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Semi-Quantitative Indicators of Safety Culture Evolution Through Graduate Researcher Led Initiatives

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Abstract: Since 2012, the Joint Safety Team (JST) has led initiatives aimed at increasing safety awareness and improving safety culture in research laboratory environments at the University of Minnesota. Specifically, its Analysis and Compliance committee has implemented biannual lab safety walkthroughs and safety surveys to monitor safety culture, sentiments, and compliance. Despite several lab safety teams (LSTs) using similar initiatives, the logistics and effectiveness of these initiatives have yet to be reported. Hence, JST has analyzed the decade of overall lab safety walkthrough scores and scores of individual safety items in the context of the evolution of our rubrics and external factors. Similarly, the changes to the safety survey content have been analyzed to demonstrate the dynamic approach of gauging sentiments towards arising safety issues. Generally, the results suggest that these initiatives improved laboratory safety. Furthermore, safety compliance was observed to vary by semester, with fewer safety issues in the spring semester compared to the fall semester, and to be affected by the COVID-19 pandemic. These observations support the effectiveness of these student-led initiatives, despite the initiatives being designed for internal use. Additionally, the initiative logistics are described to inform LSTs of strategies for creating, sustaining, and improving their own initiatives.

Keywords: joint safety team; laboratory safety team; laboratory safety; hazard evaluation; safety culture; graduate education; laboratory management

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1. Introduction

A higher commitment to lab safety at the University of Minnesota (UMN), encouraged and supported by Dow Chemical, spawned the formation of the Joint Safety Team (JST) in the Chemical Engineering and Materials Science (CEMS) and Chemistry (CHEM) departments. Over the past decade, the graduate researcher-led JST has worked toward the goals of improving safety culture and increasing safety awareness [1–3]. To do so, the JST organized and launched initiatives across its four committees: Analysis and Compliance (A&C), Education and Resources (E&R), Public Relations (PR), and Community Connections (CC). Each committee is composed of a chair and four other members who each receive a USD 200 stipend per semester that is financed jointly by the two departments. Outside of our committees, the JST is primarily composed of the lab safety officers (LSOs) in the two departments that it directly serves through its initiatives. LSOs typically volunteer and

serve for 1–2 years as a safety liaison for their research group by engaging in JST initiatives, relaying safety knowledge to their group as needed, and directing peers to safety resources when prompted or when safety issues arise in the lab. Each research group has 1–2 LSOs, depending on the size of the lab, the range of research areas, and if an LSO is transitioning out of their role. For information on other LSO programs, see Donaghy et al. [4]. Generally, the JST works to provide LSOs with guidance, resources, and support through its various initiatives to supplement support from faculty, department safety officers/committees, and the Department of Environmental Health and Safety (DEHS). Since 2012, several universities have established similar lab safety teams (LSTs) inspired by the model of the JST [5–11].

Briefly, the A&C committee organizes biannual lab safety walkthroughs and safety surveys for the fall and spring semesters. The E&R committee hosts bimonthly educational events for LSOs and maintains a repository of LSO educational materials, including a description of the LSO rules and responsibilities [12]. The PR committee manages social media and creates safety content, such as posters posted in hallways and stall wall newsletters posted in restrooms. The CC committee, which was recently formed, connects industry, local high school teachers, and primarily undergraduate institutions with the JST to create educational opportunities for both parties [13]. To carry out these initiatives, committee chairs and members are expected to attend monthly 1 h planning meetings and to individually accomplish set action items that may require 1–3 h of work each month. These sustained initiatives support and empower our LSOs and follow our CARES objectives: compliance, awareness, resources, education, and spread [3].

For evidence of achieving these objectives annually, we look toward A&C initiatives that record the state of labs and sentiments of the departments. Biannual lab safety walkthroughs executed by LSOs provide data to understand the state of safety items in laboratories, identify rising safety issues, and guide future walkthrough revisions. To supplement our picture of safety, biannual safety surveys are sent to researchers and staff/faculty to reveal sentiments across a variety of safety topics. The JST also maintains its Learning Experience Reports (LERs) near-miss reporting system that was previously discussed by Kou et al. [2] and will not be discussed herein. These initiatives were initially developed with help from Dow Chemical during the formation of the JST. They resembled the best practices common to industrial laboratories [14–16] and have since been adopted by research universities [16–18]. The JST has since tailored these initiatives to rising safety concerns and to lab-specific hazards.

During lab safety walkthroughs, LSOs are tasked with walking through each other's lab spaces and scoring each safety item in the lab, using a rubric designed by the A&C committee. An extensive description of lab safety walkthroughs, including their organization and scoring, is offered in the Methods Section. For one semester of the year, walkthrough groups are organized by the lab's hazard classification. Here, LSOs can discuss their hazard-specific safety items with peers and view how similar labs address them. To diversify exposure to lab environments and offer alternative safety perspectives, walkthrough groups are also organized to intermix hazard classes in the other semester. With walkthrough data, the A&C committee and individual labs gather a sense of how safety is addressed within the lab. The summers are typically a rest period from all JST activities.

Similarly, individual department safety surveys are sent out to (1) researchers and (2) staff and faculty on a semesterly basis. More information on survey organization and distribution is included in the Methods Section. These surveys compile the departments' safety sentiments on a variety of topics within teaching and research lab environments. Biannual safety surveys are also a platform to gauge the effectiveness of JST initiatives and to address rising safety concerns, like the COVID-19 pandemic. Since these surveys are

routine methods to monitor safety sentiments internally without the intent of answering preplanned research questions and we are reflecting on these results to pose potential explanations, our Institutional Review Board (IRB) office advised that this work does not require IRB approval. These surveys effectively round out our perception of safety culture and sentiments across the two departments and prevent the exclusion of important stakeholders.

Beyond the UMN JST, there are several other student-led laboratory safety teams across the country, some of which have similar tactics to gauge safety compliance and culture. The most exhaustive lists of current LSTs can be found on the American Chemical Society (ACS) website for LSTs [5] and in the publications by Martin et al. [6,10]. In this growing LST movement, it was noted by Martin et al. [6] that metrics to measure the impact of LSTs are the next steps, and several other LSTs utilize similar techniques as UMN. Notably, safety teams at Northwestern University [7], University of Notre Dame, Ohio State University, Texas A&M University, University of Illinois Urbana Champagne, University of Chicago [8], University of Connecticut, University of Texas at Austin, and the Georgia Institute of Technology [9] organize a version of peer walkthroughs, and the latter five, in addition to the University of Iowa and University of North Carolina at Chapel Hill, utilize surveys to gauge safety culture, needs, and concerns [10]. Furthermore, the University of Chicago has developed a walkthrough rubric considering hazard-specific safety items, which we expand upon by developing separate rubrics for various hazard classes [8]. Generally, the detailed logistics around conducting walkthroughs and safety surveys are limited in current reports, and the initiatives have yet to be explored as indicators of the impact an LST can have on safety in academic laboratories. Hence this report provides some insight into this knowledge gap by detailing the logistics of the walkthrough and safety survey initiatives of the JST to inform and inspire other LSTs and by reporting some of the exploratory results that suggest the effectiveness of these initiatives at improving safety compliance and safety culture in academic laboratories.

To examine the evolution of safety within labs and across the two departments, we have delved into the decade's worth of data. The adaptation of walkthrough rubrics and surveys reveals emerging safety items and concerns, demonstrating a dynamic and innovative approach to safety that can be used by a researcher or student-led lab safety team [6–11], like the JST. Further, scores from lab safety walkthroughs reveal how the fruition of the JST, our adaptations, and external forces, such as the COVID-19 pandemic, influence safety in research labs. In acknowledging our dynamic approach, we also recognize the inward and outward flux of LSOs and researchers in labs, which, in turn, limits observation of global changes in our safety data. Regardless, we offer this case study exploration of these semi-quantitative indicators of safety to inspire adoption at other institutions and more rigorous inquiries into the impacts of LSTs.

2. Materials and Methods

2.1. Lab Safety Walkthroughs

2.1.1. Organizing Lab Safety Walkthroughs

Lab safety walkthroughs are conducted by LSOs in groups of 3–4 labs once a semester with every research group participating, even computational groups in recent years. The A&C committee is responsible for revising walkthrough rubrics, organizing walkthrough groups, setting deadlines, and handling submitted rubrics. As shown in Figure 1, several strategies have been used to group walkthrough participants. From the Fall 2012 semester (Fall 2012) to Fall 2014, LSOs were grouped randomly, without considering experiences with particular hazards. In the Spring 2015 semester (Spring 2015), research groups were designated with a hazard classification based on the research being undertaken. Then, from

Spring 2015 to Fall 2019, walkthrough groups were organized by shared hazard class in the spring and by intermixed hazard classes in the fall. The pattern was interrupted by COVID-19 in Spring 2020, when no walkthroughs were organized, and subsequent social distancing required self-guided walkthroughs in Fall 2020 and Spring 2021. Then, from Fall 2020 to the present, the grouping has been reversed, with groups organized by hazard class in the fall and by intermixed hazard classes in the spring. Since its creation in Fall 2020, hazard class-specific rubrics have been used in all walkthroughs organized by hazard class. General walkthrough rubrics were used prior to Fall 2020 and continue to be used for walkthroughs organized by intermixed hazard classes.

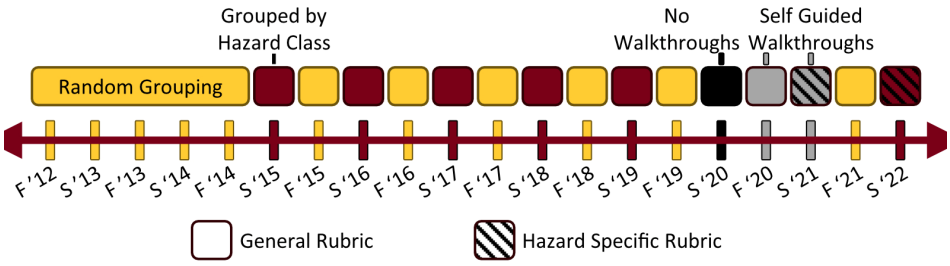


Figure 1. Timeline of walkthrough grouping strategies and the walkthrough rubrics used by semester.

To properly organize walkthrough groups, surveys are periodically sent out for LSOs or laboratory principal investigators (PIs) to report the lab's primary and secondary hazard classification, group size, and common hazards. In addition to hazard class, attention is paid to lab size when grouping to prevent uneven amounts of time spent in each lab. All LSOs are sent an email with the walkthrough group assignments, LSO contact list, rubric(s), and informative instructions (PowerPoint slides and video), so they can properly coordinate a time and prepare for their grouped walkthroughs. To further prepare new LSOs, those in training are encouraged to shadow their senior LSO during a walkthrough, and by grouping 3–4 LSOs, we ensure that there will be at least one experienced LSO per group. Typically, LSOs are given 1.5–2 months to complete their walkthroughs and submit their completed rubrics. Extensions are granted on an as-needed basis.

