ACS CHEMICAL HEALTH & SAFETY

ACS EDITORS' CHOICE

pubs.acs.org/acschas

Review

Starting and Sustaining a Laboratory Safety Team (LST)

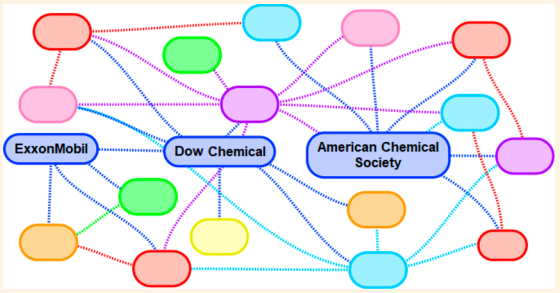
Jessica A. Martin,* Kali A. Miller, and Eugene Pinkhassik

Cite This: *ACS Chem. Health Saf.* 2020, 27, 170−182

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: The laboratory safety team (LST) movement was triggered in 2012 by Dow Chemical's exploration of ways to strengthen academic research safety culture from the bottom up. This necessitated a new form of leadership from graduate students and postdoctoral scholars. This movement has been spreading throughout chemistry and engineering academic research departments in the United States in a grassroots fashion. However, few publications exist providing the details of LST structure and activities. In this paper, we share results from interviews with 16 currently active teams and outline a best practices guide for starting and sustaining LST programs. Interviews yielded five common components that have been identified as useful to establishing an LST as well as six top common challenges. Strategies to overcome these challenges through proper documentation of activities, maximizing relationships within the academic hierarchy, and developing meaningful safety culture metrics to track are discussed. This paper showcases the power of connecting players in the various active LSTs and emphasizes the need for quantifiable and trackable metrics in the next wave of the movement.



KEYWORDS: *graduate student, joint safety team, laboratory management, laboratory safety, laboratory safety team, leadership development, postdoctoral scholar*

INTRODUCTION

Current challenges in academic research laboratory safety are rooted in independent management of a diverse set of chemicals and procedures as well as a high turnover of graduate student and postdoctoral researchers. While all researchers receive relevant Environmental Health and Safety (EH&S) compliance training, site-specific training and the development of a safety-oriented mindset are usually left to individual research groups. Uneven training outcomes not only increase the chances of laboratory accidents but also may negatively impact the career trajectory of newly independent scientists since knowledge of and leadership in chemical safety is a requirement of any PhD-level position.

Traditionally, the safety record of an academic institution has been tracked through the number of reported accidents, the number of and attendance at trainings provided, and availability of resources. However, the tracking of these metrics fails to give us a real sense of the culture of safety of an institution. For example, an increase in laboratory accidents may indicate riskier experimentation, but can also be attributed to increased reporting brought on by better communication. In fact, studies have shown that the accuracy and robustness (and therefore communication) of incident data itself can be used to indicate the health of an institution's culture of safety.[1,2] Additionally, safety trainings for the whole researcher population are typically focused on regulatory compliance and general rules and information, with more specific training being handled by Principal Investigators (PIs) and senior group members on an ad hoc basis. Although resources are provided to educate researchers on safety awareness and practices, they are often not properly integrated in universities to effectively teach newer researchers the core practices of chemical safety.[3−6] All of this can amount to researchers passively receiving safety compliance information in a piecemeal way. However, it is the expectation upon completion of a PhD that an individual be capable of providing leadership on safety issues to a research team, which requires the ability to communicate with different audiences.[7,8]

In recent years, graduate and postdoctoral researchers began leading safety groups called laboratory safety teams (LSTs), which have begun spreading as an increasingly popular grassroots movement.[9] LSTs have the potential to enhance communication among researchers at all levels, enrich the professional development of newer researchers, and improve the culture of safety across academic institutions.

The modern researcher-led LST was first defined by the efforts at the University of Minnesota (UMN).[10] In 2012, UMN already had a system in place that required each laboratory to have a designated Laboratory Safety Officer

Received: February 17, 2020
Published: April 30, 2020

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

Table 1. Summary of Currently Existing and Active Laboratory Safety Teams and Electronic Means of Connecting with Them[a] (with Apologies to Teams We Might Have Missed)

institution	LST name	website	group email	social media
Johns Hopkins University	Chemistry Student Safety Committee (CSSC)	https://sites.krieger.jhu.edu/chemssc/		TW: @JHU_ChemSSC
Northwestern University	Research Safety Student Initiative (RSSI)	https://northwesternrssi.wixsite.com/rssi	rssinorthwestern@gmail.com	TW: @NU_RSSI
Pennsylvania State University	Student Safety Leadership Team (SSLT)	https://chem.psu.edu/about/safety-resources		
Texas A&M University	Chemistry Student Safety Committee (CSSC)	https://www.chem.tamu.edu/safety/	cssc@chem.tamu.edu	
The Ohio State University	Joint Safety Team (JST)	https://chemistry.osu.edu/safety/jst	cbc-jst@lists.osu.edu	
University of Arkansas	Engineering Safety	https://hogsync.uark.edu/organization/engineering-safety		
University of California, Irvine	Graduate Safety Team (GST)	https://www.chem.uci.edu/graduate/safety	graduatesafetyteam@uci.edu	
University of California, Los Angeles	Joint Research Safety Initiative (JRSI)	https://sites.google.com/chem.ucla.edu/jrsi/	jrsi@chem.ucla.edu	
University of Chicago	Joint Research Safety Initiative (JRSI)	https://jrsi.uchicago.edu	jrsi@uchicago.edu	TW: @UChicago_JRSI
University of Connecticut	Joint Safety Team (JST)	https://chemistry.uconn.edu/research/safety/joint-safety-team/		
University of Illinois at Urbana—Champaign	Chemistry Joint Safety Team (JST)	https://publish.illinois.edu/chemistryjointsafetyteam/	chemsafety@illinois.edu	TW: @UiucJ FB: @UIUCJST
University of Iowa	Chemistry Safety and Responsibility Stewards (CSARS)		grp365-chemistrycsars@iowa.onmicrosoft.com	TW: @UIowaCsars
University of Minnesota	Chemistry and CEMS Joint Safety Team (JST)	http://www.jst.umn.edu	jst@umn.edu	TW: @UMNJST FB: @umnjst
University of Texas (UT) at Austin	Chemistry Student Safety Organization (CSSO)	http://sites.utexas.edu/csso/	csso.utaustin@gmail.com	TW: @UTAustinCSSO FB: @UTAustinCSSO IN: csso.utaustin
Washington University of Saint Louis	Chemistry Peer Review Safety Group (CPRSG)	https://chemistry.wustl.edu/safety		
Yale University	Chemistry Joint Safety Team (JST)	https://jst.chem.yale.edu	chemjst@elilists.yale.edu	TW: @JstYale FB: @yalejst LI: Joint Safety Team—Yale Chemistry Department

[a]TW: Twitter; FB: Facebook; IN: Instagram; LI: LinkedIn.

(LSO) who was a graduate or postdoctoral researcher. From this pool, leadership from the Chemical Engineering and Materials Science (CEMS) and Chemistry departments recruited seven volunteers to begin assessing safety practices and attitudes in conjunction with mentors at Dow Chemical, thereby establishing what they called the Joint Safety Team (JST). It is important to emphasize in this structure that the LST was not looking to step into a responsible training function such as that of a faculty member, nor was it looking to take responsibility for EH&S compliance functions. The LST was meant to function *in addition to* and *in collaboration with* both of these pre-existing structures. The stated purpose of the LST was to address "the need for an improved culture of safety in research-intensive science departments ... which involves enabling leadership by graduate student and postdoctoral associate laboratory safety officers."[10] Since this time, LSTs have launched across the United States with differing structures and objectives depending on the institution's organization, needs, and resources.[9]

As LSTs have spread, the term *safety culture* has remained intimately linked to them. However, many researchers and practitioners have struggled to define, and by extension measure, improvements in safety culture in academic research laboratories. In an exhaustive analysis of the literature on safety culture in industrial, applied, and occupational psychology, Megan E. Gonzalez defined safety culture for academic research laboratories as "the shared values, beliefs, attitudes, social and technical practices, policies, and perceptions of individuals in an organization that influence the opportunity for accidents to occur."[11] She goes on to say that a "healthy safety culture will be one that minimizes the opportunity for accidents and near-misses and are characterized by open communication, a system designed to continually improve upon the culture of safety, and provides for the confidence in the efficacy of training and preventative measures."[11] It should be noted that all three of these parameters are related to reciprocal communication throughout the hierarchy of an institution. While LSTs are not designed to solve every challenge related to safety culture (nor should they be), they have the potential to make a valuable contribution by enhancing communication pathways to enable this reciprocal communication within and across the institution.

