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Commentary

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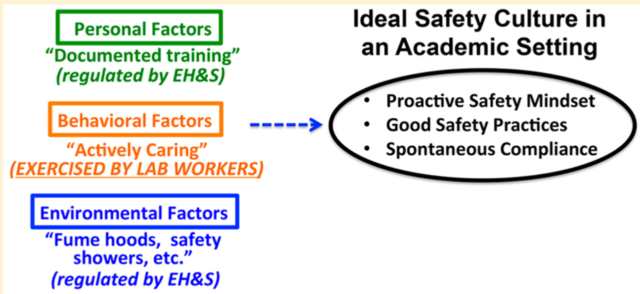
An Approach To Enhance the Safety Culture of an Academic Chemistry Research Laboratory by Addressing Behavioral Factors

Ira O. Staehle, Tim S. Chung, Antoine Stopin, Geeta S. Vadehra, Scott I. Hsieh, James H. Gibson,*[,†] and Miguel A. Garcia-Garibay*

Department of Chemistry and Biochemistry, University of California, Los Angeles, Los Angeles, California 90095, United States

Supporting Information



ABSTRACT: Safety culture is often divided into three domains, which include personal, environmental, and behavioral factors. In order to improve the behavioral components of the safety culture in the research group of the authors (the Garcia-Garibay group, or GG research group), we implemented three safety practices intended to sensitize group members on the importance of best practices that depend on simple actions taken by individual researchers. These best practices include (1) a rotating twice-daily safety inspection to enhance an appreciation for the value of safety regulations that may be considered less significant and are frequently overlooked, (2) frequent safety discussions followed by quizzes to give researchers an opportunity to assess their safety knowledge on a range of topics, and (3) the use of an overnight reaction form that is posted on lab entryways as a safety communication best practice to ensure that other researchers in the laboratory and emergency responders are aware of the potential hazards associated with ongoing chemical reactions that do not require continual monitoring. To determine the impact of these measures we analyzed the UCLA Office of Environment, Health and Safety (EH&S) laboratory safety inspection records from the GG research group and compared the findings with those of all other experimental research groups in the Department of Chemistry and Biochemistry at UCLA from the period of 2011 to 2013. We propose that in the absence of any other (either punitive or rewarding) actions, an accelerated improvement in the reduction of the number of inspection findings in the GG research group can be associated with behavioral components of a safety culture addressed by those measures.

KEYWORDS: *Graduate Education, Research, Safety, Hazards, Organic Chemistry, Laboratory Management*

INTRODUCTION

In response to the call from the Chancellor of the University of California Los Angeles for the campus to be the "Best in Class" in academic laboratory safety,[1] it will be essential not only to implement and meet all the top-down safety regulations required by regulatory agencies, as they can be considered the minimum requirements,[2] but it will also be important that every researcher in an academic setting takes ownership of measures that will help make their working environment safer. This will require the development of a safety culture based on a state of mind where every researcher feels responsible for everyone's safety and does something about it on a daily basis.[3−7] While several models exist to address a safety culture,[8−13] Geller suggests that a safety culture is composed of three domains, a triad that includes environmental factors, personal factors, and behavioral factors (Figure 1), and his model focuses on changing the behavior and the mindset of the individual.[14] Within the context of Geller's triad, individual research groups should be able to generate the desired safety culture by implementation of a few additional practices that are not required by the safety structure of the organization. In particular, we describe the initial results of an approach that helps by addressing the behavioral component.

In an academic setting, environmental factors are closely regulated by EH&S. Environmental factors include operations involving fume hoods, safety showers, eyewashes, and standard operating procedures (SOPs), to name a few. Personal factors are learned and practiced via formal documented training in safety areas provided by the UCLA Office of Environment, Health and Safety (EH&S), which includes laboratory fundamentals, fire extinguisher training, hazardous waste training, etc. In addition to formal classroom and online training offered by EH&S, laboratory specific training is also provided by the Principal Investigator and other senior researchers. All research groups are encouraged to openly discuss and document safety issues and concerns pertaining to their research activities during scheduled group meetings, which act as an open forum for safety communication. Behavioral factors are the most difficult to address and are essential for a safety culture. Geller explained that behavior is composed of complying, coaching, recognizing, communicating, demonstrating, and "actively caring".[15] However, getting a laboratory worker to actively care about safety without it being for the sake of compliance can be difficult. It has been suggested that a