2.1.2. Walkthrough Rubric and Its Usage

In their groups, one LSO is responsible for evaluating one external lab, so there is only one rubric submitted for each lab. If more than one rubric is submitted, the scores are averaged. Other LSOs in the group contribute to discussions and can view how each lab handles safety items. The general rubric has a total of 13 safety items with a 1–3 or 1–5 scoring system (see Table A1) to rate the state of the item (1 = "Needs Attention", 3 = "Acceptable", 5 = "Exemplary"). Hazard-specific rubrics are now utilized in the fall, beginning in Fall 2020, where the safety items have been adapted to suit the hazard class's common safety issues. Adaptations to these rubrics will be discussed in the Section 3, and all rubrics can be found in Appendix C. A definition of each rating is detailed in the beginning of the rubric. For each safety item, there are detailed descriptions for each potential score to facilitate walkthroughs, educate the LSOs, and act as a guide for consistent scoring. The rubrics also include a set of questions intended to guide discussion of the lab's improvement since the last walkthrough, areas for improvement, and other safety items (e.g., standard operating procedures (SOPs), shared spaces). For all items receiving a score of 4 or 5, the LSO is responsible for justifying the score with either a description or picture of the exemplary approach. This requirement helps dissuade LSOs from assigning high scores based on their own guidelines. If no justification is provided, the score is changed to a 3 by the A&C committee. Along these lines, if a safety item is not applicable to a lab, a default score of 3 is given.

2.1.3. Organizing Walkthrough Data

The submitted scores are totaled for each group and normalized to the maximum score by the A&C committee in a master spreadsheet. Normalization is especially important for hazard-specific walkthroughs where the maximum score is rubric-dependent. The "Safe Labs" are identified based on the criteria of not having a score below a 3 (i.e., no needs attention items) for all safety items. For each hazard class, the top-scoring group is identified, and for each department, the top-scoring lab is identified as one of two "Safest Labs". The A&C committee also collects feedback from the rubrics for consideration in future walkthroughs.

2.1.4. Incentivization for Labs

Participating groups have the potential to win one of three prizes (e.g., USD 50 for a group activity or a communal item). One lab is randomly selected from all participating labs, and one lab is randomly selected from the top-scoring labs in their hazard classes from each department. The JST recognizes the "Safest Labs" and "Safe Labs" on their website and further recognizes the "Safest Labs" in each department with an engraved plaque hung in the main office of each department.

2.1.5. Normalization of Walkthrough Scores

The first walkthrough, Fall 2012, simply had a "Yes" or "No" rating for whether items are acceptable or not. From Spring 2013 to Spring 2015, groups evaluated one another based on scores of "Needs Attention", "Acceptable", and "Exemplary". The first point system, introduced in Spring 2015, assigned scores of (−1, 0, 1) to "Needs Attention", "Acceptable", and "Exemplary" items, respectively, but was changed in Fall 2016 to the 1–5-point system that is currently used and discussed above. To compare these data sets, we assigned each rating to its corresponding score (1 = "Needs Attention", 3 = "Acceptable", 5 = "Exemplary"), including Spring 2015. Scores for each participating lab were summed and normalized to the maximum score for that rubric. Normalization is necessary to accommodate any adaptations to the scoring of safety items over time and to accommodate situations where safety items were left unscored. Items that are not applicable to a lab receive an "Acceptable" score of 3. Additionally, the introduction of hazard-specific rubrics in Fall 2020 introduced and adapted safety items, changing the maximum scores from one hazard class to another. From the normalized scores, the average and standard deviation among all participating labs for each semester were calculated.

2.1.6. Evaluating Changes in Ratings for Each Walkthrough Semester

For all safety items, the total number of labs was counted, having the following types of rating: "Needs Attention", "Acceptable", and "Exemplary". Because some safety items have a scoring system including scores of 2 and 4, "Needs Attention" items included scores of 2 (Below Average), and "Acceptable" items included scores of 4 (Above Average). See Appendix A for a statistical justification of this conversion. The number of labs was normalized to the total number of participating labs for that semester to obtain a percentage. To observe the changes in "Needs Attention" scoring over time, the percentage of "Needs Attention" scores was summed for each semester.

2.1.7. Processing of Hazard-Specific Walkthrough Safety Items

The first in-person hazard-specific walkthroughs took place during the Fall 2021 semester. The rubric safety items were categorized as common and hazard-specific. The common items make up our general walkthrough rubric and were found in all rubrics, with a few exceptions. The hazard-specific items were designed based on unique safety

considerations for that hazard class and differentiated the rubrics, despite some of these items being shared between 2–3 hazard classes. The normalized scores for each hazard class were determined considering all safety items, common safety items, and hazard-specific safety items to explore the effect of hazard-specific items on the total normalized scores between hazard classes. The average score of the hazard-specific items for each hazard class was also considered since the maximum score of hazard-specific items is 3 or 5, and hence they are normalized to different totals.

2.1.8. DEHS Inspections

Inspection results from the University of Minnesota's Department of Environmental Health and Safety were shared to compare the LSO-obtained to safety professional-obtained results. The results are for all research groups within the CHEM and CEMS departments between 2015 and 2022, except for 2017, 2020, and 2021. Inspections are typically carried out by the DEHS representative for the two departments and the department's safety officer or committee. The DEHS inspections first occurring post-quarantine were in late 2021–early 2022. In these inspections, labs either received an "Unacceptable" or "Acceptable" rating for each of the 11 safety items, and the results were shared with the lab.

2.2. Safety Surveys

2.2.1. Preparation of the Departmental Safety Surveys

Departmental safety surveys are created in Google Forms by the A&C committee. All responses are anonymous and are specified as such in the beginning of the survey. The content of the survey from the previous semester is examined by the A&C committee, and any modifications are made during this step. The source of inspiration for new questions comes from comments received in the previous survey, desired feedback for JST initiatives from other JST committee chairs, and safety discussions within the JST. The preparation of the survey is typically carried out during the timespan walkthroughs are being conducted, and new questions are typically run by the JST administrative committee, comprised of committee chairs, officers, presidents, and the DEHS representative. Examples of safety surveys can be found in Appendix C.

2.2.2. Distribution of the Surveys

Typically, after the semester's walkthroughs are completed, an email is sent to all research members of the CEMS and CHEM departments with the corresponding link to the safety survey. Prior to 2019, a single survey was provided to all members of the community (researchers, staff, and faculty). In 2019 and onward, two surveys were instead designed and distributed: one for researchers and one for staff and faculty. This enabled the JST to separate safety sentiments between the two groups and provide the department with insights into unobserved and/or unreported discrepancies in safety training and resources. The time given to complete the survey is 4–6 weeks, and reminders are sent 1–2 times before the deadline. Extensions are granted when the number of respondents is lower than usual, and the heads of each department are asked to endorse the survey by forwarding the email.

2.2.3. Organization of Survey Data

All the responses are stored in the JST Google Drive, which the members of the A&C committee have access to. The A&C committee organizes responses to each question into a slide deck. The slides are then shared with the departments, so everyone is aware of the current safety sentiments, and the slides are referenced in the JST meetings with the heads of the departments.

2.2.4. Incentivization for Survey Respondents

Since Fall 2015, participants have had the potential to win one of ten prizes (e.g., USD 10 coffee gift cards). A second survey is linked at the end of the safety survey to ensure anonymity and prompts respondents to fill out their name and email to be entered into a random drawing for a prize. The department with the higher rate of responses receives six of the ten prizes, while the other one receives four of the ten prizes. The random drawing is performed during the A&C committee meeting using a random number generator.

2.2.5. Evolution of Surveys

All data herein were pulled directly from the Google Forms sheet for the corresponding semester's survey. The evolution of survey topics was determined by comparing the original survey questions in the first two semesters of the JST (Fall 2012–Spring 2013) to those of the following surveys and identifying the new questions and sections.

2.2.6. Processing of Safety Culture Responses

One of the longest-running questions asks if people, or researchers starting in 2019, would speak up after observing an unsafe practice and was used to understand how safety sentiments within the two departments have changed over time. Since participants could select multiple responses for why they would not speak up in addition to indicating that they would speak up, each survey response was given one vote that was split equally between the responses selected, and the partial votes were summed into a percentage by response option. The responses indicating that they have or would say something were grouped and compared to the all-time average to understand the change in safety sentiments by semester.

3. Results and Discussion

3.1. Lab Safety Walkthroughs

Despite several LSTs conducting peer-to-peer lab safety walkthroughs [6–11], the walkthrough results have yet to be published, making direct comparison of results difficult. These results are instead presented as a case study example of how walkthrough results can be interpreted by an LST to guide its other initiatives and as a demonstration of the effectiveness of lab safety walkthroughs at improving safety compliance.

3.1.1. Fall 2021 Demographics and Common Safety Items

To organize walkthroughs, a survey is sent to both the CHEM and CEMS departments to classify each lab by their primary hazard, secondary hazard(s), and group size. The survey results, shown in Figure 2, represent all the 53 labs in both departments that were involved in the Fall 2021 hazard-specific walkthroughs. The hazard classes include chemical biology (chem bio), computational, inorganic, lasers, organic, polymers, and physical (or mechanical) hazards. As shown in Figure 2a, organic comprises over a quarter of labs, while the distribution of the other classes ranges from 7.5–17%. It is important to note that computational groups were excluded from our later analyses due to their recent inclusion in lab walkthroughs (Fall 2021) and their limited number of applicable safety items. Once groups are organized based on their primary hazard class into hazard-specific or intermixed groups, lab sizes are considered. The organization of groups by lab size enables a lower likelihood of unequal time spent in each lab during the walkthroughs. Figure 2b shows the distribution of lab sizes: large ($\geq$16 researchers), medium (8–15 researchers), and small ($\leq$7 researchers). Most labs are either large- or medium-sized. As mentioned earlier, secondary hazard(s) are also provided by labs. When it is difficult to organize labs into either hazard-specific or totally mixed groups, the secondary hazard is used to further

distinguish the lab. Secondary hazards could also be utilized in future walkthroughs in place of intermixed walkthroughs.

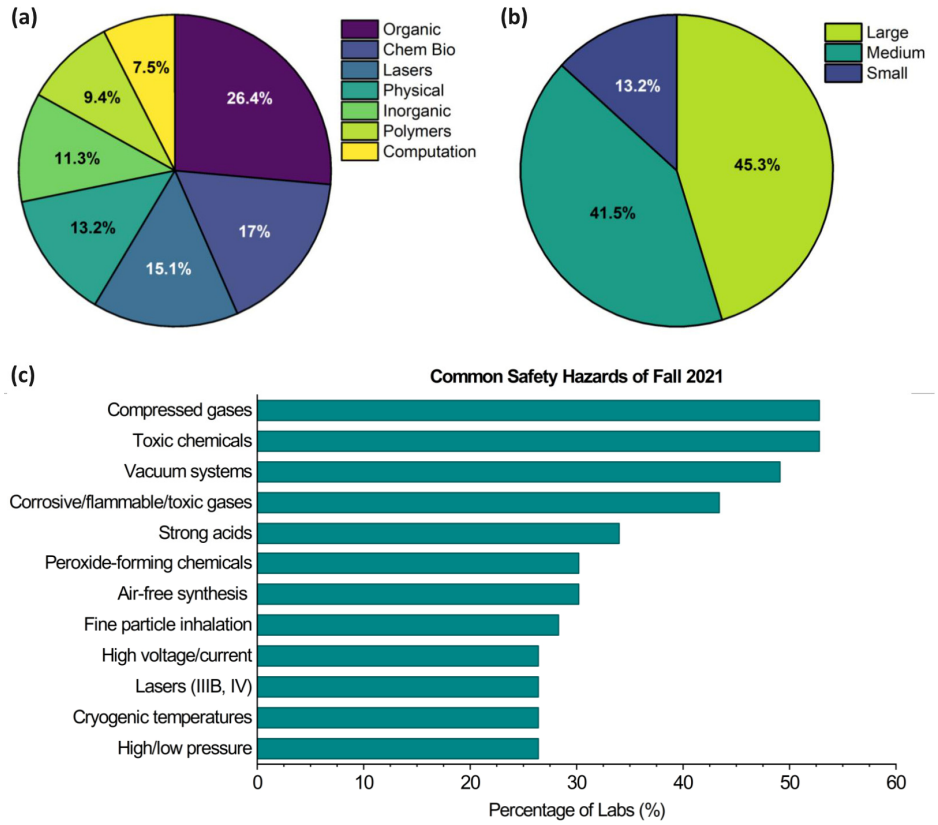


Figure 2. Survey responses of participating labs in the CHEM and CEMS departments in Fall 2021 (n = 53), identifying (**a**) primary hazard classes, (**b**) lab sizes, and (**c**) the most common safety hazards (>25%) for all labs. For lab sizes, large is ≥16 researchers, medium is 8–15 researchers, and small is ≤7 researchers.