Critical to communication is a sense of empowerment to speak up about safety issues. Studies in industrial settings have shown the criticality of involving and empowering workers at all levels in the development of programs and initiatives to

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

improve safety outcomes.[5,12−14] Defining safety as "the ability to perform work in a varying and unpredictable workplace environment", Conklin highlighted the importance of workers to learn from each other and for the management to learn from the workers.[15] One of the cornerstones of the recently emerged paradigm of human and organizational performance is the concept of learning teams.[15−17] In an academic research department, a well-designed LST can play this role, serving to empower graduate and postdoctoral researchers to step into their new roles of responsibility and learn how to effectively communicate about chemical and laboratory safety.

In this Review, we aim to provide a framework to establish and strengthen LSTs based on the experiences of others over the past eight years, highlighting the diversity of approaches and helping to build a network of collaborative graduate and postdoctoral researcher groups. While there are large aggregated studies attempting to measure safety culture across multiple institutions at one time point,[11,18,19] few teams have published case studies in which specific issues are identified and resolved over time.[10,20,21] We first share the content of interviews with the leadership of currently existing LSTs to uncover the unpublished details of this grassroots movement (Table 1 and Table S1). Methods used to identify and interview LSTs are outlined in the Supporting Information along with means to connect with this growing network. Then, we elucidate the role that LSTs can play both in strengthening academic research departments and in improving the career preparation of PhD-level scientists. Finally, we conclude with a discussion about suggested metrics to measure the evolving culture of safety of an individual department.

■ ESTABLISHING YOUR LST

To date, almost all of the identified teams are housed either within chemistry departments or within chemistry combined with a closely related discipline (biochemistry, materials science, chemical engineering). Chemistry departments stand out in having a large number of students working with materials possessing diverse sets of hazards. While chemistry departments are likely to nucleate the formation of LSTs through a critical mass of motivated researchers, we hope that the information presented here will be helpful for building LSTs in other departments and forging cross-departmental collaborations.

Interviews with current LST leadership and published case studies have yielded five common components that are useful to establishing an LST. These components are not temporal in nature, so they can be incorporated in different orders throughout the process. Additionally, not all of the components are essential to launching an LST. We list these components below with no particular hierarchical order. Members of a budding team should evaluate their specific needs and action plan in the context of their own institution.

Identify a Champion. So far, each LST had some sort of champion at the outset. The champion needs to be someone who will be with the institution for the long-term. This person also needs to show a level of commitment to the survival of the LST that will inspire that person to look for ways to make the LST longer lasting. Finally, this person needs to be in a position to know of ways to make the LST permanent, beyond the scope and view of graduate students and postdoctoral scholars.

The champions that have emerged have been EH&S staff members, department heads, department safety committees, faculty members, chemical companies with whom the university has a relationship, deans, office and facilities staff members, and vice presidents for research (Figure 1). What

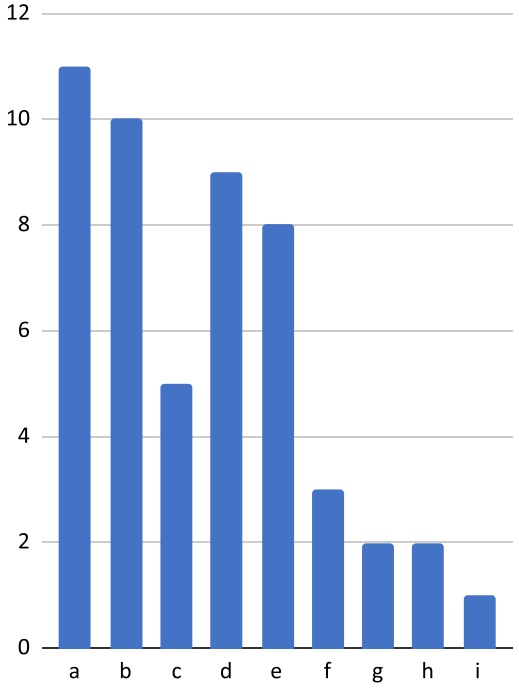


Figure 1. Summary of the number of interviewed institutions that have cited each source of a champion: (a) university EH&S staff member, (b) head of department, (c) department safety committee (DSC), (d) faculty member (nonhead, non-DSC), (e) chemical company, (f) dean, (g) office staff member, (h) facilities staff member, and (i) vice president for research.

sources are more likely to produce a champion are heavily dependent upon the department and its relationships to EH&S and chemical companies in the region, as well as how heavily influenced academic leadership has been by the conversations around safety that have been taking place over the past decade.[5,22−29] It was also notable throughout these interviews the warmth with which students discussed engaged faculty and EH&S staff. Many of the heavily involved students have used these teams as vehicles to forge relationships outside of their own research laboratories. Those individuals who are both intimately knowledgeable about the potential safety issues faced in laboratories and physically present in an accessible space to researchers would naturally make the most sensible champions. To that end, those schools that have made strides to develop the role of their safety personnel beyond compliance enforcement appear to be enjoying a synergistic effect between LSTs and EH&S personnel.

As the current movement was initially launched as part of a relationship between a university and a chemical company, it is unsurprising to find that eight LSTs mentioned chemical companies as being a source of a champion. Some of these relationships involve a representative from the company having regular contact with the LST in an advisory capacity while others involve company representatives visiting the university to give talks or presentations or participate in events. Other relationships involved hosting laboratory tours at chemical companies with an emphasis on the habits and teamwork necessary to maintain a safe workplace. Several teams

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

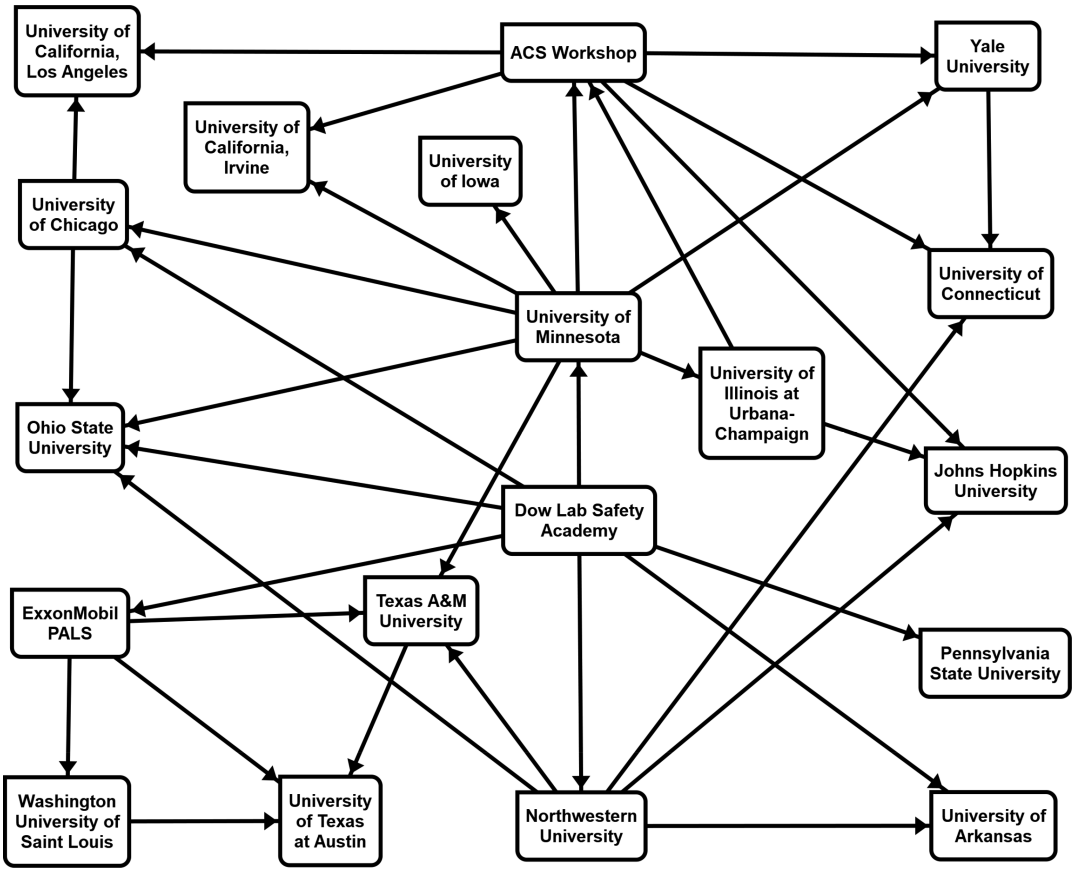


Figure 2. Schematic representation of the network connections between teams at the time of their launch with arrows indicating influential entities as recalled by the teams themselves.

expressed the importance of having a voice from industry emphasizing to researchers that an understanding of all roles played in chemical safety was a component of hiring decisions and an expectation in the field.

