Collaborative Audits as a Tool for Increasing Safety Awareness

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Abstract

Educators that are closest to the students, such as lab instructors and research advisers, primarily influence academic safety culture. Since individual departments control both curriculum and enforcement of initiatives directly to the staff and faculty, the academic department can also play a pivotal role in a safety culture. Departmental led initiatives such as the collaborative audit can lead to increased cooperation among students, student clubs, faculty, staff, and environmental health and safety. The design of this cooperative audit allowed peer-to-peer education and interaction among graduate and undergraduate students. Results from a feedback survey indicated that the intra-departmental audit achieved a positive effect on student safety knowledge and confidence level. An interesting outcome was the change in attitude toward the primary barrier to a safety culture within the department after audit participation.

Keywords

Safety, departmental safety program, safety audits, collaborative audits, student-led audits, safety culture

Introduction

The chemical engineering laboratory is an inherently dangerous environment for untrained and inexperienced students. Their work requires them to carry out novel reactions, design processes which involve potentially hazardous chemicals and gases, and work at high pressures. Most chemical engineering curricula, in-line with ABET credentials, focus on foundational safety principles that are found throughout the student's chemical engineering career (Vogel and Tomasko 2015). By the end of the student's college education, chemical engineers should be able to integrate safety into their design work in both experimental research and focused industrial applications (Davidson 2018). However, most students only learn the value of safety when something goes wrong or when safety is particularly relevant to their work. Additionally, the multidisciplinary nature of modern research makes safety a more complex issue to teach as well as assess.

Academics are between 2 and 11 times more likely to have accidents than industry (Banholzer et al. 2013; Gibson and Schroeder 2013). Recent accidents in several chemical research laboratories have highlighted the need to emphasize and practice safety in academic institutions (Kemsley 2013; Benderly 2016). To help stem this trend, organizations such as the American Chemical Society (ACS), the American Institute of Chemical Engineers (AIChE) and the UC Center for Laboratory Safety have developed resources and directives designed to aid in safety education (Wenzel et al. 2015; Czornyj et al. 2018; Hill 2016; AIChE 2018). Additionally, we have a real obligation to train future professionals.

Most chemical engineering graduates will find work in industry. Chemical engineering students need to be able to handle issues involved with process safety in the industrial setting where consequences can be catastrophic Behm et al. 2014). The fundamental basis for the application of process safety is the understanding of personal safety principles. Without an understanding of what workers might need to deal with, a process cannot be designed inherently safe. The academic research laboratories offer a venue to practice personal safety, as well as some of the basics of process safety on a smaller scale.

So, the question to be asked is how do we better train these future engineers to be technically competent and to work safely in industry. This training will involve a multi-faceted approach to be successful.

Universities have been moving toward a self-audit process to help recognize safety problems early and to assess the safety culture. Self-audits involve a compliance checklist designed to monitor laboratory practice in line with the significant components of one's chemical hygiene plan. These audits are useful in determining gaps in knowledge, the need for resources, and the ability to address problems at the beginning before becoming established laboratory practice. An increasing trend in software management systems, such as *Bioraft*, is the incorporation of self-audits into their features as well as other assessment tools in collaboration with educational entities (University of California Center for Laboratory Safety 2012). Self-audits can be one of several feedback mechanisms for continuous safety improvements with proper follow-up (APLU Council on Research Task Force on Laboratory Safety 2016; Pluta 2012).

A cooperative audit within the chemical engineering department was created to look where resources could be shared in cooperation with the University's Environmental Health and Safety Office. One of the benefits of this type of self-audit was consistency and proactive communication throughout the program. A feedback survey studied student attitude changes resulting from personal involvement in the audit process. Participation was voluntary but, due to departmental expectations, the group inspected 100% of the chemical engineering research laboratory spaces.

This type of safety audit required cooperation on multiple levels. One of the key ingredients to this self-audit program was buy-in from individual professors whose laboratories were to be audited and whose students were participating. To deter any faulty reasoning that could occur when acclimated to a specific lab, students were not allowed to audit laboratories in which they worked. A motivating factor and benefit to engaging in the departmental self-audit was that corrective actions could be made before outside inspection agencies arrive. More frequent monitoring prevents reoccurrence of citable issues and a documented method for continuous improvement. Another key aspect leading to the success of the audit process was the willingness of the University's Laboratory Compliance Personnel to provide training and be on-site during the audits.