The survey also prompts respondents to identify the top five most relevant or common hazards in their labs. Common hazards faced by more than 25% of the respondent pool are shown in Figure 2c. Here, the top three most common hazards are compressed gas, toxic chemicals, and vacuum systems. Although this information is not used to organize walkthrough groups, it is useful in identifying new safety items or inclusive language for walkthrough rubrics. It is also useful to look toward the chemical safety literature to realize specific safety items for future walkthroughs [19,20]. For Fall 2021, the survey also included a question regarding the comfort level of reintroducing peer evaluation walkthroughs (vs. self-guided). Our reintroduction of peer evaluation walkthroughs also came with the option of self-guided walkthroughs for labs uncomfortable with the logistics of a peer evaluation walkthrough (e.g., social distancing difficulties). This option extended into Spring 2022. Our records indicate a total of six labs, and one lab opted for self-guided walkthroughs in Fall 2021 and Spring 2022, respectively.

3.1.2. The Effect of Hazard-Specific Rubrics on Scoring

As noted earlier, the A&C committee created hazard-specific walkthrough rubrics, regarding the previous rubrics as "general" walkthrough rubrics. The general rubrics sometimes contained safety items that were not applicable or not detailed enough for the research activities in a lab. The goal of the hazard-specific rubric was to ensure safety assessments were more comprehensive and specific for the lab being audited. The newly introduced safety items for each hazard class are listed in Table 1 with their correspond-

ing maximum score in parentheses. These safety items are similar to those reported for walkthroughs and audits in both the academic and industrial research settings [8,16,18,21].

Table 1. Common safety items and hazard-specific items listed in lab safety walkthrough rubrics. The maximum score for each safety is included in parentheses.

Common Safety Items	**Hazard-Specific Items**	
Proper Signage (5)	ChemBio	Inorganic
Personal Protective Equipment (5) No Food/Drink (3) Checking Eyewashes (5) Clutter (5)	Bio Workspace (5) Biohazardous Waste (5)	Glovebox (3)
Organization of Electronics (5)	Lasers	Organic
Optimization of Hoods (5) Secure Placement of Chemicals (5) Secondary Containment (5) Segregation by Compatibility (5)	Beam Control (5)	Glovebox (3)
Sample Labeling (5)	Physical	Polymers
Waste Labeling (5) Waste Age (5) Transport (5) Safety Kits (5)	Furnaces (5) Glovebox (3)	Schlenk Line (3) Liquid Nitrogen (3) Glovebox (3)

Hazard-specific rubrics were created through discussions in A&C meetings and by consulting a few LSOs for their advice. Each laboratory hazard class rubric had 1–3 hazard-specific items that were scored with the (1, 3, 5) system. The only exceptions were the glovebox, liquid nitrogen, and Schlenk line items, which did not have a 5 option, and biohazardous waste, which included 2 and 4 options. Some items do not have a 5 option because the state of the item is either in a safe condition or not. With continued use and feedback on the rubrics, we may identify conditions for these items that are considered "Exemplary". Hazard-specific rubrics were adjusted in some hazard classes to exclude or regroup common safety items from the general rubric. For example, due to their limited use of chemicals, the Lasers rubric grouped secure placement of chemicals, secondary containment, segregation by compatibility, and sample/chemical labeling into a chemical storage safety item while waste lifetime was included in waste labeling. The Joint Research Safety Initiative at the University of Chicago utilized similar hazard-class-specific safety items in their peer-to-peer walkthroughs, but provided these safety items in a single, general rubric [8]. Hence, for this study, the influence of the hazard-class-specific safety items on the individual rubric scores must be understood.

To deduce whether the hazard-specific items introduced caused large changes in scores for the corresponding hazard class, the average normalized score received for each lab during hazard-specific rubrics in Fall 2021 was broken into three categories: all safety items, common safety items, and hazard-specific safety items (Figure 3). The only hazard class to experience lower scores for hazard-specific items compared to common items is ChemBio (−2%). Hazard classes that were awarded significantly higher scores were Inorganic (+30%), Organic (+28%), and Polymers (+23%). This could lead one to think that the hazard-specific safety items could greatly impact the overall score of a research lab based on its hazard class, which could bias the "Safest Lab" or "Safe Lab" award.

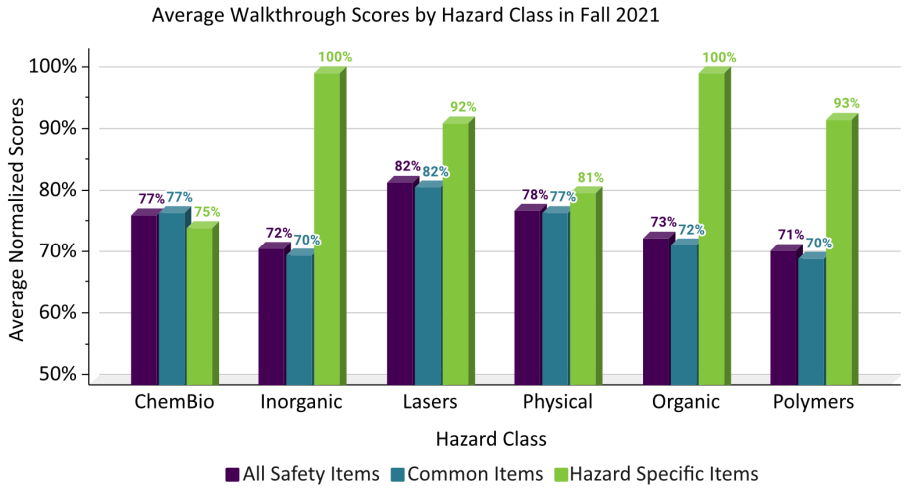


Figure 3. The average normalized scores for walkthroughs in Fall 2021. The score is distinguished by its score with and without hazard-specific items.

However, when comparing the average normalized scores obtained by the groups including all the safety items to those including only common items, the results suggested there has little impact on scoring from hazard-specific items. The average normalized score containing all the items shifted a maximum of +2% when compared to the score of common safety items. When taking into consideration the number of common vs. hazard-specific items, these results make sense. There are 12–15 total common safety items, while, depending on the hazard classification, there are 1–3 total hazard-specific safety items. Further, hazard-specific items either had maximum scores of 3 or 5, further decreasing the weight of the former on the final score. As such, the hazard-specific items caused a non-negligible, small impact on the final score. However, as hazard-specific rubrics become more specific with time through discussion with LSOs, we will turn to this analysis to understand how the new and/or removed items impact scores. In future work, it may be useful to break down safety item scores among the hazard classes to see if there are items where groups are consistently receiving "Needs Attention" scores to adjust scoring criteria or design JST initiatives or educational resources addressing the item(s).

3.1.3. Characterizing Changes in Walkthrough Scores

Over the 19 semesters, an average number of 51 $\pm$ 5 research groups have participated in the walkthroughs. The change in normalized overall scores with time since the first semester of the JST walkthroughs (Fall 2012) is shown in Figure 4. Although the average scores are seemingly steady over time, key changes to the rubrics and COVID-19 impacts have been indicated for further discussion. These changes are supplemented with the changes in the distribution of scores for all safety items, shown in Figure 5. The hazard-specific items were excluded from the analyses performed in Figures 4 and 5 for consistency. It is important to acknowledge the fact that there is a flux of LSOs and researchers in and out of the department (i.e., recently trained vs. experienced). For this reason, we can only form hypotheses for long-term changes that reflect the developing structure of our LST and its initiatives.

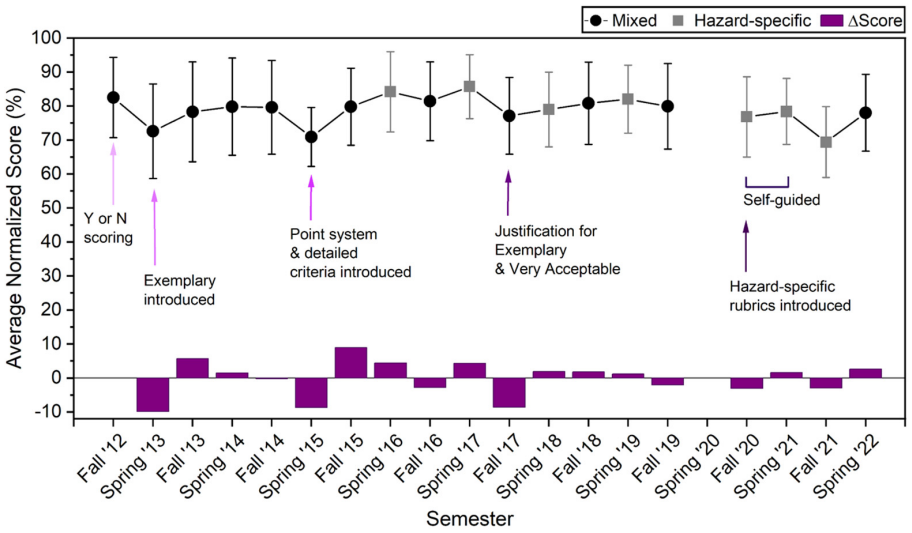


Figure 4. Average of the overall, normalized walkthrough scores for each semester (line graph) and changes in the scores compared to the previous semester (bar graph). Error bars represent the standard deviation among the participating labs. Purple arrows and brackets indicate significant events or changes to rubrics that perhaps influenced scores. Note that no walkthroughs occurred in Spring 2020.