The majority of teams have partnered with EH&S staff and identified them as a source of a champion. Some teams were originally launched with primary support coming from EH&S staff members. The relationship between student researchers involved in these teams and EH&S personnel speaks to the robustness of the culture of safety that exists in the department. On the other hand, a small number of LSTs avoid EH&S altogether. There are views expressed that EH&S personnel are primarily focused on legal compliance and function as "the police" within the university; other schools have teams that are actively trying to change this perception.

Alongside the growth of the LST movement has been a parallel movement to find ways to transition the roles of safety professionals from being merely the "compliance police" to more of a partnership role with departments in supporting better (and safer) research. These strategies have manifested in many ways including changes to how EH&S personnel do business, the establishment of Research Safety offices, and the use of embedded safety professionals within research departments.[5,23,27,30−40] Anecdotally, the success of these campaigns is highly variable in research universities throughout the US, leading to a multitude of approaches to safety. There is also very little in the published literature regarding the institutions' experiences with these new approaches although the need for understanding the impact of these changes is great. Elevating the role of EH&S as a critical component of good research has been cited both by Dow Chemical and ExxonMobil as a key component to the programs that they have launched with universities (discussed further below).

Even if faculty members are not identified as champions, their active, vocal, and consistent support of LST activities has been cited by almost every team as critical to the establishment, growth, and continuation of the teams. The role that a faculty or staff advisor plays in the teams is also highly variable, with some teams cultivating that relationship after coming together, and other teams being directly managed by faculty advisors. The close professional relationship between PIs and their group members necessitates an ability to discuss safety-related laboratory issues.

Of the sources of support that were cited less often, active involvement from deans or vice presidents for research seemed to lead to changes that were important to the long-term development of a more robust culture of safety in a department. This is likely due to their ability to influence core values for the institution, allocate resources, and incorporate the service of advising LSTs into faculty evaluations. How comfortable these administrators were with getting involved does appear to be related to their educational backgrounds. We observed that those with a chemical background were more likely to fully understand the importance of chemical safety and to feel they were well-qualified to lead on this issue. Additionally, support from facilities and services personnel was found to be critical at universities at which a department was split across multiple buildings. In these instances, they were able to play the following roles: sending out facility-wide communications,

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

coordinating training for emergency response, and coordinating laboratory renovations and projects.

Connect to the Network. In his interview for this paper, Tim Alford of ExxonMobil stated, "Safety is not proprietary."[34] It was expressed by student researchers from several of the teams that within the safety space, instead of competing with each other, all of the teams were working to help each other. These sentiments speak volumes to the importance of the collaborative network that has developed among all of the participants in this movement (Figure 2). This network is maintained via social media, websites, email lists, ACS workshops and resources, company mentorship, and team members directly communicating with one another.

Through this work, it has been made clear that this movement has grown organically through the contact and mentoring between LSTs (Figure 2). Although modes of contact differ from group to group, there are particular mechanisms that have been used more often than others. For example, Twitter and Facebook have been the two most consistently used social media platforms by the teams (Table 1). LinkedIn and Instagram are less commonly used, but this choice seems to depend on the audience and norms of the institution. All of these platforms allow for the teams to self-publicize and are a cost-effective way to communicate information about resources and events. The most successful pages have weekly or daily posts to maintain engagement with the community, but if only basic communication of information is desired, then less activity can still be successful. The disadvantage of social media is the lack of space to add information pages and the lack of calendar interface. It is also challenging to give a holistic view of the accomplishments of the LST or distribute materials developed by LSTs on such a present-focused platform. Thus, many groups have also developed or expressed interest in developing websites. This project often takes considerably more time and effort (and sometimes money) to launch. However, once a website has been established, it typically takes less effort to keep it current and fresh. An additional mode of communication is creating a group email which fosters continuity as members of the LST change over time. Overall, the team members' strengths and interests, along with institution norms, are considered when deciding on the LST's electronic communications strategy.

Although the development of LSTs is considered to be a grassroots and researcher-led movement, the importance of a supportive network should not be underestimated when considering how groups have grown across the country (Figure 2). Dow Chemical through the Dow Lab Safety Academy and ExxonMobil through the PALS program have taken lead roles in the growth of this movement by emphasizing that a deep understanding of and appreciation for safety will be imperative for obtaining a job and being successful with a career in industry (see the Supporting Information for a description of relevant company-sponsored programs). ACS has played a role in the growth of this movement by providing workshops and emphasizing the importance of safety leadership in a chemistry student's professional development.[41,42] Faculty, staff, and administrative leadership at universities have played a role in the growth of this movement by supporting student, faculty, and EH&S staff attendance at workshops, company-sponsored symposia, and visits to other schools that already have teams. By providing and supporting these spaces, this network both educates researchers on the importance of safety in their chosen field and empowers them to connect their LST in the network by both seeking support and giving it to others. In the near future, we anticipate that this network map will look radically different as more mature teams inspire and support the establishment of additional teams in more departments and universities and as dormant teams find ways to become active again. For those interested in connecting to this network, please consult Table 1 and the Supporting Information for details.

Locate Resources. Resources necessary to starting a successful LST have included the following: physical resources (copy machines, areas to post information, conference rooms, lecture halls), technological resources (email listservs, websites), captive audiences (seminar series, classes), access to one another's lab spaces, and money. The level of access a team has to these resources has been directly linked to sources of champions described above.

One way to secure resources that was found to be successful by many groups is incorporating LST ideas into pre-existing programs. Many members of LSTs have strengthened their networking skills by identifying and pursuing projects in which an LST activity would be an add-on to an already occurring event or assist in the restructuring of an event. As an example of an add-on, some LSTs have successfully introduced "Safety Moments" (also known as Safety Minutes) to the beginning of seminar lectures or classes required for first year graduate students. As an example of a restructure, many LSTs have become more involved in the safety training given by their institutions, with an emphasis on making training more interactive, relevant for the individual, and accessible. Finally, some LSTs have worked closely with EH&S or department safety committees to provide feedback from researchers on safety concerns in the department.

Currently existing lab and shared building spaces themselves have also been utilized for LST activities that include near-miss reporting projects, peer lab walkthroughs, and new or improved signage. While incident reporting is typically required by the department and/or EH&S, the concept of near-miss reporting is still relatively new and is often not clearly incorporated into current structures. This gap has created an opportunity for several LSTs to introduce the near-miss reporting concept to their departments and develop mechanisms through which stories can be shared and used to educate others. Peer lab walkthroughs prepare participating laboratories for actual EH&S inspections and also enable student researchers to practice spotting noncompliant practices. Finally, teams have developed creative ways to improve signage in departments to support the more consistent implementation of safety practices. A few teams have introduced gloves on/gloves off stickers for equipment in laboratories, universal hazard and safety contact sheets for outside of all lab doors, and safety posters to remind researchers of safe practices to be displayed in commonly utilized spaces such as in elevators or bathroom stalls. All of these ideas used existing infrastructure and minimal additional expenses on printing to create new communication pathways and learning opportunities for everyone in the department.