In 2012, ACS published a report by the Safety Culture Task Force outlining seven elements which reinforce and promote a strong safety culture (University of California Center for Laboratory Safety 2012). A collaborative audit targets at least four of these areas and possibly more. Specifically, this audit encourages: 1) leadership and management of safety, 2) cooperative interactions at multiple levels, 3) the development of positive safety attitudes, safety awareness, and safety ethics, and 4) the promotion and encouragement of communication about safety. The paper, *Academic Leaders Create Strong Safety Cultures in Colleges and Universities* by Robert Hill and David Finster, argues that the most important element of the ACS's seven elements is leadership and should begin at the level of the president (Hill and Finster 2013). In their view, the academic department also has considerable influence in establishing what is or isn't taught about safety. A department's contribution should not be overlooked or diminished especially in an atmosphere of weak leadership on campus. A bottoms-up approach by a department, in collaboration with other partners, can successfully influence a university's safety culture (McGarry et al. 2013). A collective commitment to safety can begin at the departmental level and be reinforced by activities such as a departmental level audit.

Methodology

Objective

The objectives of the collaborative departmental self-audit were to: (1) develop and implement a platform for student involvement and interaction in safety audits, (2) determine background and motivation of students who volunteered, and (3) measure any major changes in attitudes of students participating in audits.

Collaboration and Requisite Training

The audits were developed in collaboration with a student-led organization, the Engineering Safety Club (ESaf), and the University of Arkansas Department of Environmental Health and Safety (EH&S), and specifically the Laboratory Safety Compliance Coordinator. ESaf hosted a training session and helped recruit student volunteers. Professionalism was emphasized and clear expectations were communicated during the session. The EH&S coordinator provided a one-hour training session which was required for all volunteers. The training session included slide-presentation examples matched to every item on the audit sheet. Additionally, an EH&S Laboratory Compliance Audit Definitions hand-out was given to volunteers which elaborated on specific criteria for audit items. The hand-out was used in a booklet given to the student groups for use during an audit, along with supplemental information provided by the department safety coordinator

Audit Volunteers

Volunteers were limited to students within the Department of Chemical Engineering. This student population had sufficient prior knowledge to help conduct the audits in a chemical engineering laboratory. Chemical Engineering requires students, both undergraduate and graduate, to receive OSHA Hazard Communication training as well as training related to both research and classroom labs such as gas cylinder safety and emergency procedures. More extensive safety training is required for graduate students and staff with areas of concentration in specific hazards and aiding undergraduate students in the labs. Yearly refreshers are mandatory for work in the classrooms and research labs. Students were paired into small working groups of two to three students with at least one graduate student or staff member in the group.

Chemical Engineering faculty who had assigned labs were contacted to verify participation. All of the labs within the department, even the labs away from the main campus, agreed to participate.

Audit

Two days were set aside to complete the audit for 28 lab spaces in four different buildings. Labs were assigned to groups based on volunteer availability and designed to be accomplished within 1-1.5 hours maximum. Students were given audit information booklets and audit sheets. Students were encouraged to bring phones so that pictures could be taken as the audit proceeded and then sent to a cloud-based site. Students sent photos of items that were found to be non-compliant or for which they had questions. The audit sheet and audit definitions can be found at https://enhs.uark.edu/chemical-safety.php. A sample description of supplemental information is found in Figure 1 and general audit violations are described in Table 1. Audit results were emailed to each laboratory supervisor along with photographs as described above. Corrections were asked to be made within two weeks of the audit and the departmental safety officer followed-up to ensure safety violations had been corrected.