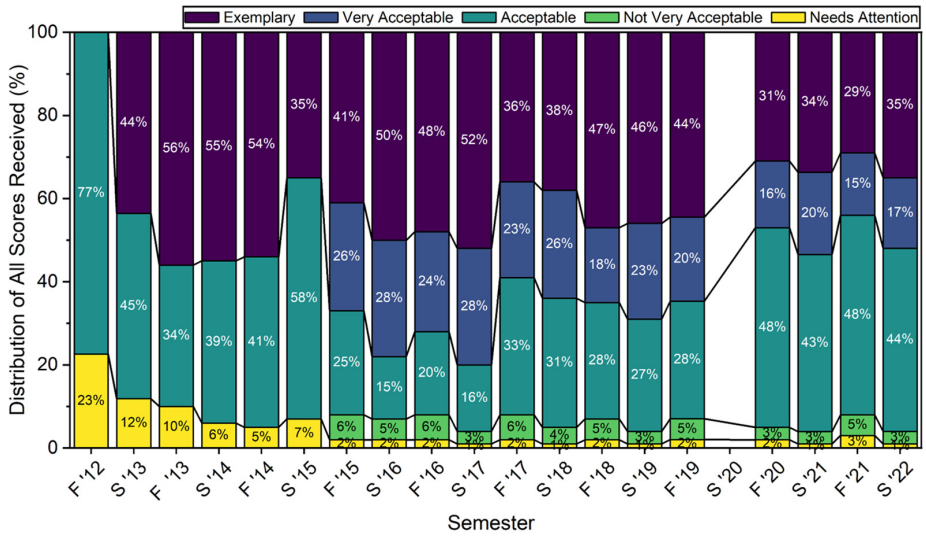


Figure 5. Distribution of scores received among all safety items for each semester with percentages denoted for each type of rating.

Initially, we found that the average score decreased 9.6% with the introduction of an "Exemplary" score in Spring 2013. With the higher standard associated with "Exemplary" scores, we posited that LSOs perhaps did not reward each other with "Exemplary" scores frequently, but we find a nearly equal number of "Exemplary" scores received as "Acceptable". Further, the percentage of "Needs Attention" scores is approximately half of that in 2012. With this, we posit that the change in the scoring system (1, 3 vs. 1, 3, 5) initially penalized groups' scores since the maximum score was now awarded to "Exemplary" rather than "Acceptable", decreasing their overall score if the same scores were awarded between the two semesters.

The normalized score increases and steadies after Spring 2013 until Spring 2015, where we find an 8.7% decrease from Fall 2014. In Spring 2015, an explicit point system with detailed criteria for scores was first introduced. Until then, the guidelines for scoring each safety item were based on general criteria dictating all safety items (listed in Appendix C), placing weight on the safety knowledge and judgment of the visiting LSO. The clearer,

and potentially stricter, criteria can explain the lower scores received compared to past semesters. This is evidenced by the decrease in "Exemplary" scoring (−19%) and increase in "Acceptable" scoring (+17%).

Fall 2015 introduced "Not Very Acceptable" (2) and "Very Acceptable" (4) scoring for several safety items. In taking a closer look, we find a fraction of what would be "Needs Attention" and "Acceptable" scores are awarded as "Not Very Acceptable" and "Very Acceptable", respectively, increasing the average score by 8.9%. From Spring 2015 to Spring 2018, there is a general trend of lower scores in the fall than in the spring semesters. Fall 2015 is also when the A&C committee first started assigning one semester to mixed walkthrough groups (fall) and one semester to hazard-specific walkthrough groups (spring) for each academic year. The trend of lower scores in the fall is explored later with "Needs Attention" items.

The final large, subsequent change in average score was in Fall 2017 (−8.6%). In this walkthrough, the rubrics explicitly list the need for justification of a "Very Acceptable" or "Exemplary" score with a comment or picture. If nothing is provided, the score would be changed to "Acceptable". Approximately 12% of the labs were docked points due to this rule, reducing the "Exemplary" scoring (−16%) and increasing the "Acceptable" scoring (+17%) from Spring 2017. Justification is still a requirement for current walkthroughs, but we believe the way in which rubrics are completed and submitted must change such that no lab is penalized, and all necessary information is documented. This semester sees over 70% of labs scoring lower than in the previous walkthrough, while only 21% increased their overall score. Nonetheless, the changes to scores are only made in the A&C data set, so LSOs reviewing their lab's scores (from the completed rubric) see and can communicate the original scoring.

The COVID-19 pandemic, and subsequent quarantine, which began in Spring 2020, paused JST walkthroughs, like it did for several other LSTs and their initiatives [10]. The safety measures in place at the university-, departmental-, and lab-levels prevented peers visiting other labs, so JST walkthroughs temporarily became self-guided, or internal, for the Fall 2020 and Spring 2021 semesters. During the lab quarantine period, the A&C committee took their meeting times to develop hazard-specific walkthrough rubrics for future use. Table 1 shows the hazard-specific safety items introduced for each hazard class. Hazard-specific rubrics were first implemented in Fall 2020 and Spring 2021 during self-guided walkthroughs. There are no major changes to the normalized scores for these semesters relative to pre-pandemic scores, but there is a 20% increase in "Acceptable" scores and a 13% decrease in "Exemplary" scores. The change in the overall average score is most likely due to the changes in scoring for individual safety items. For example, the scoring for food/drink was changed from (1, 3, 5) to (1, 3) upon concluding that there are no exemplary means of not having food or drink in the lab. This pulls all "Exemplary" scores out of this category, reducing the percentage of "Exemplary" scores without harming the normalized score.

Once peer evaluation walkthroughs were reintroduced in Fall 2021 following COVID-19 social distancing restrictions, hazard-specific grouping was implemented to maintain the use of hazard-specific rubrics in the fall, and mixed grouping was used in Spring 2022 for the general rubrics. With this, hazard-specific vs. mixed grouping semesters were swapped. Fall 2021 sees the lowest normalized score (69.4 ± 10.4%) in JST walkthrough history. We hypothesize one major variable contributing to this result: the reintroduction of peer evaluation walkthroughs. The following semester, Spring 2022, sees an increase in the average score to 78.0 ± 11.3%, which is similar to the last walkthrough before the pandemic in Fall 2019 (79.9 ± 12.6%), potentially revealing that the negative impacts of COVID-19 on lab safety were not long-lasting and promptly remedied. The

reintroduction of peer evaluation walkthroughs identified and addressed safety concerns that had become commonplace during the pandemic and self-guided walkthroughs. The doubling in "Needs Attention" and "Not Very Acceptable" scores at the cost of "Very Acceptable" and "Exemplary" scores from Spring 2021 to Fall 2021 demonstrates this point.

Before the COVID-19 pandemic, we observe a steady increase in scores after each major adaptation to the walkthrough rubric (indicated by the arrows in Figure 4). To further understand the individual effects of COVID-19 on the impact of the JST as an LST and walkthrough grouping, deeper analyses into individual safety items and "Needs Attention" scoring were performed. It is worth noting that the COVID-19 pandemic also affected environmental safety with reports of personal protective equipment (PPE) and hospital waste water negatively affecting the environment [22,23].

To explore changes since JST inception and around the pandemic, the percentages of "Needs Attention", "Acceptable", and "Exemplary" scores for individual safety items across four Fall semesters, 2013, 2019, 2020, and 2021, are shown in Figure 6. The analysis was isolated to only fall semesters to remove any seasonal influence, like summers off. Further, fall semesters are highlighted here because the first self-guided walkthrough and reintroduction of peer evaluation walkthroughs took place in Fall 2020 and 2021, respectively. It is important to note that the latter two semesters used hazard-specific groupings, but as shown earlier, that effect is minimal. Fall 2013 used the three-category scoring system and was hence chosen as the first semester to highlight. The next semester selected, Fall 2019, tracks changes over a 6-year period prior to the pandemic. Eyewash and chemical transport are safety items excluded from this analysis due to their absence in Fall 2013 walkthrough, and food/drink are excluded for having variable scoring of (1,3) or (1,5) across the semesters. For simplicity, "Needs Attention" scores include "Not Very Acceptable" scores, and "Acceptable" includes "Very Acceptable" scores. The same approach is taken for spring semesters shown in Figure A1.

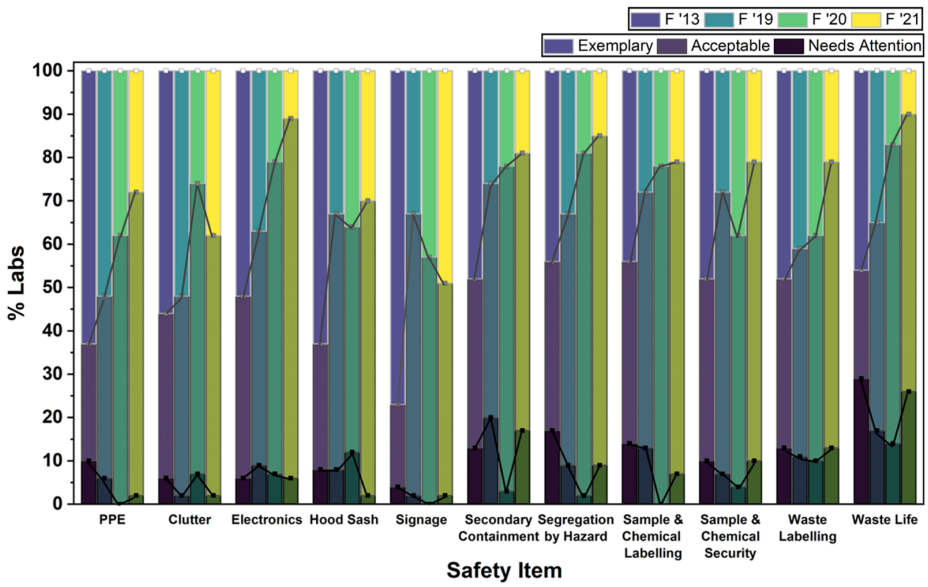


Figure 6. Changes in scores received for specific safety items across four fall semesters (2013, 2019, 2020, and 2021). Within a semester, the dark, medium, and light colors indicate "Needs Attention", "Acceptable", and "Exemplary" scores. The black line tracks the changes in "Needs Attention" items over time. The gray line tracks changes in "Exemplary" items over time. "Not Very Acceptable" scores are included in "Needs Attention", and "Very Acceptable" scores are included in "Acceptable".

Over the 6 years from Fall 2013 to 2019, there is an increase in "Acceptable" scores and a decrease in "Exemplary" and "Needs Attention" scores for all safety items. One

explanation is the adoption of explicit scoring criteria for each safety item and the addition of the scores of 4 ("Very Acceptable") and 2 ("Not Very Acceptable") in Spring 2015. It is possible that the new criteria were stricter than the LSOs opinions, such that safety items they previously scored as "Exemplary" now fell under the "Very Acceptable" score. Additionally, having functioned several years as an LST, we suspect the events, resources, and safety information (e.g., safety moments, LSO guidebook) we provided improved the safety mindset of LSOs to have higher expectations than at its fruition. With explicit criteria and well-equipped LSOs, we can rationalize a decrease in "Exemplary" scoring for "Acceptable" scoring. The "Needs Attention" scores are explored in greater detail over all ten years later.

Conclusions on the COVID-19 impact on lab walkthrough scoring are drawn from changes in scoring between Fall 2019 and Fall 2021. For many safety items, such as PPE, secondary containment, and sample/chemical labeling, there is an observable decrease and subsequent increase in the percentage of "Needs Attention" scores from Fall 2019 to Fall 2021. With restrictions in place in Fall 2020 due to the COVID-19 pandemic, there was a higher degree of attention paid to COVID-19 safety compliance (e.g., PPE, signage, sanitation, and social distancing). Also, less time physically spent in the lab can result in a lower frequency of safety violations. The combination of these implications can explain the dip in "Needs Attention" scoring, but the self-guided walkthroughs this semester can be a compounding or alternative factor. Because of restricted access to labs and social distancing, LSOs conducted self-guided walkthroughs in Fall 2020. This grants the opportunity to change the state of that safety item (i.e., correct the issue) before assigning themselves their score. Due to the rationale of both self-guided walkthroughs and increased safety awareness from the COVID-19 pandemic, we posit both affected the results observed in Fall 2020. The preferred manner to conduct walkthroughs continues to be peer-to-peer evaluation, as we view this as an educational opportunity for all LSOs involved, and it gives the opportunity to catch unrecognized hazards and celebrate good lab practices.