The final much-discussed resource is money. Most groups have reported receiving some sort of monetary support either from the department or from EH&S. In some instances, an outside company has provided it. When getting started, many groups described being funded on a project-by-project or seed fund basis. Other institutions have allowed for individual students to compete for awards through internal contests that

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

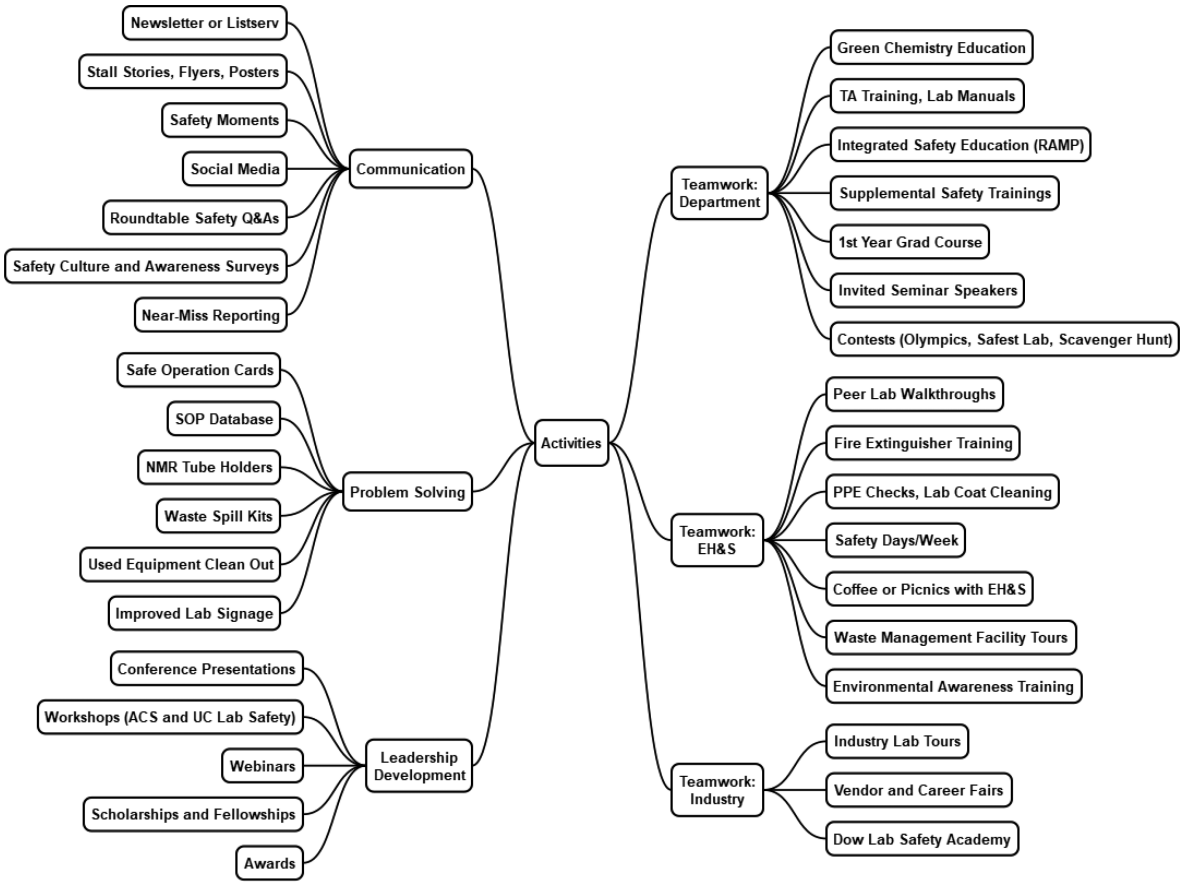


Figure 3. Common activities executed by current LSTs organized by type.

can then be used to support LST activities. Most projects have been easily supported on tens or hundreds of dollars. Some teams have managed to secure a line-item in the yearly budget of their department and/or EH&S of anywhere from $1000 to $5000. This has allowed these teams to plan activities further ahead and on a larger scale. It also serves as a way of assuring team members that the department is willing to continue to support the activities, making planning activities more worthwhile and recruitment efforts easier. One institution offers a fellowship valued at the same level as a teaching assistantship during a student's final year of study to manage the team. To earn the fellowship, the student researcher has to have shown a prior commitment to the team in earlier years. While a source of money is not a requirement for the successful launch of an LST, it has proven to be an important way to maintain support for and stabilize a team as it matures.

Establish a Project Management Structure. LSTs have been established with structures that range from egalitarian and informal to those defined by hierarchies with constitutions and bylaws. While no particular structure stands out as preferred among the interviewed teams, what does stand out as important is that these structures remain open and collaborative. Since LSTs have functioned as a way to build relationships that have proven difficult to build by other means, it has been critical for various teams to also consider how to work most appropriately with pre-existing committees and departments.

Many teams described bringing researchers together initially in a very informal structure. This capitalized on the energy of a new project and gave everyone an equal footing in idea generation. As ideas were molded into projects, some teams found that this informal structure worked very well. In some teams, members took charge of the projects that interested them, while other teams had members working collaboratively together on all projects. Others found that structure and setting expectations became necessary as workloads were found to be unevenly distributed. Finally, some ideas necessitated a certain level of organizational hierarchy in order to be executed, especially when it came to handling finances.

Common components of more formalized structures have included the establishment of an executive board with the standard leadership positions, as well as the formation of committees to focus on particular project areas. Some teams have focused particular attention on having members that represent all divisions within a department. A few teams have even included undergraduate students in their membership or leadership. Others have gone further and recruited representatives from each lab which are either brought together for regular meetings and event planning or employed as facilitators between the LST leadership and each laboratory. In institutions in which LSOs predated the LST, such as that described of UMN in the Introduction, this proved to be a sensible way to utilize and improve upon a pre-existing organizational arrangement in the department. Many groups discuss the importance of having representatives from each lab involved in some way, such that there is a feedback structure in place: the LST will be aware of specific issues in the department, and each group will have access to the resources that the LST offers.

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

How the LST interacts with pre-existing actors also varies widely. There are some cases in which a faculty or staff member takes a direct management role, although this is rare. Much more commonly found is a structure in which a faculty or staff member plays an advisory or supporting role, either suggesting possible projects and collaborations or giving feedback on LST member ideas. In some cases, either LSTs have worked collaboratively with department safety committees, or a member of the LST has served as a representative on the department safety committee. Finally, several teams have at least one member of EH&S staff keeping current with LST activities and looking for ways to collaborate on projects of joint interest.

No matter what structure has been chosen, the importance of documentation of activities and reporting processes has had to be considered. There are some cases in which the LST has functioned so independently and maintained such an informal structure that there was essentially no documented history of activities and no one outside of the team who is knowledgeable about them. This has proven to be extremely problematic when attempting to attract champions, secure resources, and recruit students. At the other extreme, some teams have experienced that having an overly complex structure from the beginning can make recruitment and retention difficult. That being said, those teams that have developed a formal reporting mechanism have maintained better documentation and have been more successful at informing leadership in various departments of LST activities. Some teams submit monthly or quarterly reports to the department safety committee, while others submit them directly to the head of the department and/or to a staff member at EH&S. This documentation allows student members and champions to share information easily with other departments, other universities, or at conferences. In some instances, this documentation has culminated in a case study publication discussing the work of the team.[10,20,21]

First Project: High Profile and Low Resource. There was unanimous agreement among the teams that it was important for the first project to require few resources and be as visible as possible to all members of the department. A low-resource project means that the group is not financially dependent and can gain a victory without the project becoming too much of a time sink. Teams frequently cited that because they were recruiting graduate and postdoctoral researchers, it was important to remember that volunteers are already managing many demands on their time and are looking to their PIs for direction on what to prioritize. In order to maximize the impact a volunteer has with their time, projects selected that had the widest impact were cited to be the most motivational for the group, possibly because it was perceived to be worthy of the time spent. High-profile projects include those that have a wide reach and pique the interest of people at all levels in the department.

The type of event that was successful depended on the department's present safety priorities. However, successful LST events cluster around four types: communication, problem solving, leadership development, and teamwork (Figure 3). Communication projects are often focused on written communication methods (newsletters, flyers, and posters) as many described these as the easiest to design and distribute, either in physical spaces in the building (bathroom stalls, elevators, display boards) or online (social media, websites, listservs). Near-miss reporting projects include another layer of complexity as the project is requesting that department members provide the content by sharing their near-miss stories, which often requires anonymity in reporting and trust-building with the LST. Safety Moments have taken the form of written communication distributed by electronic means but have also been delivered in person to captive audiences (seminars, classes, group meetings). Roundtable Safety Q&As are a creative upgrade to this idea that invites an interested audience to take in a Safety Moment and add to it by sharing stories, experiences, and guidance with peers.

A department-wide survey has been employed by multiple teams to determine initial goals and define projects (UMN's approach discussed in ref 10 and University of Chicago's approach discussed in ref 21). Developing a survey that results in actionable and sensible information is more difficult than it may sound. While not a typical skill set acquired by those going through a chemical education, effective survey research methods are a much debated and challenging aspect of social science research.[43,44] There are a small number of examples in which surveys have been developed and utilized in order to measure the safety culture of research laboratory environments and can function as a good starting place.[11,18] Additionally, if the survey is developed with care, it could function as a measurement tool over time for success of LST efforts. This will be discussed further below.