Gas Cylinders *–Gas in a compressed gas tank of any size, including large or small lecture bottles.*

- Compressed gas sticker on door or flammable gas sticker if flammable gases in lab
- Gas alarms present if in a confined space, large amounts of gas cylinders (>4), toxic, or flammable gases present
- Oxidizing gases must have barrier or separated by 20ft

Nano lab *– A lab where nanomaterials are stored, nanoparticles used or synthesized.*

- Must have Nano label on door
- Refrigerators/freezers need Nano label if storing nanomaterials
- Separate Nano waste container available

Laser lab *– A lab where an "open" laser or instrument with lasers is used.*

- Entrance areas and doors have signage stating a laser may be in use as well as class of laser
- There is an indicator that the laser is in use outside of room for class 4 lasers
- Laser is secured to table and not at "eye" level
- For class 3b and 4 lasers, the laser beam is enclosed or has barriers in place

Bio labs- *A lab where biological material is worked with or stored. Biological material can be tissue samples, cell cultures, waste effluent, or animals.*

- Must have Bio label on door
- Refrigerators/freezers need Bio label if storing biomaterials
- Bio waste container need to have lid and be sealable
- Bleach must be available for decontamination and sterilization
- If Biological cabinets are present they must have inspection sticker within 1 year

Figure 1. Example of Additional Criteria Added to Audit Sheets

Table 1. Audit Results

Audit items (grouped)	**Number of labs that had at least one issue**
Emergency equipment/Inspection stickers	2
PPE	1
Hazardous waste accumulation	3
Laser	3
Labeling & signs	5
Electrical	1
SDS folder	2
Sharps	2
Gas cylinders	1
Chemical storage	4
Organization/Cleanliness/Trip hazards	5
Specific process related	3

Students entered the laboratories only in the presence of a lab representative, prearranged with the faculty member ahead of time. The EH&S Laboratory Safety Compliance Coordinator and the Chemical Engineering Safety Coordinator were available on-site during the audits for questions and clarifications.

Feedback Survey

Participating students were surveyed after the audits to assess whether participating in the audit has a positive effect on attitudes towards safety. Participation in the survey was voluntary. The survey was comprised of 30 questions outlining four key segments: 1) general background information, 2) knowledge and attitudes, and 3) assessment of audit instruction. These questions were based on findings presented in several published studies (Van Noorden 2013; Staehle et al. 2016; Schröder 2015), and are shown in Figures 2-4. Questions were multiple choice with answers such as “yes or no”, “strongly agree, agree, neutral, disagree, or strongly disagree” or choosing a number to indicate the most important answer. Students completed the survey immediately after audit training but before completing the audits. The same survey was given to students immediately following their participation in the audits.

Working Hypothesis

The working hypothesis for the safety audits was that the students’ knowledge of safety would increase and what the students recognized as a most important safety problem or question would change following the audits.

Results

The feedback survey was included in the materials presented to the students with the audit booklet and returned at the completion of the audits. Surprisingly, all students voluntarily completed the feedback survey. Twenty-five students who attended instruction participated in the audits. Backgrounds from the participants are shown in Figure 2.

A slight majority of the students were undergraduates (14) versus graduate students (10). One staff member participated that had recently graduated from the Chemical Engineering Department. Most (72%) had not engaged in any type of safety audit prior to this audit. This group of volunteers was a well-experienced group with 64% of them having at least three years of lab experience. All had lab experience due to chemistry class labs and, additionally, 68% had taken a Junior or Senior engineering lab and 52% had experience in research. To delineate between safety compliance knowledge versus safety application, students were asked if they had done risk assessments. Safety compliance focuses on meeting standards, similar to an audit, but risk assessment is a more involved task. Risk assessment involves the ability to identify hazards, evaluate them, and estimate risk. Sixty-four percent had completed some type of risk assessment before starting their work, which might correspond to the same percentage of students with three or more years of lab experience. Such a high-risk assessment practice rate is not the norm for a student population, which is probably skewed due to our more experienced volunteers in this audit (Mcewen et al. 2018).

Additional questions, not described in Figure 2, were asked such as if the students had ever been involved in an accident or incident. Several studies have shown people to become more motivated to engage in safety-related activities after an incident or accident (Alaimo et al. 2010; Curnow and Wilk 2012; Hoff 2003). Only one participant had been involved in a small unpreventable accident, with no injuries resulting. For this group, student motivation seemed to be more knowledge-based. Students seeking knowledge was a key reason for participating, as is shown in Figure 3. When students were asked to pick from an array of motivating factors, 73% were participating to gain knowledge.