"Needs Attention" scores draw attention to the safety items that labs take issue in properly maintaining. Taking a closer look into how "Needs Attention" scoring over time can reveal the initial and sustained influence of the JST on chemical safety in the labs we support. Further, we can identify safety items that are consistently scored more heavily as "Needs Attention", either drawing attention to a safety item we can focus on for future initiatives or pointing out a flaw in our scoring criteria. A breakdown of the "Needs Attention" scoring for each item over time is shown in Figure 7.

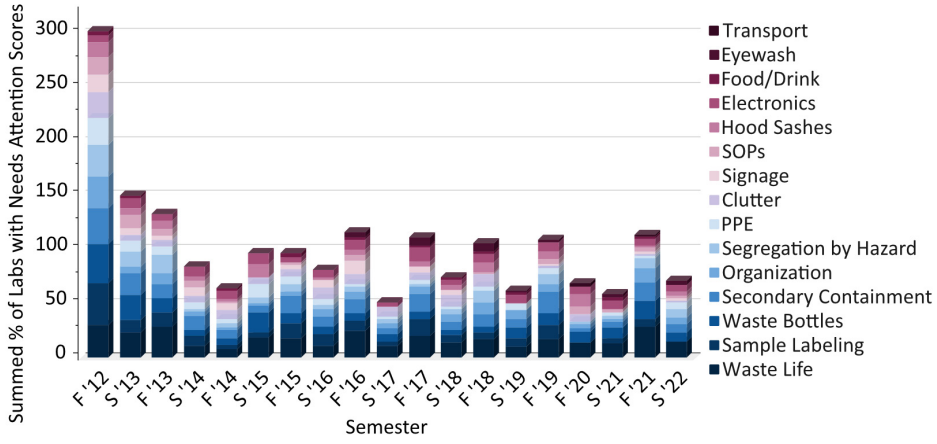


Figure 7. The summed percentage "Needs Attention" scores received by labs for common walk-through safety items from Fall 2012 through Spring 2022.

While the department safety attitudes improve and LSOs have observably become stricter in walkthroughs as evidenced by opting for "Acceptable" over "Exemplary" scores, we would expect more "Needs Attention" over "Acceptable" scores. In fact, the "Needs Attention" items that are more severe safety concerns have been addressed with the presence of the JST to their apparent asymptote, likely a result of LSO turnover. The summed percentage of labs scoring a "Needs Attention" in common safety items dropped off precipitously after the formation of the JST and the first peer safety walkthroughs in Fall 2012. During the first two years of walkthroughs, the "Needs Attention" scores decrease each consecutive semester, indicating that the peer evaluation system is effective in identifying and subsequently addressing safety issues in labs.

Following Fall 2014, we see that spring scores are almost always lower than fall scores, and this trend persists through Spring 2022. Furthermore, a Mann–Whitney U test [24] comparing the fall and spring semesters from 2014–2022 yields a U value of 0.5 that is below the two-tailed critical value of 2 ($\alpha = 0.5$), demonstrating a statistical difference. For one, this could suggest that in the spring, safety concerns identified in the fall walkthroughs are addressed and resolved but seem to re-emerge over the summer. Summers see a higher flux of researchers in the lab, as there is a break from courses and teaching. This enables undergraduates, visiting scholars, and graduate students to increase their research activities. That is especially true for the newest lab members who were burdened with courses through the semester and have yet to adopt laboratory safety best practices. Consequently, LSOs are burdened with training, and labs can have more occurrences of researcher-inflicted safety violations, making the LSO duty of ensuring compliance more challenging and potentially undoing changes implemented after walkthroughs. Additionally, the JST committees lessen their activities in the summer and do not organize walkthroughs, so it is less likely that a lab will run its own internal walkthroughs, leaving various safety items unnoticed and unaddressed in the meantime.

Importantly, the grouping of LSOs into hazard-specific walkthroughs did not begin until Spring 2015. With hazard-specific groups meeting in the spring (until 2020), LSOs are entering similar working environments as their own. This familiarity with specific safety items could result in better adherence to the criteria for scoring than in the fall when LSOs are in mixed groups and less familiar with the working environment. However, in Fall 2021 and Spring 2022, the walkthroughs receive a similar trend in summed percentage of "Needs Attention" items as pre-pandemic semesters despite the reversed organization of walkthrough groups. This challenges the idea of walkthrough group organization impacting the percentage of "Needs Attention" scoring, supporting the former explanations surrounding summers off.

One interesting semester is Fall 2020, where, despite still seeing more "Needs Attention" scores than Spring 2021, it has significantly lower scores than the other recent fall semesters. This can be seen more clearly by looking at the safety items that consistently have the greatest number of "Needs Attention" scores over the 10 years of data (Figure A2). In Fall 2020, they all dropped significantly and subsequently increased the following semester. There are several possible explanations for this result. As explored earlier, the walkthroughs in Fall 2020 and Spring 2021 were self-guided due to COVID-19 safety concerns, whereas, in Fall 2021, the JST returned to the traditional peer evaluation walkthroughs. We suggest that self-guided researchers were more likely to give themselves fewer "Needs Attention" scores when assessing their own labs as compared to their peers. Despite overall normalized walkthrough scores remaining fairly constant (Figure 4), we observe that more LSOs gave themselves acceptable scores (3–4) rather than a "Needs Attention" or "Exemplary" score (Figure 5) in Fall 2020. With peer walkthroughs resuming in Fall 2021, LSOs that perhaps became accustomed to safety concerns in their lab, in

turn, receive "Needs Attention" scores for those corresponding items. In the same vein, becoming accustomed to safety concerns with time can also occur over the summer. This complacency to hazards is a common safety concern that can effectively be mitigated through proper initiatives that include lab walkthroughs and audits [25,26]. To reiterate a past explanation, the decrease in "Needs Attention" scores in Fall 2020 could be the result of fewer researchers working in the lab due to implications of the COVID-19 pandemic and therefore fewer safety concerns. It is challenging to suggest a single explanation, as greater safety awareness, less usage of the lab, and less strict adherence to our detailed scoring criteria may have all played a role in the dip in "Needs Attention" scoring during the pandemic.

3.1.4. Comparison to DEHS Inspections

With the lack of other LST walkthrough data for comparison, we instead compare our results to those from safety professionals and can look toward the past decade of DEHS inspection data. Figure 8 displays the percent of labs meeting an "Unacceptable" rating for 10 different safety items. A standard rubric for DEHS inspections used from 2014–2022 is shown in Appendix D. DEHS inspections are typically conducted throughout the academic year, whereas JST inspections occur semesterly. Items not included in JST walkthroughs are training and emergency preparedness, but it is worth considering both as either safety items or discussion questions in future JST walkthrough rubrics. DEHS inspection data finds that the three safety items needing the most attention include chemical storage, labeling, and waste, similar to JST results (see Figure 6). PPE and signage both have a higher passing score ("Acceptable" and above) for both the JST and DEHS. However, more than 20% of labs received "Unacceptable" ratings for half of the safety items from DEHS, whereas, in Fall 2021 walkthroughs, waste life was the only safety item receiving either a "Needs Attention" or "Not Very Acceptable" score for more than 20% of labs. Like the JST results, there is an increase in "Unacceptable" items from 2019 to 2022, suggesting that the COVID-19 pandemic had an influence on lab safety. Drawing back to the JST inspection analysis, here it is suspected that LSOs were unaware of some of the safety issues in their labs. Items given high attention during the COVID-19 pandemic, PPE and signage, are the two lowest items with "Unacceptable" scores in 2022.

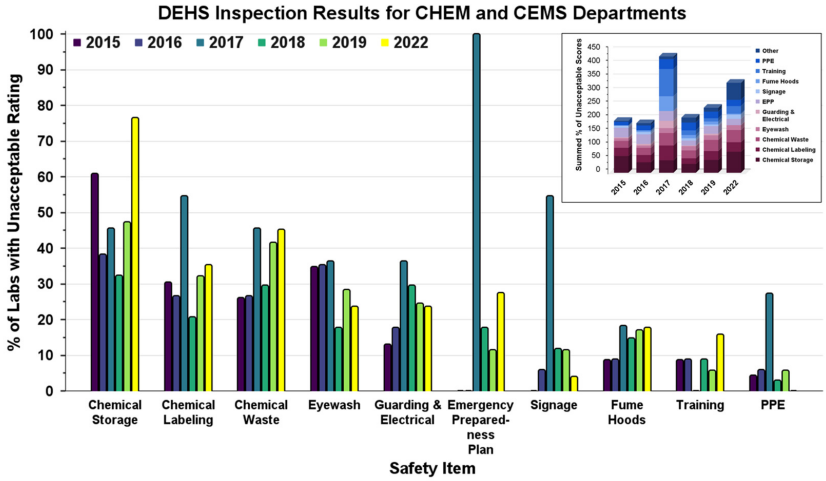


Figure 8. DEHS inspection data for various safety items in the CEMS and CHEM departments. The main bar plot shows the percentage of labs that received an "Unacceptable" rating from 2015 to 2022, broken up by safety item. The inset figure shows the summed percentage of "Unacceptable" scores for all safety items for overall comparisons from year to year. Inspections were not conducted in 2020 and 2021.

Due to annual inspection data only going back to 2015 and the data excluding 2020 and 2021, it is difficult to draw exact conclusions on lab safety regarding the formation of the JST using this data set, but there are some general observations. Furthermore, the same DEHS auditor did not conduct every year's inspection, similar to the JST walkthrough being conducted by different LSOs. Overall, we find that DEHS rates research groups with more "Unacceptable" scores than the JST. In 2017, the summed percentage of "Unacceptable" scores increased significantly where Emergency Preparedness Plan, signage, and chemical waste had the largest contributions. The Emergency Preparedness Plan was first introduced in 2017, resulting in all groups failing to satisfy the criteria. The semesterly fluctuations seen in the JST inspections are not seen in the DEHS inspections conducted throughout the year. However, those fluctuations likely still affect the DEHS data depending on when certain labs are inspected in the year. On average, DEHS identifies a higher percentage of "Unacceptable" scores compared to the JST's "Needs Attention" scores. The annual and biannual occurrence of DEHS and JST inspections provides labs with the opportunity to identify and resolve lab safety issues, maintaining a safe space for researchers. As opposed to JST inspections, labs are required to resolve safety items and submit their resolutions online to the DEHS representative.