Problem-solving activities have included problems that have been identified in the department that LSTs have taken the actions to solve. The Teamwork cluster (Figure 3) includes activities that LSTs have improved upon by serving as a conduit for student researcher feedback on safety issues and needs in the department. These are examples of where an LST has provided the continuous feedback loop necessary to building a stronger safety culture with both the department and EH&S. Including contact with industry has served as a means of learning safety culture strengthening tactics from industry to adapt them for the academic research environment. Finally, the Leadership Development cluster (Figure 3) enables student researchers to share their work with others and connect to the network described above (Figure 2).

As groups start planning events, lab safety can quickly become a rather serious topic, and LSTs have reported feeling overwhelmed by the safety "horror stories" from their colleagues. This has left many with a feeling of great responsibility that comes with trying to change a department's safety culture. Successful groups stressed the importance of quickly organizing and prioritizing project goals in order to take advantage of the initial rush of excitement rather than being paralyzed by the enormity of the issues at hand.

■ TOP CHALLENGES OF LSTS

The top challenge described by the teams was trouble with recruitment (Figure 4). Many teams have experienced difficulty not only with recruiting numbers of individuals but also with recruiting a representative diversity of individuals across years and disciplines.

Taking second place is a group of challenges: limited faculty support, lack of organization, and a low sense of effectiveness. Several teams have observed that lack of enthusiasm or outright rejection of an initial presentation of LST ideas has posed an obstacle to recruitment and successful project implementation. The perception that LST engagement would incur opportunity costs in terms of lost time for research was cited as a concern.

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

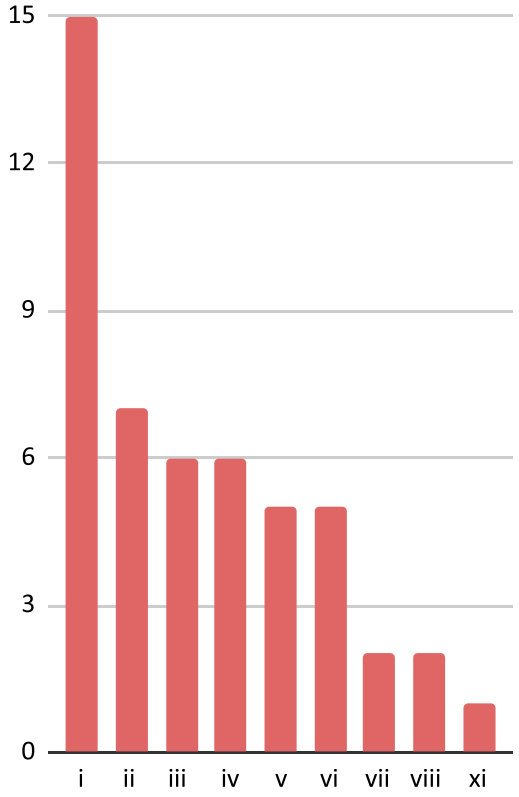


Figure 4. Top challenges described by active LSTs: (i) trouble with recruitment, (ii) lack of organization, (iii) limited faculty support, (iv) low sense of effectiveness, (v) lack of visibility among students, (vi) uneven work distribution, (vii) old infrastructure, (viii) low funding, (ix) struggles with idea generation.

When positioning the team within the broader institutional community, several teams have experienced friction or lack of alignment with other pre-existing groups (department safety committees, facilities, EH&S). Some have also reached out to local companies for lab tours or mentorship with little progress. Finally, flush with a bit of success, a few have attempted to work with other departments to enlarge the LST but have found departmental cultural differences to be larger than originally anticipated.

As teams have matured, some are observing a lack of effectiveness after the initial excitement of the founding and are now realizing that habit change in the laboratory is more challenging than initially anticipated. The voluntary nature of most activities initiated by LSTs, such as peer lab walkthroughs, equates to high variability in participation. Near-miss reporting systems in particular have taken time and effort to set up, yet several teams have said they do not live up to expectations as students do not submit incidents even though casual conversation reveals they are occurring. Many teams cite fear of retaliation as the main reason for lack of participation, so anonymizing forms and discussing accidents in a nonpunitive way (focused on learning experiences) is designed to overcome this issue. However, teams report that students believe that the details of the incident will reveal them anyway. The other reason for nonreporting heard often is a lack of interest or the view that nothing potentially dangerous ever happens in their laboratories. Both reasons are directly related to a gap in educating the student researchers on this concept that is difficult to fill.

A third set of challenges plagued several teams that included uneven work distribution and lack of visibility among the students. While many have experienced the first flush of excitement from brainstorming with a core group of enthusiastic volunteers, the reality has meant struggles with distributing work appropriately and getting the message out to all members of the department.

As a team struggles with recruitment, organization, and effectiveness, it is critical to have a means of passing information from one executive board to the next. Current teams are relying primarily on two strategies: (1) overlap in senior and junior leadership, and (2) an electronic database of some sort with documentation accessible to all members. The situation is particularly precarious given the constant turnover one must anticipate in graduate school. This is a critical point for a strong champion to be able to play a role by ensuring continuity. A small number of teams have a faculty or staff member who plays a larger organizational role that works to ensure continuity. Another approach taken by one school has been to fund a fellowship position for one student researcher in their fifth year to manage the otherwise volunteer team (referred to above). This struggle also reveals the importance of thinking through the structure of the team and determining a documentation and reporting plan from the outset as described above.

The analysis of challenges expressed by existing LSTs highlights the importance of addressing the communication pathways and being cognizant of the structure and function of an academic institution. Successful LSTs articulate the value of their activities, discussed in more detail below, to obtain the buy-in from the entire institutional hierarchy. Being part of a network has helped these LSTs attract external resources for promoting their activities to their institutions. Some of the founding influences identified in Figure 2 consisted of supportive company representatives and department members of a university with a successful LST speaking at other universities about this success. A well-placed invitation to a speaker for a department's seminar series has gone a long way for some teams both to encourage more enthusiastic faculty support and create higher visibility among the students. The unifying characteristics of successful LSTs included the engagement of the learning audience in the LST activities comprising researchers, faculty, and university administration. This continuous engagement is particularly important considering high turnover of graduate students and post-doctoral scholars.

It is also imperative to recognize that the teams being discussed are the ones we found that were verifiably active through the networks described in the Introduction and detailed in the Supporting Information. Some of these teams have gone through significant dips in activity from which they have been able to rebound. Other teams, not detailed here, have yet to come back from those dips and can be described as in a state of dormancy. The strategies elucidated here are meant to assist new LSTs in establishing themselves, as well as assist teams currently going through dips, or teams currently in a state of dormancy. Multiple teams included here did describe support coming from individuals who were once students in similar teams themselves now in faculty and/or EH&S positions either at the same university or at different ones. By exposing early career researchers to stronger safety cultures, this movement carries with it the ability to have a ripple affect across all of academia.

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

THE BROADER CASE FOR ESTABLISHING AN LST

A recent performance audit of the University of Utah's Laboratory Safety Practices from the Office of the Legislative Auditor General has served as a bellwether for many state institutions that could easily identify similar deficiencies in inspection procedures.[45,46] As the University of California system has experienced, attracting heightened scrutiny from state regulators due to public pressure triggered by a high-profile event can be expensive and time-consuming.[47,48] Thus, from the university perspective, motivation for supporting a more robust culture of safety within research-intensive departments is clear.

As laid out in the Introduction, LSTs can play an important role in enabling the reciprocal communication necessary to improve a department's culture of safety. However, given all of the demands of a graduate-level program and the "short-timer" status of graduate students and postdoctoral scholars within these universities, why would they expand their responsibilities and lead on initiatives that likely will not make a noticeable difference until they have long since moved on? The answer lies within the critical element of professional development of researchers. On one hand, an institution's educational mission aims at preparing early career researchers for their professional career with an implied expectation for leadership in safety involving hazard assessment and planning of experiments and processes. On the other hand, early career researchers contribute to the research mission of the institution by conducting innovative and groundbreaking research that requires a deliberate approach to safety considerations. Whether it is Geller describing "Total Safety Culture", Conklin elucidating "Human and Organizational Performance", or Smith introducing the "Systems Approach to Accident Prevention", all emphasize the criticality of having the worker in the room as an empowered member of the team to share their everyday level of expertise acquired through hands-on experience with current hazards.[15,49,50] LSTs have the potential to become a powerful mechanism for learning among students to develop hazard assessment skills and facilitating the multiway communication among trainees, faculty, EH&S personnel, and administration that reduces the risks inherent in hazardous work.