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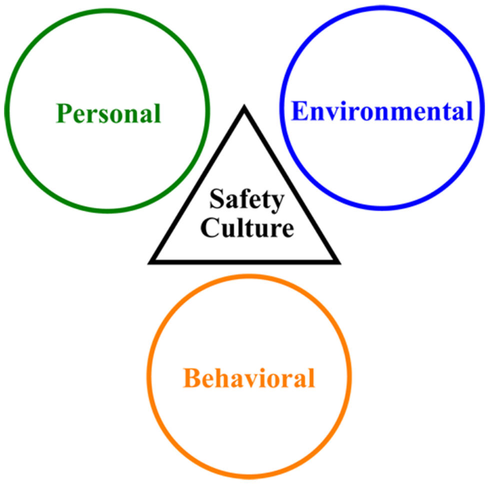

Figure 1. Geller's Safety Culture Model illustrated with the three domains including personal factors, environmental factors, and behavioral factors.

positive safety culture can be more effectively generated by engaging workers in creating, applying, and evaluating a peer-to-peer, behavior-based coaching process.[4,16] This pursuit of striving for a stronger safety culture in an academic setting has recently been undertaken by student researchers at the University of Minnesota in conjunction with the Dow Company.[17] A desirable safety culture entails an attitude where even small details are given significant attention and is manifested in workers that routinely take actions that others may consider burdensome or unnecessary. Generally based on a combination of limited knowledge and what may be considered a negative attitude, someone with a poor safety culture may absent mindedly leave a chair by a fire exit, block a safety shower, place a heavy item on a high shelf, leave a power strip on the floor, carry shiny objects in the laser lab, or fail to deface the label of dangerous waste bottle that was originally intended for a harmless chemical. It is important to recognize that doing the "right thing" in these examples does not require special training, and that doing the "wrong thing" puts everyone in the work environment under unacceptable and unnecessary risk. It is reasonable to assume that a poor safety culture is based on prior practice where the magnitudes of the risks involved, and the simple ways to avoid them, are not recognized and appreciated. With that in mind, we suggest that the best way to improve a safety culture is by learning how to recognize those risks and increase the level of awareness to the level of a knowledgeable safety inspector. To attain active caring and engagement, researchers must be invested in the practice of maintaining a safe environment, and there must be a tangible measure of progress. We suggest that a measure of improvement in the safety culture of a research group can be established by measuring the number of findings during safety inspections in comparison to those of other research groups.[18,19] To attain a safety mindset that aims at a positive safety culture without punitive actions or rewards, the GG research group implemented three new practices intended (1) to engage every researcher in an understanding of safety from the point of view of someone who has excellent safety awareness, such as a well-trained laboratory safety inspector, (2) to provide frequent feedback on the level of knowledge expected within the framework of the institutional safety governing principles, and (3) to create an environment where safety and communication is integrated in preventive actions. Importantly, while all the GG group members participated in this exercise, none were aware that the results would be summarized in this article, such that changes in behavior, if any, would not be compromised by their awareness that the end results would be shared with the academic and chemical safety communities.

CREATING AN UNDERSTANDING OF SAFETY AND SAFETY COMPLIANCE

In a transition period, while a positive safety culture is being enhanced to the level of self-perpetuation, the main challenge in an academic laboratory setting is to persuade researchers to adopt good practices that may be perceived as not having sufficiently high value. Academic research laboratories are occupied by creative individuals with a high degree of curiosity (PIs, postdoctoral fellows, and senior graduate students) who have learned how to solve challenging problems with a wide range of techniques and methods. In the recent past, ad hoc and informal safety practices have been helpful, but not ideal. Safety measures left to the discretion of individuals often display a higher level of risk and may not be integrated with all the factors that affect the workplace operations, including all of the documented outcomes considered by governing bodies. Thus, in order to develop a strong safety culture all workers need to understand why safety rules are valuable. Researchers also need to develop an appreciation and understanding of the knowledge and expertise of the group safety officer and/or the EH&S safety inspector, whose presence is sometimes perceived as a nuisance rather than as a resource. To accomplish that, we decided to experiment with a protocol where the role of the inspecting safety officer would be rotated among all researchers in the laboratory. The specific setting is an organic chemistry laboratory with personnel ranging from ca. 12 to 18 co-workers occupying three wet chemistry laboratories and two instrument rooms with lasers, cryogenic fluids, pressurized gas tanks, and a very high-pressure, high-temperature vessel. There is a head safety officer for the group, and there is one safety officer responsible for each of the three wet chemistry laboratories. A checklist of commonly cited safety issues (Appendix A) was generated specifically for the GG group. Each researcher was assigned to walk through all the laboratories twice a day for one full week, doing an inspection and notifying each researcher of potential safety issues or concerns, which would be fixed on the spot. This approach was meant to improve overall safety and was expected to reduce the number of formal findings from EH&S inspections, to the point that safety findings should eventually disappear. By the time the data was analyzed, the GG research group had been utilizing the twice-daily safety inspection for almost two years, with checklists documented and archived. As noted below, the data suggests a good level of success in developing an enhanced safety culture. The twice-daily inspection form was modified once in order to address key findings (Appendix B) and includes critical as well noncritical items. The first two points of the checklist highlight proper personal protective equipment (PPE) usage. Points 3 and 5 both focus on overall laboratory cleanliness. Point 4 focuses on chemical communication. Points 6, 11, and 13 correspond to proper waste labeling and disposal. Chemical segregation is highlighted in points 7, 8, 10, and 12. Point 9 is a specific focus dealing with labeling peroxide formers, which was added to the checklist as a revision. The rotating twice-daily safety inspection allows all researchers to get experience with what to look for