A&C meetings, where rubric discussions and editing take place, typically include the DEHS representative responsible for the CHEM and CEMS departments. For future A&C meetings, it is worth considering a direct comparison of the DEHS and JST criteria for scoring among all safety items to address where discrepancies between the two inspections may lie. Another rationale for the higher percentage of groups receiving "Unacceptable" ratings is the difference between the auditors: safety professionals vs. LSOs. It is important that both the expertise of the auditor and the seriousness of that responsibility are considered. All graduate students are required to complete safety training at a department level (e.g., safety modules, fire extinguisher training) and lab-specific training. LSOs are also involved in JST activities (e.g., bimonthly educational meetings) to supplement their chemical health and safety knowledge. However, safety professionals retain greater safety expertise and accountability. To instill accountability for labs and their safety issues, walkthrough rubrics ask the auditor to review whether past safety issues have been addressed (Appendix C), and the JST asks LSOs to share the results of their walkthroughs with their PIs and group members. As walkthroughs are an educational opportunity and safety check-in for our labs, the JST does not enforce protocols for labs receiving poor feedback but hopes they hold themselves accountable. Annual, group-specific safety refreshers are also required and separate from walkthroughs. Additionally, LSOs are informed to contact DEHS and their Department Safety Committee if they feel a lab's practices or environment is unsafe.

3.2. Departmental Safety Surveys

3.2.1. Fall 2021 Survey Demographics

Departmental safety surveys are distributed biannually to all graduate students, postdoctoral associates, faculty, and staff within the CEMS and CHEM departments. In 2020 a separate survey for faculty and staff was developed and focused on research and teaching assistant training and discussions around safety. For the analysis here, we will focus on the researcher safety survey (undergraduates, graduate students, postdoctoral associates, and researchers) more focused on gauging safety attitudes. The demographics of the Fall 2021 safety survey are shown in Figure 9. Fall 2021 is highlighted based on the high response rate, as compared to recent years, in order to better reflect the current demographics of our research labs. Most respondents in Fall 2021 were graduate students. This is no surprise, as they are the most active group in research labs in the department and have the most exposure to the JST's activities (e.g., LSO meetings, walkthroughs). There is

an even split of respondents between the two main departments: CEMS and CHEM. There is a nearly even distribution of respondents with 1, 2, and 3 years in their department(s), making up about three quarters of the respondents. Interestingly, respondents having 5 years in their department make up the lowest percentage of all respondents. We aim to increase this percentage, as these researchers have the most experience in their respective labs and departments. The survey also prompts respondents to choose the hazard class that most suits their research activities. The hazard classes with the most respondents were ChemBio, Polymers, and Physical Hazards. These results differ from the walkthrough demographics in Figure 2 in that Organic and Lasers both have less representation.

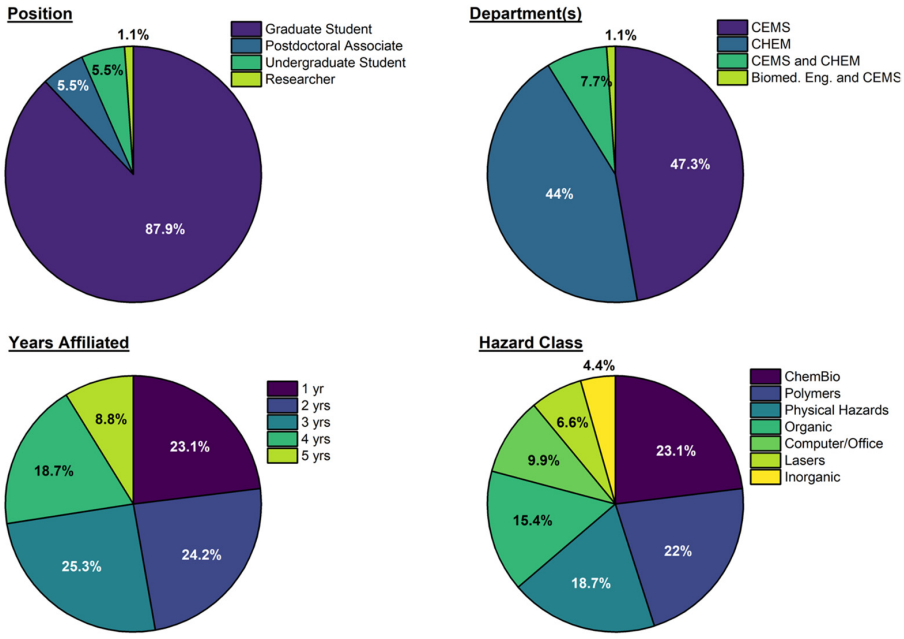


Figure 9. Demographics for the Fall 2021 researcher safety survey (n = 91), including the respondents' position, department(s), number of years affiliated with the department, and their lab's hazard class.

3.2.2. Survey Evolution

The surveys started with the conception of the JST in Fall 2012. The number of respondents over time is tracked in Figure 10. Up until Spring 2020, a single survey was sent to all researchers, staff, and faculty in the two departments, which is reflected in the number of respondents. During the first four years, there is a decrease in the number of participants that steadies off until Spring 2022. In 2015, entry into a gift card drawing was used as an incentive to increase the number of respondents. Although there is no increase observed, the number of respondents did level off, and this reward is still used today to also thank our respondents for their participation.

Elements of the safety survey were changed, and new sections were implemented over time, as needed. The original survey contained the following topics for the questions: demographic (researchers, staff, and faculty), PPE, unsafe lab practices by lab mates, JST safety posters, overall lab cleanliness and organization, and advisor support to students. As shown in the branch diagram (Figure 11), the survey has evolved to become more comprehensive with time. The addition of sections is a result of internal A&C committee discussions, administrative committee discussions, and comments left from respondents.

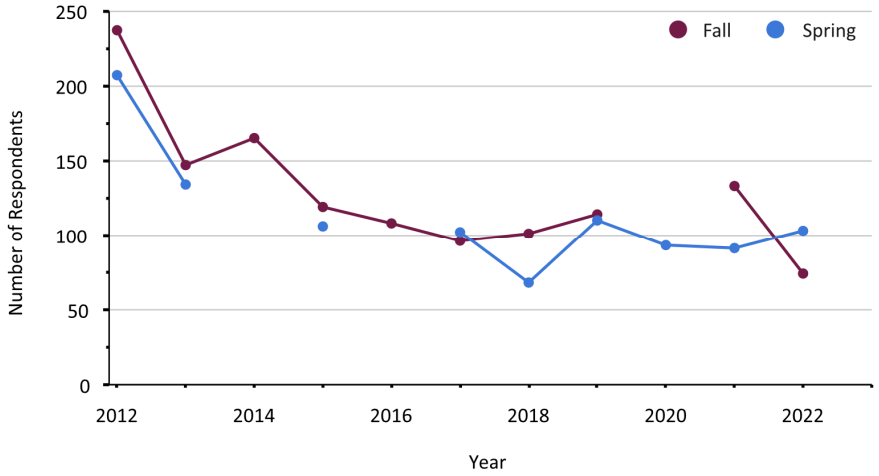


Figure 10. Number of total survey respondents over time for the fall (purple) and spring (blue) department safety surveys. Missing data points represent semesters where surveys were not distributed.

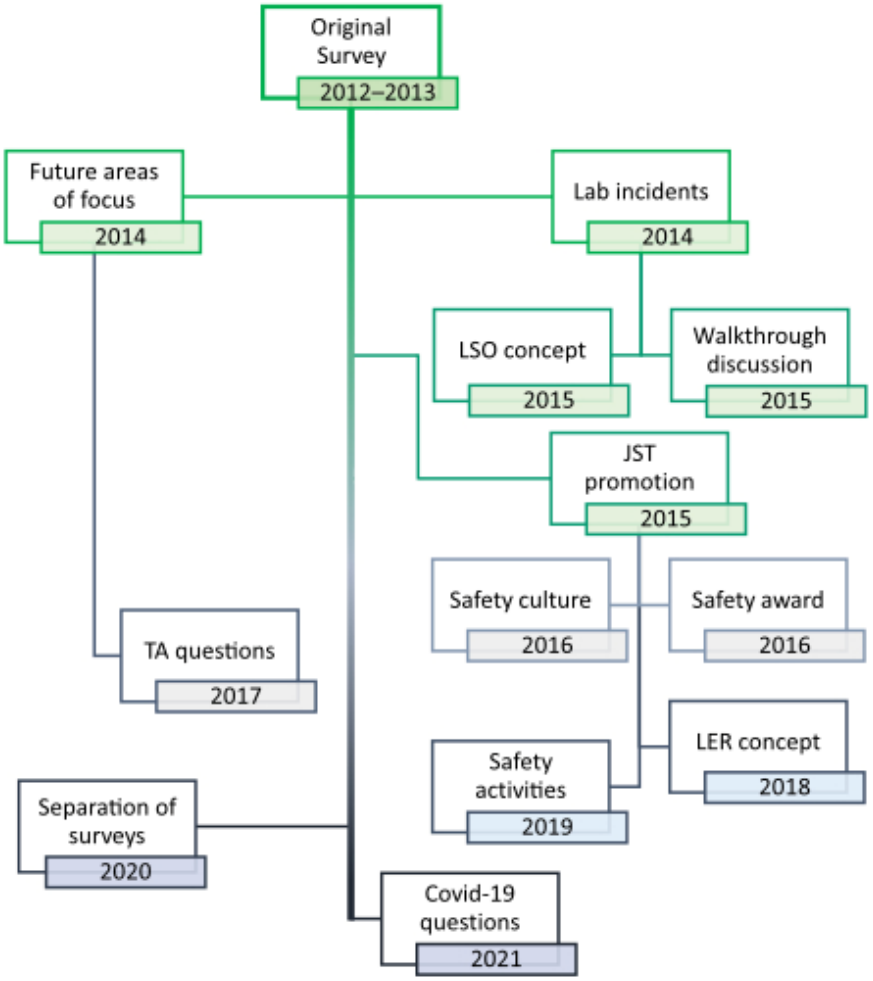


Figure 11. Branch diagram detailing the evolution of the JST departmental safety surveys through the past decade. Branched segments are sections introduced to the safety survey in addition to the contents of the original survey (2012–2013).

The first two years contained the most modifications, given that the original survey had the bare minimum, and the feedback from those early surveys provided insight to the committee on topics that were of interest to the respondents. The organization of the survey evolved with the addition of new questions to house them all in one cohesive section (i.e., safety culture housing all questions regarding how safety is viewed in the department in

2016). All feedback that relates to topics that are not touched on in the current survey is revised by the committee, and the corresponding modifications are undertaken to satisfy this feedback, either by modifying existing questions, creating new ones, merging questions that are seen as redundant, or deleting ones that are deemed irrelevant. An example of this is the Teaching Assistant (TA) section added in 2017 due to a need for clarity on safety in teaching labs.

In addition to looking at the departments' safety attitudes, the JST also uses surveys to probe the effectiveness of our events, incentives, and tools, viewed as the JST promotion section in Figure 11. Here, we have asked questions about how the JST has influenced safety culture, whether respondents are aware of some of our tools (e.g., website: jst.umn.edu, anonymous near-miss reporting) [2], and how they receive our activities and resources (e.g., LSO concept, Walkthrough discussion). This provides space for stakeholders to advise us on ways to improve our organization.

Additionally, the surveys have contained semester-specific questions. A recent addition, COVID-19 questions, was used to gauge how the JST could support labs during and after the hibernation and reopening periods, if labs continued to adopt COVID-19-spawned safety protocols, and which protocols they anticipate keeping permanently. We also included questions on how well labs have adopted COVID-19-related precautions, if there are scenarios where precautions would be compromised (e.g., over lab safety precautions), and who to contact when there is a perceived violation. Generally, there is a semester-specific section in the survey for questions that are not intended to be permanent and instead address arising concerns or gauge interest in new JST activities.