Companies in particular have helped motivate student involvement by drawing ties to the future job market. Dow Chemical and ExxonMobil helped establish LSTs by reaching out directly to the universities from which they recruit. Lori Seiler, Director for Global Research and Development (R&D) EH&S and leader of the program, explained that Dow Chemical was motivated to get involved by the scientists working with university researchers.[51] Dow Chemical was working with multiple universities on projects that required Dow Chemical scientists to work in the university laboratories. They found themselves surprised at the conditions of the university laboratories and went back to headquarters asking if there was a way Dow Chemical could help with this situation. This led to the launch of the Dow Lab Safety Academy in 2012 with three schools initially participating. Since then, three more schools have become directly involved with Dow Chemical projects, and an online version of the Dow Lab Safety Academy has been launched to share best practices with a broader audience (see the Supporting Information for a description of relevant company-sponsored programs).[52]

Tim Alford, a Senior Research Technician in Research and Development at ExxonMobil, discovered the Dow Lab Safety Academy through reading an article about it in C&EN in 2012.[53] This made him think about the struggles his own company has seen in transitioning new out-of-academia hires into the company safety culture. He reached out to Seiler, who shared her experience setting up the program, and then, he convinced his manager to support setting up the ExxonMobil PALS (Partners in Academic Laboratory Safety) program. In 2014, Alford and Deborah Davis, now in customer development and marketing, launched PALS with a few schools and about 40 individual participants. The program continues today with six participating partner universities and over 80 participants (see the Supporting Information for a description of relevant company-sponsored programs).

In establishing their respective programs, both aimed to reach as high up into the hierarchy as possible within the universities. While they were looking to bring graduate student researchers into the projects as leaders, they recognized that participation from the top was going to be essential in recruitment and in sustaining the student-led projects. Just as management sets the tone for the rank-and-file of a company, PIs and university hierarchy set the tone for the students.

Another important part of the Dow Chemical and ExxonMobil programs is the inclusion of EH&S departments. The ability to properly document a risk assessment and respectfully communicate with those outside of your particular area of expertise, including EH&S personnel, is critical to working effectively in an industrial environment.[54] Teams across companies must support and communicate with one another in order to protect the bottom line, whereas this mindset does not innately exist in more autonomous academic laboratories. Considering traditional independence of research groups and high turnover of researchers, adherence to uniform safety standards requires a special effort. In a study by Schröder et al. the authors stated, "If no formal identification of hazards is conducted, a false sense of safety may prevail where the scientific outcome of an experiment becomes more important than the hazards involved."[18] The authors were analyzing results of a survey that suggested that safety issues exist more extensively in the academic research environment due to a false sense of safety felt by a population that is on average significantly younger than in government or industry and regularly utilizes either nonstandardized forms for hazard identification and risk assessment, or none at all.[18,55]

Recent publications are making the point about the importance of teamwork and communication in other ways as well. As chemical companies have come under increased scrutiny regarding sustainability practices, many are working to establish themselves as ahead of the curve on these issues. In tandem with that are growing expectations of new PhD-level employees to have a broader understanding of safety issues and of larger sustainability and circular economy challenges.[56−61]

Transferable skills professional development for STEM graduates is a much-discussed area. As one example, the American Chemical Society (ACS) has invested heavily in professional development workshops and webinars in an attempt to remain relevant for earlier-career job-hunting or mid-career-transitioning members.[62] The ACS has also contributed a great deal to the conversation around safety culture. Specifically, ACS has invested heavily in developing tools to educate chemistry students on hazard assessment of experiments, leading with the concept of RAMP which stands

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

for Recognize hazards, Assess the risks of the hazard, Minimize the risks of the hazards, and Prepare for emergencies.[26,63] Additionally, the ACS Division of Chemical Health and Safety has been supporting a workshop targeting graduate students since 2018 to support the spread of LSTs at more universities across the US as a means of strengthening academic laboratory safety culture from the bottom up.[42]

THE FUTURE IS METRICS

The transformative work done by Dow Chemical and the UMN JST has cascaded into a movement that stretches across the country. While these researcher-led teams are doing great work, we have found that they are struggling to evaluate their own effectiveness. The two most common means of evaluation of event success have been reported as (1) if the event is held and (2) the number of attendees. A summary of event types is discussed in Figure 3. Some events are specific trainings while others are intended to build communication opportunities. Nonevent projects include raising awareness about safety issues and sharing reminders of best practices throughout the department. While specific numbers reached can be recorded, this does not capture the follow-on conversations among peers nor does it inform how these messages are being integrated into actual research practices.

As explained in the Introduction, the purposes of these teams are to enhance professional development of trainees and support a more robust culture of safety through improved communication regarding safety matters in academic departments. However, it is exceedingly difficult to determine how all of this communication is integrated into the safety attitudes and practices of the target audience—the ultimate manifestation of a department's culture of safety. In the last 40 years, safety *climate* research has shown the measurements of perceptions of employees at discrete time points to be a robust leading indicator of organizational safety.[64] As this approach is designed to uncover the behaviors that "get rewarded and supported" from the perspective of the target audience, this is a fitting approach for an academic department to borrow from industry.[64] This research has also shown that, in order for safety climate evaluations to be capable of providing actionable information, they must be intentionally specific to each work environment with its own set of hazards.[64,65] An understanding of the "collegial, collectively governed, participatory, consensual, and democratic" nature of how academic departments are run helps to elucidate why LSTs have had the freedom to grow in the way that they have and can also help us understand the unique challenges to growing and sustaining them.[66] Quantifying the components of what constitutes a positive safety climate in their specific work environment will enable departments to create an informative safety climate tool that can guide efforts to support the growth of a culture of safety.

In the case of academic research laboratories, there has been admirable work done in the past decade toward developing tools to evaluate safety attitudes and practices.[11,18,67,68] Some LSTs have been contributing to this work through the use of department-wide surveys to determine initial projects to pursue.[10,20,21] However, since this work has not yet developed into a properly recognized field of research, connecting these ideas into a meaningful body of work can be challenging.[19] This presents a magnificent opportunity for collaborative work among the fields of chemistry, environmental health and safety, and industrial psychology to develop this preliminary work into an effective safety climate survey tool. All three fields can bring pivotal insights to the table, and none would be capable of developing an effective metric without the others.

Another aspect to documentation and reporting that LSTs need to consider is how best to support their champions, in particular when those champions are faculty members. Faculty members are typically evaluated by their departments based on three components: research, teaching, and service. While it is typically understood that service is weighted the least of the three in evaluations, it is still a component that needs to be strategically considered by any faculty member that may be approached as a champion.[69] Care needs to be taken to ensure that a champion supporting the efforts of an LST not become invisible work.[70−72] Documentation and reporting of activities done and the results of a regular evaluation survey can be utilized for others in the institution to make the argument to heads of departments, tenure committees, and administrative management that the service work being done by a faculty member through support of an LST is of great value and should be considered in evaluations.

CONCLUSION

In this review, we share for the first time details of the full scope of the LST movement in the United States. Using methods described in the Supporting Information, 16 currently active teams were identified and leaders were interviewed. This work showcases the power of connection and collaboration in current grassroots efforts and emphasizes the growing need to develop quantifiable and trackable metrics. We hope this work provides interested graduate students, postdoctoral scholars, university faculty and administration, EH&S staff, and chemical companies useful information to start, sustain, and connect a program at their own institutions.

In order to start an LST, five common components have been identified:

(1) Identify a champion. Critical in the success of a new LST is a champion that shows commitment to the survival of the group beyond graduate student turnover. Cited champions include university EH&S staff, department heads, department safety committees, faculty members, chemical companies, deans, vice presidents for research, and office/facilities staff members.

(2) Connect to the network. Mentorship between LSTs at different institutions has been cited to be a key factor in their success. The connections between different groups are represented schematically to demonstrate the magnitude of this collaborative effort.

(3) Locate resources. Physical, technological, personnel, space, and monetary resources are obtained and utilized in ways that are dependent on both the LST champion and group needs. A summary is provided of various resources that were useful in the launch of current programs.

(4) Establish a project management structure. One of the first challenges a new LST may face is defining its organizational hierarchy. Different strategies vary drastically but structures can include laboratory safety officers, executive boards, and department safety committees.

(5) First project: high profile and low resource. All teams agreed that it was imperative that the first project(s) require minimal resources and achieve maximal visibility.

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

Successful LST events were found to cluster around four types: communication, problem solving, leadership development, and teamwork.

In order to sustain an LST, four main strategies have been identified:

(1) Making a case for establishing an LST. Institutions with the most sustainable teams have clearly and strongly convinced critical members of the importance of having an LST. A recurring motivation was cited to be the improvement of student and worker safety by strengthened workplace safety culture.

