trained to implement risk management in instructional labs. These include hosting a lab safety training day for incoming graduate students and incorporate safety instruction during weekly TA meetings.

Group participants also suggested that industry and government should be involved in safety education. For example, safety officials from industry, government and professional organizations can exchange ideas with lab safety coordinators about safety training and safety materials (e.g. APLU guidelines). Participants suggested that academic institutions, in collaboration with industry and national labs, should organize safety days where safety officials from industry and national labs speak to students about hazard identification and risk assessment, and how these are implemented at their institution. Government and professional agencies could also become engaged in safety education by creating templates for safety assignments, create a repository of curriculum material in safety, and create a Lessons Learned library. Professional organizations might also be able to provide a safety fellowship and training support for students interested in pursuing a career in safety.

In addition to providing multiple ideas that can improve safety education in undergraduate instructional labs, participants recognized some of the challenges in teaching undergraduates risk management. These include the lack of a centralized oversight of labs, limited time and money, the need for material to use across the curriculum in lecture and lab courses, and the limited support for faculty to participate. However, some of these challenges might be overcome by engaging administrative leadership in safety education, increasing institutional support, educating faculty on risk management, and fostering a collaboration between EHS and undergraduate teaching programs.

G. What should be the role of laboratory design, renovation and maintenance in risk mitigation?

Workgroup participants initiated their group discussion by delineating the common phases of a laboratory life cycle which include construction, maintenance, renovation and decommissioning/demolition (Figure 4). Group participants expressed the importance of engaging researchers, engineers, architects, administrators and safety personnel in every step of the construction, renovation and decommissioning/demolition processes. Stakeholders should work together to establish agreements, appoint roles and delineate expectations including financial responsibilities. Group members indicated that stakeholders should be aware of the impact of the building design on adjacent buildings/laboratories.
The challenges and the solutions to common mistakes made during the design of the facility, maintenance, and renovation that hinder safety were also discussed. As indicated by participants, some of the challenges when designing and building new facilities include:

- Integrated labs with combined office and lab space
- Local and state authorities having jurisdiction over lab design
- Faculty are perceived as temporary occupants
- Design flexibility to accommodate current and future users

The proposed solution to some of these issues is for all stakeholders to be involved in the developmental process from beginning to completion. Official funding agreements should be generated where roles and expectations are clearly specified. In addition, laboratories should be design according to specific research needs, therefore, it is important to challenge design suggestions versus research specific needs. Participants pointed out that funding should be flexible, and account for finishing touches and activation costs.

Inadequate lab maintenance might also impede safety. As stated by workgroup participants, some of the common challenges to improve lab maintenance are:

- Access to utility systems
- Impact on surrounding labs
- Inaccurate as-built documents
- Improper faculty self-maintenance/alterations
- Funding and ownership

The solutions proposed by participants to improve maintenance were to establish a regular maintenance schedule, and to report and address maintenance concerns before critical failures. In addition, as-built documents should be updated as modifications are made. An effective decommissioning, and a close-out and clearance procedure should be developed in order to improve lab maintenance.
Moreover, lab renovations also pose a challenge to research safety. Some of the issues often encountered during lab renovations that might hinder safety include:

- Meeting new code requirements in older buildings
- Inappropriate space allocation due to limited space/resources available
- Insufficient funding and contracts
- Contaminated and/or abandoned space, materials and equipment
- Overall campus impact on utilities and surrounding infrastructure

As suggested by group participants, some of the solutions to the issues stated above are to build new instead of renovating existing lab spaces. As indicated by group participants in old structures might not meet current safety requirements. Instead of renovating old building it might be more cost efficient to build a new facility. Alternatively, lab users could establish collaborations with other entities (e.g. core facilities) in order to gain access to a lab facility or equipment required to perform specific procedures. Oversight of renovations by stakeholders is also important to ensure all safety guidelines and requirements are met.