Using the tools provided by Google Forms, the answers are compiled in a slide deck. These results are used by the JST president(s) to discuss safety issues needing attention with department heads to create action items. The PR committee can be inspired to create new content surrounding a common safety issue detailed in the survey. Similarly, the E&R committee can plan educational LSO meetings surrounding a rising safety issue.

3.2.3. Safety Culture Survey Question

To view how safety sentiments within the two departments have changed over time, we focused here on one of the longest-running questions that asks if people or researchers would speak up after observing an unsafe practice. Until Spring 2013, the question was, "If you see a researcher in your lab participating in unsafe behavior, how likely are you to discuss it with them?" To better understand why people would not confront safety issues, the question was changed to "If you see a lab mate participating in unsafe lab practices, which of the following reasons would prevent you from discussing better lab practices with that lab mate?" The responses were also changed, and both sets of responses are listed in Table 2. After several typed responses conveying the same sentiment, the following response option was added in Fall 2018: "I've said things in the past, but it hasn't helped".

Table 2. Survey question and response options around responding to unsafe behavior in the lab.

Fall 2012–Spring 2013	After Spring 2013
If you see a researcher in your lab participating in unsafe behavior, how likely are you to discuss it with them?	If you see a lab mate participating in unsafe lab practices, which of the following reasons would prevent you from discussing better lab practices with that lab mate?
I will not discuss it	It's not my responsibility to regulate others
Unlikely to discuss it	Don't want to disrupt lab mate
It depends (e.g., seniority, personality, severity)	Personality differences
Likely to discuss it	Seniority
I will definitely discuss it	Lab practice isn't too dangerous
	I've said things in the past, but it hasn't helped
	I'll definitely say something

With respondents able to select multiple answers, each submission received one vote that was split between the selected responses, such as if seniority and personality differences were selected, then each would receive 0.5 votes. The percentage of summed partial votes was compared for each response option (Figure 12). The results indicate that "seniority" and the "lab practice not being too dangerous" are the main reasons that prevent people from saying something. "Personality differences", "avoiding disrupting peers", and "not my responsibility" followed in diminishing priority. The most popular response for every semester was that respondents "would say something" despite the addition of the response option that "previous advice was ignored" seeming to detract from its votes.

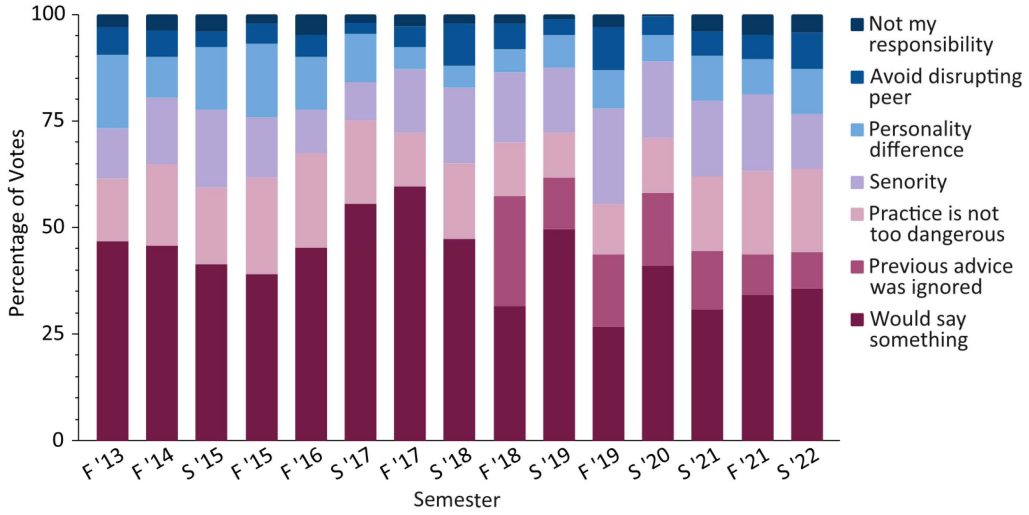


Figure 12. The percentage of summed partial votes for each response to the survey question, "If you see a lab mate participating in unsafe lab practices, which of the following reasons would prevent you from discussing better lab practices with that lab mate?", from Fall 2013—Spring 2022.

However, it was difficult to observe trends in safety sentiments with the two "would or have said something" response options, so those partial votes were combined and compared to the all-time average (Figure A3). The all-time average included the "I will definitely discuss it" and "Likely to discuss it" response options that summed to 55% of the responses in both Fall 2012 and Spring 2013. The results vary from semester to semester, indicating that sentiments are changing as researchers enter, acclimate to, and leave their labs. JST initiatives seemingly improved the departmental safety cultures with greater than a standard deviation above the mean (68% confidence), indicating they have or would say something in Fall 2017, Fall 2018, Spring 2019, and Spring 2020. Interestingly, after the onset of COVID-19 precautions, the percentage of respondents indicating they have or would say something has been below the average, which could be a result of decreased interactions between lab mates and a lack of comfort in calling out a lab mate's unsafe practices.

4. Future Directions

Looking forward, we have many considerations for the design and organization of lab safety walkthroughs that are supported by these data. These walkthrough results have been useful in creating JST events to target safety concerns that have consistently high needs attention scores, such as a need to improve chemical waste storage and manifesting. Based on walkthrough results, the JST had an event to discuss waste management in Spring 2021. One step taken by the JST considering these results has been the E&R educational event for LSOs surrounding lab safety walkthroughs. Here, breakout rooms for each hazard class were organized for LSOs to discuss safety with peers within their hazard class and share written feedback on hazard-specific rubrics for the A&C committee. As such, we look

toward optimizing our hazard-specific rubrics and perhaps utilizing hazard-specific rubrics for both semesters. Along similar lines, LSOs may want to exclusively have hazard-specific walkthrough groups, where one of the semesters could place them in their secondary hazard class. For example, a surface science group that specializes in organic synthesis and device fabrication could benefit from both the physical hazard and organic classification to offer safety advice for all hazard-specific aspects of their lab. This question has been posed to researchers in our Fall 2022 department safety survey.

In our ongoing process of editing rubrics and surveys, we plan to update our current data sets to gather how our changes have impacted results. For example, in changing the "Needs Attention" criteria for a safety item to better suit compliance with DEHS, we can decipher whether the change had a significant impact on scoring compared to past semesters. Such a reiterative process can track how our adaptations evaluate the safety of the labs we serve and potentially reveal areas of concern that were not realized earlier.

Further, our current data sets present potential faults of the A&C committee in designating scoring criteria. For example, chemical waste lifetime ("Acceptable" for waste < 90 days old) is a consistently lower-scoring safety item. After discussion with DEHS, changes to the scoring criteria were made to match DEHS expectations, ultimately relaxing the safety expectations of the JST in lab walkthroughs. This change has been implemented for our Fall 2022 walkthroughs, and we look forward to seeing how the scoring has changed for this safety item.

Surveys serve as a platform to further investigate the success of our initiatives by gauging their receptiveness by department members, and we look toward utilizing this platform to address whether new initiatives or changes to initiatives are wanted by the community. Furthermore, we recognize a body of literature reporting effective strategies and insights within the laboratory safety community that aim to improve safety culture [20,27–34]. With this, surveys, discussions, and reports will supplement the design of all JST initiatives, resources, and programming. As for surveys, our current dynamic approach has been successful thus far, and we plan to continue observing local changes in researchers' safety needs to inform and inspire our committees to support researchers.

These preliminary findings and discussions provide some insight into the impacts of lab walkthroughs to improve chemical safety practices and surveys to gauge safety sentiments. However, the rubrics and surveys discussed herein were designed for internal use and hence give limited insight into the effectiveness of these methods. Instead, a structured investigation aimed at statistically understanding the impact of lab walkthroughs and the reliability of safety sentiment surveys is needed. With the proper forethought, a study could be designed to accurately discuss the usefulness of these techniques. For now, we hope this description of the lab walkthroughs and safety surveys conducted at the University of Minnesota by the Joint Safety Team will motivate other LSTs to consider similar initiatives to improve the safety of graduate research labs.

5. Conclusions

In analyzing lab walkthrough and safety survey data collected over the last decade, we find that the student-led Joint Safety Team initiatives have improved safety culture and lab safety. Key findings include the following:

1. The "Needs Attention" walkthrough scores decreased over the decade due to JST initiatives.
2. LSOs adapted to more detailed and strict walkthrough rubrics and developed stricter safety mindsets as indicated by the decrease in "Exemplary" scores.

3. The hazard-class-specific safety items in the hazard-specific walkthrough rubrics only changed overall scores by 1% and allowed scores to remain comparable between hazard classes.
4. The self-guided walkthroughs reported fewer "Needs Attention" scores during the COVID-19 pandemic, possibly due to less time spent in lab or the emphasis on safety items like PPE and signage. However, as peer-to-peer walkthroughs resumed, "Needs Attention" scores increased and overall scores decreased, suggesting that the observed scoring trends were due to researcher complacency to hazards in their lab.
5. Fall walkthroughs routinely had more "Needs Attention" scores and lower overall scores compared to the spring walkthroughs, likely due to fewer JST activities and more researchers in the labs over the summer. Issues from the fall walkthroughs are also likely addressed prior to the spring walkthroughs, hence improving the scores.
6. Generally, DEHS inspections rated labs with more "Unacceptable" scores than the JST walkthroughs rated labs with "Needs Attention" scores. The absence of DEHS inspections in 2020 and 2021 and the different scoring criteria limited further direct comparisons between the DEHS and JST data sets.
7. Biannual safety sentiment surveys have maintained consistent response rates through incentives and have adapted to include pertinent safety concerns. The survey results indicated that more researchers would speak up when observing an unsafe practice, suggesting that JST initiatives positively impacted safety culture.

JST walkthrough data has provided good semi-quantitative indicators of research lab safety and safety culture within the Department of Chemical Engineering and Materials Science and the Department of Chemistry at the University of Minnesota. With LSO and overall graduate student turnover, the JST is limited in its ability to observe long-term changes in lab safety and safety culture. However, we can acknowledge that these strategies are effective to enhance safety education. The practice of peer-to-peer walkthroughs better prepares students for the expectations of industry positions and educates them on both general safety considerations and those pertinent to their field of study. Meanwhile, safety survey data has been critical to the JST's understanding of safety culture over time, proving to be a good resource for designing and adapting initiatives. With the right incentives and engagement with department heads and safety officers, participation in walkthroughs and safety surveys can be maintained and improve the safety culture for future cohorts.

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Institutional Review Board Statement: The surveys and walkthrough data used in this article are routine methods to monitor safety sentiments internally without the intent of answering preplanned research questions. We are reflecting on these results to pose potential explanations, and our IRB office advised that this work does not require IRB approval.

Informed Consent Statement: Due to the retrospective nature of the study and anonymised participant data, the Institutional Review Board waived the requirement for informed consent.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on a reasonable request.

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Appendix A. Five-Option System Conversion to Three-Option System

Table A1. Scoring options for the various semesters (note that walkthroughs were not conducted in Spring 2020).