(2) Motivating student involvement. Pressures on graduate students' time necessitate a strong reason to be involved in activities outside their core program requirements. The involvement of industry in these programs demonstrates the improved employability prospects of researchers active in safety teams.

(3) Mitigating top challenges. Learning about the difficulties faced by established LSTs will help focus group objectives that are critical to long-term success. Top challenges have been cited to include trouble with recruitment, lack of organization, limited faculty support, low sense of effectiveness, lack of visibility among students, uneven work distribution, old infrastructure, low funding, and struggles with idea generation.

(4) Developing metrics. Evaluation of the effectiveness of the activities of LSTs is critical for the growth of the LST movement. The assessment should include both the professional development of researchers and contribution of LSTs to the culture of safety. As the measurement tools specific to LSTs are currently emerging, communication across the LST network is likely to be vital for focusing and refining the efforts of LSTs.

Safety training does not work if it does not influence perceptions and attitudes about how researchers approach their jobs. Offering a multitude of resources makes no difference when researchers are not regularly encouraged to engage them as a standard part of their work. Peer-to-peer correction does not happen without the continual support of superiors. Empowering researchers to take on these challenges as leaders within LSTs strengthens the institution today and improves the workforce of tomorrow.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.chas.0c00016.

Details of how the Dow and ExxonMobil programs are set up and a detailed description of the search for LSTs (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Jessica A. Martin − *Department of Chemistry, University of Connecticut, Storrs, Connecticut 06269, United States;* orcid.org/0000-0002-4083-0848; Email: jessica.a.martin@uconn.edu

Authors

Kali A. Miller − *Global Journals Development, American Chemical Society, Washington, DC 20036, United States;* orcid.org/0000-0003-3632-0615

Eugene Pinkhassik − *Department of Chemistry, University of Connecticut, Storrs, Connecticut 06269, United States;* orcid.org/0000-0003-1429-0435

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.chas.0c00016

Notes

Views expressed in this paper are those of the authors and not necessarily the views of the American Chemical Society or *ACS Chemical Health & Safety*.

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors acknowledge all of the people who graciously participated in the interviews from the LSTs listed in Table 1 and Table S1. We would also like to acknowledge the guidance and support provided by many members of the ACS Division of Chemical Health and Safety, ACS Committee on Chemical Safety, and ACS Graduate and Postdoctoral Scholars Office, as well as EH&S and Research Safety personnel at Northwestern University, Yale University, University of North Carolina—Chapel Hill, and University of Connecticut. In particular, we would like to acknowledge the tireless efforts of Marta Gmurczyk, PhD of ACS Chemical Safety Programs. K.A.M. would like to acknowledge the support of the Department of Chemistry and Division of Research Safety at the University of Illinois at Urbana-Champaign. Finally, J.A.M. and E.P. would like to acknowledge the support of the National Science Foundation through CHE-1709921 and the Graduate Research Fellowship Program through Award DGE-1747453.

■ REFERENCES

(1) Probst, T. M.; Estrada, A. X. Accident under-reporting among employees: Testing the moderating influence of psychological safety climate and supervisor enforcement of safety practices. *Accid. Anal. Prev.* **2010**, *42*, 1438−1444.

(2) Probst, T. M.; Brubaker, T. L.; Barsotti, A. Organizational injury rate underreporting: The moderating effect of organizational safety climate. *J. Appl. Psychol.* **2008**, *93* (5), 1147−1154.

(3) Meyer, T. Towards the implementation of a safety education program in a teaching and research institution. *Educ. Chem. Eng.* **2017**, *18*, 2−10.

(4) Hill, D. J.; Williams, O. F.; Mizzy, D. P.; Triumph, T. F.; Brennan, C. R.; Mason, D. C.; Lawrence, D. S. Introduction to laboratory safety for graduate students: An active-learning endeavor. *J. Chem. Educ.* **2019**, *96*, 652−659.

(5) National Research Council. *Safe Science: Promoting a Culture of Safety in Academic Chemical Research*; The National Academies Press: Washington, DC, 2014.

(6) Burke, M. J.; Sarpy, S. A.; Smith-Crowe, K.; Chan-Serafin, S.; Salvador, R. O.; Islam, G. Relative effectiveness of worker safety and health training methods. *Am. J. Public Health* **2006**, *96* (2), 315−324.

(7) American Chemical Society. *Employer's safety awareness expectations for new hires*, 2014. https://dchas.org/chemical-safety-resources/ (accessed 2020/01/20).

(8) Miller, A. J. M.; Tonks, I. A. Let's talk about safety: Open communication for safer laboratories. *Organometallics* **2018**, *37*, 3225−3227.

(9) Miller, K. A.; Tyler, K. I. Impact of a pilot laboratory safety team workshop. *J. Chem. Health Saf.* **2019**, *26* (3), 20−26.