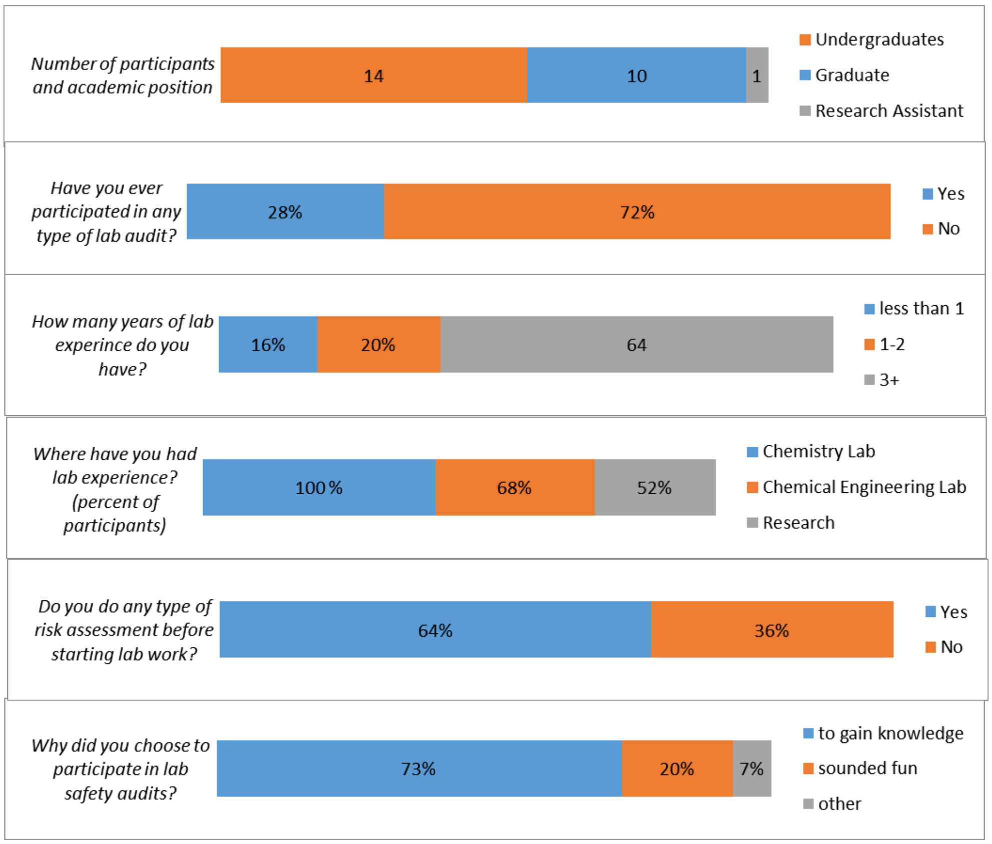
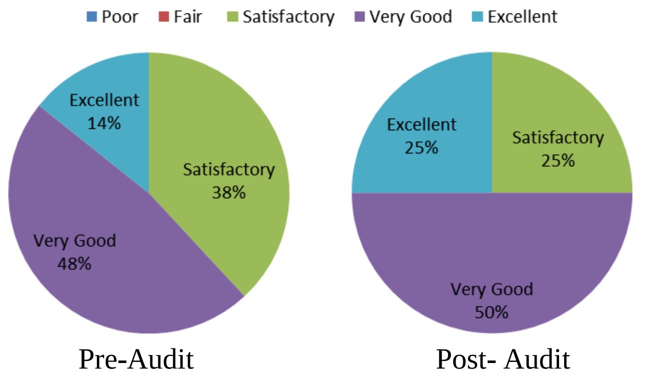


Figure 2. Backgrounds of Volunteers

The next set of questions was designed to gauge the effectiveness of the required laboratory audit training and assess student self-confidence (Figure 3). This group of student volunteers tended to be not only experienced (52% had 3+ years of lab) but also very confident. All students thought their knowledge level was at least satisfactory before the audit. Following the audit, an increase of 11% was seen in students who assessed themselves as having excellent knowledge. Overall, participating in the audits led to either no change in self-assessment or an increase, demonstrating a positive effect from participation. The same positive correlation was observed when looking at preparedness levels. Post-audit, 53% rated themselves as strongly prepared for the audits which shows a large increase in confidence, +26%. Surprisingly, 12% or three of the students did not feel they were prepared to participate post-audits, indicating prior over-confidence. However, learning still occurred as the students did become more self-aware.