Fall 2012	Spring 2013–Spring 2015	Fall 2015–Spring 2022	Abbreviation
"Needs Attention"	"Needs Attention"	"Needs Attention"	NA
		"Not Very Acceptable"	NVA
"Acceptable"	"Acceptable"	"Acceptable"	A
		"Very Acceptable"	VA
	"Exemplary"	"Exemplary"	E

With the variety of scoring systems from Fall 2012 to Spring 2022 (Table A1), we will consider converting data to one scoring system to allow comparison across the semesters. The most straightforward conversion would be adopting the NA, A, and E system from 2013–2015 such that only the 5-option system from 2015–2022 would need to be converted. For said conversion, the NVA scores should be combined with the adjacent NA or A scores, and the VA scores should be combined with the adjacent A or E scores, suggesting four possible conversion methods. Since the normalized scores were consistent from Fall 2012 to Spring 2022, we will assume the distribution of scores should also be consistent and can use the Mann–Whitney *U* test to determine if the scores from Fall 2012–Spring 2015 are statistically similar to the converted Fall 2015-Spring 2022 scores. Using the data shown in Figure 5, each of the NA, A, and E scores from Fall 2012-Spring 2015 was compared to the Fall 2015–Spring 2022 scores after applying the four conversion methods. The resulting *U* values from each comparison are shown in Table A2, and the bolded values are greater than the critical value, signifying no statistical difference. The critical value for a two-sided level of significance ($\alpha = 0.5$) is 12 when considering E scores that exclude the Fall 2012 data and is 16 when considering all other scores. From Table A2 we see that only conversion method 1, where NVA is combined with NA and VA is combined with A, satisfies the assumption that the distribution of scores remains consistent and hence that grouping was used for further analysis.

Table A2. *U* values from the Mann–Whitney tests to compare converted Fall 2015–Spring 2022 data into three bins to match the Fall 2012–Spring 2015 data. Bold signifies no statistical difference.

Method 1		Method 2		Method 3		Method 4	
NA + NVA	**20.5**	NA + NVA	**20.5**	NA	0	NA	0
A + VA	**25**	A	14	NVA + A + VA	**20**	NVA + A	**18.5**
E	**16**	VA + E	12	E	**16**	VA + E	12

Appendix B

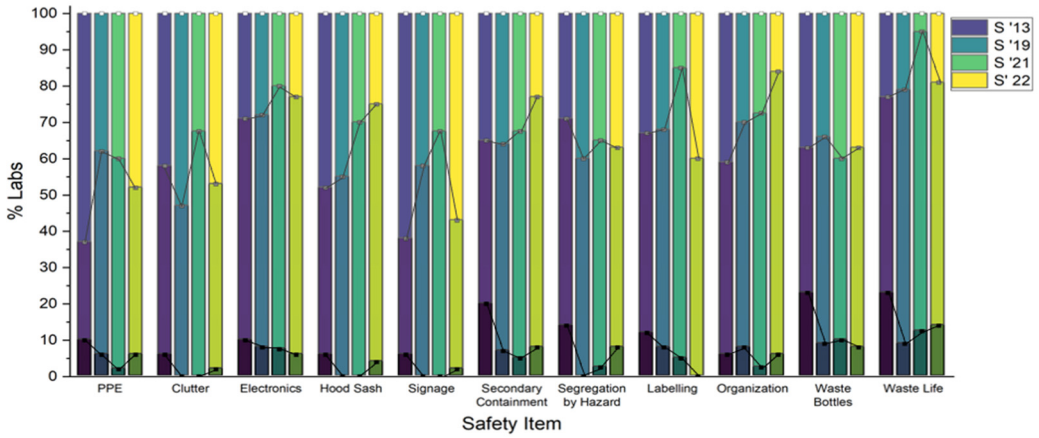


Figure A1. Changes in scores received for specific safety items across four spring semesters (2013, 2019, 2021, and 2022). Within a semester, the dark, medium, and light colors indicate "Needs Attention", "Acceptable", and "Exemplary" scores. The black line tracks the changes in "Needs Attention" items over time. The gray line tracks changes in "Exemplary" items over time. "Not Very Acceptable" scores are included in "Needs Attention", and "Very Acceptable" scores are included in "Acceptable".

Over a 6-year span, there is a similar trend in the fall semesters of a decrease in the number of labs receiving "Needs Attention" and "Not Very Acceptable" scores (1–2) and "Exemplary" scores (5). Self-guided walkthroughs in Spring 2021 see no trends in changes to scores. In looking at trends within each safety item, there is a decrease in "Exemplary" scores for labeling, clutter, and waste life. This can be attributed to the lower frequency of researchers in the lab, including the LSO. Waste accumulation is slower, and researchers may have lost a sense of responsibility when it comes to labeling their samples and cleaning up their workspaces with no LSO and other researchers around to hold them accountable. With peer evaluation walkthroughs in Spring 2022, there is an increase in "Exemplary" scores for PPE and signage relative to Spring 2019. We attribute these effects to PPE standards and lab signage being a significant part of the department and university response to lab and public safety in light of the COVID-19 pandemic.

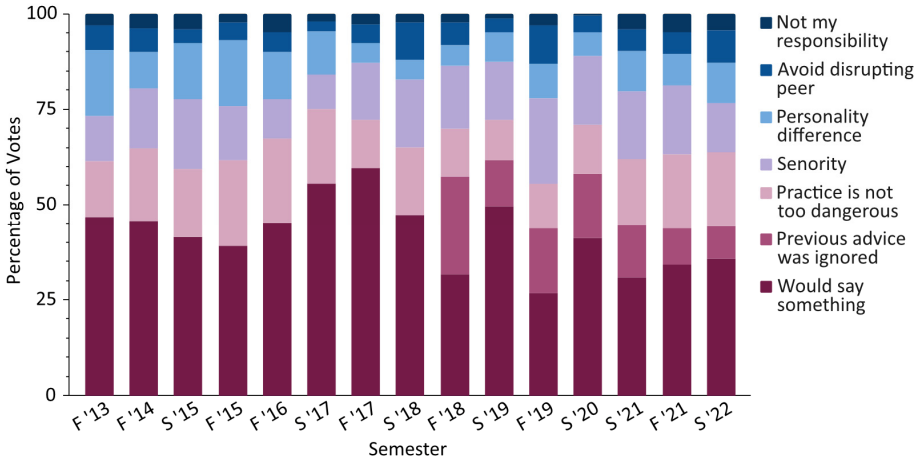


Figure A2. Percentage of "Needs Attention" scores from Fall 2012 to Spring 2022 for a few safety items. These safety items remain the greatest portion of "Needs Attention" scores.

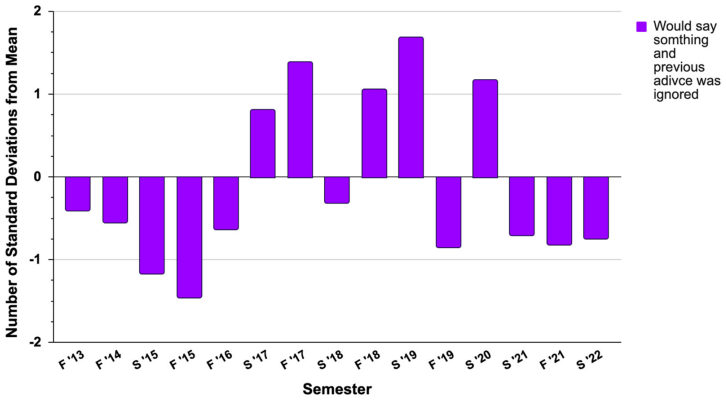


Figure A3. The standard deviation of the average for survey responses indicate respondents would or have said something regarding unsafe practices in the lab from Fall 2013 to Spring 2022. One standard deviation away indicates 68% confidence that the result is statistically significant.

Appendix C. Lab Walkthrough Rubrics and Safety Survey Details

Appendix C.1. Spring 2013 Scoring Criteria

"Exemplary"—This level of housekeeping and safety is very good and should be used as an example for other labs.

"Acceptable"—Most safety issues are being addressed adequately, although there is still room for improvement. This category could include some minor safety violations.

"Needs Attention"—The housekeeping or safety practices in this area are not acceptable and should be addressed promptly. The appropriate CHEM/CEMS safety team should be contacted for a follow-up audit of this specific area.

Appendix C.2. Fall 2015 Scoring Criteria

"Exemplary" (5)—This level of housekeeping and safety is very good and should be used as an example for other labs. These are examples of not just adherence to minimum safety requirements, but striving for 'best practices.'

Excellent/Above Average (4)—Safety issues are all addressed. The safety is better than in peer labs or good given the limitations of the space and number of types of hazards in the lab.

"Acceptable"/Average (3)—Most safety issues are being addressed adequately, although there is still room for improvement. This category could include some minor problems that were recognized and corrected during the visit. If a category does not apply to a lab, please enter a 3 into that category.

Below Average (2)—Several safety concerns are not addressed. The safety is not at the same level as in other peer labs or should be better given the limitations of the space and the number and type of hazards in the lab.

"Needs Attention" (1)—The housekeeping or safety practices in this area make you as a visitor feel uncomfortable or pose safety risks to people in the lab. It is strongly suggested that these items be addressed promptly.

Appendix C.3. Fall 2021 Scoring Criteria

For ratings of 5 or 4, a comment or picture is required. If a 5 or 4 is given without comment or picture, the rating will be changed to a 3.

"Exemplary" (5)—This level of housekeeping and safety is very good and should be used as an example for other labs. These are examples of not just adherence to minimum safety requirements but striving for 'best practices.'

Above Average (4)—Safety issues are all addressed. The safety is better than in peer labs or good given the limitations of the space and types of hazards in the lab.

Average (3)—Most safety issues are being addressed adequately, although there is still room for improvement. This category could include some minor problems that were recognized and corrected during the visit. If a category does not apply to a lab, please enter a 3 into that category.

Below Average (2)—Several safety concerns are not addressed. The safety is not at the same level as in other peer labs or should be better given the limitations of the space and the number and type of hazards in the lab.

"Needs Attention" (1)—The housekeeping or safety practices in this area make you as a visitor feel uncomfortable or pose safety risks to people in the lab. It is strongly suggested that these items be addressed promptly.

Descriptors for each score have been consistent over time. Descriptors for individual safety items have changed over time and can be viewed in the individual rubrics.

Appendix C.4. Current Lab Walkthrough Rubrics and Safety Survey Examples

Complete, current walkthrough rubrics and safety surveys are available on our website jst.umn.edu under Curated Resources for LSTs (https://www.jst.umn.edu/home/curated-resources-for-lsts, accessed on 16 January 2025) and Public Guidebook (https://www.jst.umn.edu/lab-safety-officers/public-guidebook, accessed on 16 January 2025).

Appendix D. DEHS Inspection Template

Inspection Date: Building: Laboratory: Room Department:	Principal Investigator (PI): PI Department: Lab Contact: Lab Contact Phone: Lab Contact Email:
Inspection Items	Results (Satisfactory, Unacceptable, or N/A)
Chemical Storage	
Chemical Labeling	
Chemical Waste	
Fume Hoods	
Appropriate PPE	
Eyewash/Emergency Showers	
Training	
Signage	
Emergency Preparedness Plan	
BioSafety Cabinets	
IBC Approval	
Centrifuge	
BioHazard Waste	
Sharps	
Decontamination Method	
Autoclaves	
Machine Guarding/Electrical	
Other Findings	

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