(10) McGarry, K. A.; Hurley, K. R.; Volp, K. A.; Hill, I. M.; Merritt, B. A.; Peterson, K. L.; Rudd, P. A.; Erickson, N. C.; Seiler, L. A.; Gupta, P.; Bates, F. S.; Tolman, W. B. Student involvement in improving the culture of safety in academic laboratories. *J. Chem. Educ.* **2013**, *90*, 1414−1417.
(11) Gonzalez, M. E. *Defining Academic Safety Culture: A National Study*. Ph.D. Dissertation, Texas Tech University, Lubbock, TX, 2019.
(12) Nahrgang, J. D.; Morgeson, F. P.; Hofmann, D. A. Safety at work: A meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. *J. Appl. Psychol.* **2011**, *96* (1), 71−94.
(13) Simard, M.; Marchand, A. Workgroups' propensity to comply with safety rules: The influence of micro-macro organisational factors. *Ergonomics* **1997**, *40* (2), 172−188.
(14) Probst, T. M.; Goldenhar, L. M.; Byrd, J. L.; Betit, E. The Safety Climate Assessment Tool (S-CAT): A rubric-based approach to measuring construction safety climate. *J. Saf. Res.* **2019**, *69*, 43−51.
(15) Conklin, T. *Pre-Accident Investigations*; Ashgate Publishing Limited: Farnham, Surrey; Burlington, VT, 2012.
(16) Dekker, S. *Just Culture: Restoring Trust and Accountability in Your Organization*, 3rd ed.; CRC Press, Taylor & Francis Group: Boca Raton, FL, 2017.
(17) Reason, J. T. *Organizational Accidents Revisited*, 2nd ed.; Ashgate Publishing Limited: Burlington, VT, 2015.
(18) Schröder, I.; Huang, D. Y. Q.; Ellis, O.; Gibson, J. H.; Wayne, N. L. Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers. *J. Chem. Health Saf.* **2016**, *23* (1), 12−23.
(19) Ménard, A. D.; Trant, J. F. A review and critique of academic lab safety research. *Nat. Chem.* **2020**, *12*, 17−25.
(20) Wang, X.; Thorarinsdottir, A. E.; Bachrach, M.; Blayney, M. B. Building a sustainable student-led model to promote research safety in academic laboratories. *ACS Cent. Sci.* **2019**, *5*, 1900−1903.
(21) Zinn, S. R.; Slaw, B. R.; Lettow, J. H.; Menssen, R. J.; Wright, J. H.; Mormann, K.; Ting, J. M. Lessons learned from the creation and development of a researcher-led safety organization at the University of Chicago. *ACS Chem. Health Saf.* **2020**, *27* (2), 114−124.
(22) Stuart, R. Strategic opportunities in chemical safety education: A report on the 2019 ACS Safety Summit. *J. Chem. Health Saf.* **2019**, *26* (4−5), 2−5.
(23) ACS Committee on Chemical Safety, Safety Culture Task Force. *Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the Committee on Chemical Safety*; American Chemical Society: Washington, DC, 2012.
(24) Gibson, J. H.; Wayne, N. L. Proceedings of the 2012 University of California Center for Laboratory Safety Workshop. *J. Chem. Health Saf.* **2013**, *20* (1), 4−17.
(25) Schröder, I.; Gibson, J. H.; Wayne, N. L. Proceedings of the 2014 University of California Center for Laboratory Safety Workshop. *J. Chem. Health Saf.* **2016**, *23* (1), 35−45.
(26) ACS Committee on Chemical Safety, Hazard Identification and Evaluation Task Force. *Identifying and Evaluating Hazards in Research Laboratories*; American Chemical Society: Washington, DC, 2015.
(27) Czornyj, E.; Newcomer, D.; Schroeder, I.; Wayne, N. L.; Merlic, C. A. Proceedings of the 2016 Workshop Safety By Design − Improving safety in research laboratories. *J. Chem. Health Saf.* **2018**, *25* (4), 36−49.
(28) Sigmann, S. Chemical safety education for the 21st century − Fostering safety information competency in chemists. *J. Chem. Health Saf.* **2018**, *25* (3), 17−29.
(29) Carhart, V. *A Comparative Examination of the Safety Programs at UCLA, UMN, and UVM in Response to Recent Chemistry Laboratory Incidents*. M.S. Thesis, University of Vermont, Burlington, VT, 2015.
(30) Reinhardt, P. Environmental Health & Safety, Yale University: New Haven, CT. *Personal communication*, January 2020.
(31) Karki, C. M. Office of Research Safety, University of Chicago: Chicago, IL. *Personal communication*, January 2020.
(32) Blayney, M. B. Office of Research Safety, Northwestern University: Evanston, IL. *Personal communication*, August 2019.
(33) University of Florida. *Gator TRACS*. http://www.ehs.ufl.edu/programs/lab-research/gator-tracs/ (accessed 2020/01/28).
(34) Alford, T. Polymers Research & Development, ExxonMobil: Baytown, TX. *Personal Communication*, November 2019.
(35) Sigmann, S. B.; McEwen, L. R.; Stuart, R. A community approach to academic research safety. *Trends Chem.* **2019**, *1* (3), 275−278.
(36) Johnson, J.; Kemsley, J. Academic lab safety under exam. *Chem. Eng. News* **2011**, *89* (43), 25−27.
(37) University of California Los Angeles. *Integrated Safety Management*. https://www.ehs.ucla.edu/integrated-safety-management (accessed 2020/02/12).
(38) Clayton, A. M.; Hayes, J.; Lathrop, G. W.; Powell, N. Development of an occupational risk assessment tool for laboratory animal facilities. *Appl. Biosaf.* **2019**, *24* (2), 72−82.
(39) van Kampen, J.; Lammers, M.; Steijn, W.; Guldenmund, F.; Groeneweg, J. The effectiveness of 48 safety interventions according to safety professionals. *Chem. Eng. Trans.* **2019**, *77*, 307−312.
(40) Duraj, V.; Decker, D. M. DiSCO − Department Safety Coordinators and Officers: Building safety culture. *J. Chem. Health Saf.* **2019**, *26* (6), 84−88.
(41) American Chemical Society. *Graduate Students & Postdoctoral Scholars: Safety*. https://www.acs.org/content/acs/en/education/students/graduate.html (accessed 2020/01/18).
(42) American Chemical Society, Division of Chemical Health & Safety. *Developing Graduate Student Leadership Skills in Laboratory Safety Workshop*. http://dchas.org/2018/11/09/lst-workshop-registration/ (accessed 2020/01/18).
(43) Hancock, D. R.; Algozzine, B. *Doing Case Study Research: A Practical Guide for Beginning Researchers*, 3rd ed.; Teachers College Press: New York, NY, 2017.
(44) Walonick, D. S.; *Survival Statistics*; StatPac, Inc: Bloomington, MN, 2007.
(45) Office of the Legislative Auditor General State of Utah. A Performance Audit of the University of Utah's Laboratory Safety Practices. *Report to the Utah Legislature Number 2019−06*; Salt Lake City, UT, May 2019. https://le.utah.gov/audit/19_06rpt.pdf (accessed 2020/04/04).
(46) Kemsley, J. The University of Utah's lab safety system is 'broken,' audit says. *Chem. Eng. News.* **2019**, *97* (20).
(47) Kemsley, J. N. Learning from UCLA. *Chem. Eng. News* **2009**, *87* (31), 29−34.
(48) Kemsley, J. Lab safety at the University of California. *Chem. Eng. News.* **2013**, *91* (34), 21−23.
(49) Geller, E. S. *The Psychology of Safety Handbook*; CRC Press, Lewis Publishers: Boca Raton, FL, 2001.
(50) Smith, K. U. Performances Safety Codes and Standards for Industry: The Cybernetic Basis of the Systems Approach to Accident Prevention. In *Selected Readings in Safety: A Collection of Articles by Leaders in the Safety and Loss Control Profession*; Widner, J. T., Ed.; Academy Press: Runnemede, NJ, 1973.
(51) Seiler, L. Global R&D EHS, Dow Chemical, Midland, MI. *Personal communication*, October 2019.
(52) Dow. *Dow Lab Safety Academy*. https://corporate.dow.com/en-us/science-and-sustainability/lab-safety.html (accessed 2020/03/29).
(53) Kemsley, J. Dow Chemical teams up with universities on laboratory safety. *Chem. Eng. News.* **2012**, *90* (44), 21−23.
(54) Group of 6 active scientists at different professional levels. ExxonMobil: Baytown, TX. *Personal Communication*, December 2019.
(55) Van Noorden, R. Safety survey reveals lab risks. *Nature* **2013**, *493*, 9−10.
(56) Summerton, L.; Clark, J. H.; Hurst, G. A.; Ball, P. D.; Rylott, E. L.; Carslaw, N.; Creasey, J.; Murray, J.; Whitford, J.; Dobson, B.; Sneddon, H. F.; Ross, J.; Metcalf, P.; McElroy, C. R. Industry-informed workshops to develop graduate skills sets in the circular economy using systems thinking. *J. Chem. Educ.* **2019**, *96*, 2959−2967.
(57) ACS Committee on Chemical Safety, Task Force for Safety Education Guidelines. *Guidelines for Chemical Laboratory Safety in*

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182

Academic Institutions; American Chemical Society: Washington, DC, 2016.
(58) Wells, J. W., Jr. *Professional Commitment, Ethical Reasoning, and the Belief in Regulatory Compliance as Perceived by Safety Professionals*. Ph.D. Dissertation, Union University, Jackson, TN, 2012.
(59) Rosso, V.; Simon, J.; Hickey, M.; Risatti, C.; Sfouggatakis, C.; Breckenridge, L.; Lou, S.; Forest, R.; Chiou, G.; Marshall, J.; Tom, J. Engaging senior management to improve the safety culture of a chemical development organization thru the SPYDR (Safety as Part of Your Daily Routine) lab visit program. *J. Chem. Health Saf.* **2019**, *26* (4−5), 38−43.
(60) Howes, L.; Lemonick, S. In these classrooms, chemistry is part of a larger whole. *Chem. Eng. News.* **2020**, *98* (5).
(61) Garcia-Martinez, J. Why we need a common vision for chemistry. *Chem. Eng. News.* **2020**, *98* (2).
(62) American Chemical Society. *Developing & Growing In Your Career*. https://www.acs.org/content/acs/en/careers/developing-growing-in-your-career.html (accessed 2020/01/21).
(63) American Chemical Society. *Hazard Assessment*. https://www.acs.org/content/acs/en/chemical-safety/hazard-assessment.html (accessed 2020/04/04).
(64) Zohar, D. Thirty years of safety climate research: Reflections and future directions. *Accid. Anal. Prev.* **2010**, *42*, 1517−1522.
(65) Pupulidy, I. Self-designing safety culture: A case study in adaptive approaches to creating a safety culture. *ACS Chem. Health Saf.* **2020**, *27*, 24−33.
(66) Huising, R.; Silbey, S. S. Constructing consequences for noncompliance: The case of academic laboratories. *Annals Am. Pol. & Soc. Sci.* **2013**, *649*, 157−177.
(67) Jorgensen, E. F. Development and psychometric evaluation of the research laboratory safe behavior survey (RLSBS). *J. Chem. Health Saf.* **2017**, *24* (5), 38−43.
(68) Ayi, H.-R.; Hon, C.-Y. Safety culture and safety compliance in academic laboratories: A Canadian perspective. *J. Chem. Health Saf.* **2018**, *25* (6), 6−12.
(69) Schimanski, L. A.; Alperin, J. P. The evaluation of scholarship in academic promotion and tenure processes: Past, present, and future. *F1000Research* **2018**, *7*, 1605.
(70) Hamblin, L.; Barker, D.; Arghode, V. A phenomenological approach to explore faculty perceptions about invisible labor. *Community College Journal of Research and Practice.* **2020**, DOI: 10.1080/10668926.2020.1716874.
(71) Rauhaus, B. M.; Schuchs Carr, I. A. The invisible challenges: gender differences among public administration faculty. *Journal of Public Affairs Education.* **2020**, *26* (1), 31−50.
(72) Boyer, E. L. *Scholarship Reconsidered: Priorities of the Professoriate*; Princeton University Press: Lawrenceville, NJ, 1990.

https://dx.doi.org/10.1021/acs.chas.0c00016
ACS Chem. Health Saf. 2020, 27, 170−182