Indicate what level of skill and knowledge you have of lab safety.



"You feel prepared to do a lab safety audit."

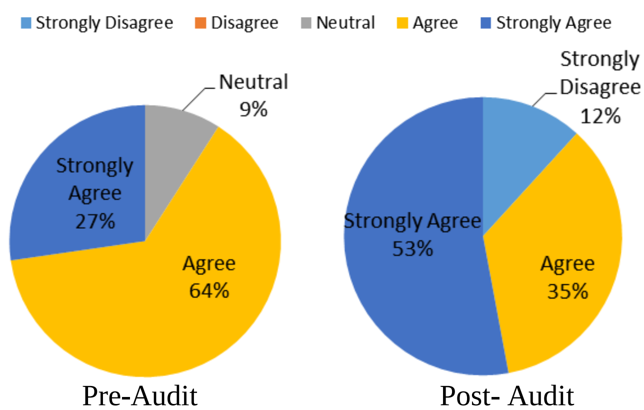


Figure 3. Self Assessment of Knowledge

The perceived state of the safety culture is an important aspect of any safety activity as negative experiences can detract from future participation in related safety activities. A summary of attitude and perspective changes is shown in Figure 4. No differences (pre-audit to post-audit) were observed in the level of agreement on several statements such as "lab managers take sufficient safety measures," "labs are a safe place to work," and "safety can be improved." There was a general increased agreement with "use of PPE is prevalent" and "labs are regularly checked for compliance," post-audit (data not shown). It is unclear whether this increase is due to increased awareness of the activities post-survey or that the realization of the impending audits changed behavior in the audited labs. However, when comparing what students felt was the most significant barrier to improving safety, interesting shifts were seen. Pre-audit, 48% said that the attitudes or apathy of individuals were the biggest hindrances. Post-audit answers indicated that several other factors might come into play such as lack of understanding of safety requirements (36%, an increase of 20%), and focus on compliance requirements over safety (16%, an increase of 16%).

What do you feel is the most significant barrier to improving safety?

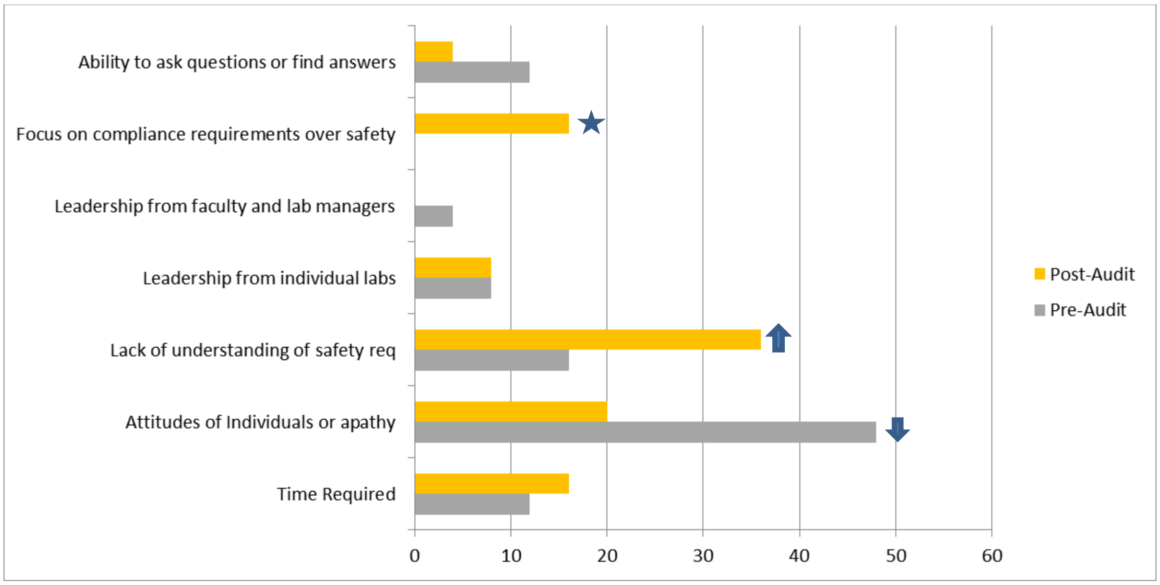


Figure 4. Attitude and Perspective Changes

Discussion

Students cannot be expected to be perfect in their laboratories, but it is our responsibility to ensure that a safe environment is maintained in which potential issues can be mitigated or reduced to small enough levels where injuries are nonexistent or unlikely. One of the mechanisms available that has been shown to increase safety is the laboratory safety audit. Safety audits provide a quick checklist of fundamental communication requirements, organizational expectations, and emergency preparedness. Conducting a rigorous departmental self-audit that simulates an actual audit supports a safety culture by allowing people outside a lab but with similar backgrounds to do the audits.

Graduate students play an important role in establishing positive perceptions of laboratory safety. They interact with undergraduates in an academic setting on a daily basis in the labs, as teaching assistants, and set precedents (ACS Committee on Chemical Safety (CCS) Task Force for Safety Education Guidelines 2016). Lack of confidence, chemical knowledge, and clarity from faculty regarding their roles, duties and expectations are some of the factors that limit graduate students from engaging undergraduate students in conceptual discussions. To help overcome this hurdle, the audit groups were set-up with a peer mentor aspect. Each undergraduate was paired with at least one graduate student where peer to peer learning could take place during the audit. Additionally, students could learn together through inquiry. Safety professionals from the department and university were available on-site during the audit. Many science academics regard involvement of hands-on, laboratory-based activities as essential elements of an undergraduate degree in science (Hill and Nelson 2005; National Research Council 2014). Lab audits have the potential to become part of this process as a mechanism to increase general awareness as well as expectations

Preparing students for the audit before-hand not only allowed them to become confident but also allowed them to self-direct the lab audits without direct oversight allowing psychological empowerment concerning safety-related issues. Safety professionals were present in the buildings and were available for questions to facilitate learning, but not directing the audits. The feedback survey indicated students gained an enhanced sense of confidence and self-assurance in their skills by participation. A change in perception of what might be hindering the Department of Chemical Engineering culture was the most interesting outcome. Students thought that attitude was the biggest hurdle before the audits, but felt that a lack of knowledge and focusing on compliance were a bigger portion of the issues after doing the audits and interacting with lab personnel. Being able to recognize hazards rather than just relying on SDS sheets is an essential part of the audit process and is probably more difficult for undergraduates. It is unclear what evolved from the student-to-student discussions within the laboratories. However, several complex hazards were noted during the audits that required follow-up and consultation with the department Safety Coordinator.

Conclusions

The intent is to repeat and improve this departmental self-audit process. Including surveys is an important component in order to create a mechanism of feedback for future improvement. After all, if the audit does not provide a beneficial experience for everyone, we are missing the point of education. Some of the limitations of this study were that the volunteers were from a single department, there was a low number of participants (25), and there was no control group of students who chose not to participate. However, insight was still gained from this small internal study. Future improvements may include more prior training on safety methodology such as hierarchical controls, rather than specific aspects of compliance.

A safety culture is a collective responsibility, especially in an educational university setting, with multiple groups sharing and contributing to the culture. This departmental self-audit included the support of the Chemical Engineering faculty, the involvement of the University's EH&S Department, the departmental Safety Coordinator, designated staff present in each laboratory, a student-led organization (ESaf) and student volunteers, and support from administrators including the Chemical Engineering Department Head and the Head of EH&S. Overall, the outcome was that an internal review was positive from each of the levels of participants. A review of the state of the laboratories was accomplished in Chemical Engineering by their own students which resulted in increased education.

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