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during a safety inspection, gain an appreciation and understanding for what the safety officer recognizes as important, and proactively prevent the actions or lack thereof that may lead to critical as well as noncritical citations.

OPPORTUNITIES FOR THE ASSESSMENT OF SAFETY KNOWLEDGE

During weekly meetings, group members often discuss current topics in safety, and sometimes give "pop quizzes" regarding safety matters (Appendix A).[20] These safety quizzes mainly cover the basic principles governing safety at UCLA, which include the Injury Illness Prevention Program (IIPP), Chemical Hygiene Plan (CHP), and the Laboratory Hazard Assessment Tool (LHAT). It is crucial that all group members who perform experimental chemistry be educated on all EH&S guidelines for safety and lab specific training. By having safety quizzes during weekly laboratory meetings, we encourage researchers to acquire the knowledge and be well informed on current safety guidelines. A global knowledge in safety beyond a researcher's specific attention (reagents, reactions, SOPs, etc.) is imperative for cultivating a safe work environment.[21]

DEVELOPMENT OF A COMMUNICATION TOOL TO ASSIST EMERGENCY RESPONDERS

An important aspect for developing a good safety culture is to be proactive with measures that inform anyone who may be affected by one's actions, including laboratory members, researchers in other groups, and emergency responders. To develop this aspect of the group's safety culture we instituted an overnight reaction form (Appendix C), intended to inform other researchers or emergency responders about overnight reactions and their associated hazardous conditions, in the event of an accident or emergency during after hours. The form is posted at the entranceway to the laboratory and is filled out by the researcher as he or she leaves the laboratory. The plastic-laminated forms can be used multiple times with washable markers and incorporate the fire diamond,[22] which is filled out by the researcher after assessing the hazards of the reagents and potential reaction. The form is posted at the entrance of the wet chemistry lab and indicates the location of the fume hood, the reaction, and any associated hazards.

DEPARTMENTAL DATA

To evaluate the combined effectiveness of the practices mentioned above, we analyzed inspection data collected by EH&S in the Department of Chemistry and Biochemistry at UCLA during the period of 2011 to 2013. It should be noted that EH&S inspectors and other personnel were not informed that the long-term experiment was in progress until June 2014 when they offered to help with departmental data and its analysis. We note that there was a turnover in EH&S personnel for the Chemistry and Biochemistry Department during this time period, however the EH&S inspector follows an inspection checklist provided by EH&S to adhere to an objective safety inspection. While data for the GG group is available for an early 2014 inspection and can be used to analyze a three-year trend, data for the entire department for the same time period is not completed. As described in detail in ref 2, EH&S inspections include an extensive checklist with 60 items covering all the CalOSHA and internally regulated safety aspects. Each item is qualified as compliant, noncompliant, or nonapplicable, and some are qualified as serious findings that require a solution within 48 h. For our data analysis, we grouped both the serious and nonserious findings for consistency, as most inspections lead to both types of findings. All research groups are inspected at least twice a year, and a few have additional inspections. Inspection categories include documentation and training, hazard communication, emergency and safety information, fire safety, general safety, PPE, housekeeping, chemical storage and compatibility, fume hoods, biosafety cabinets, chemical waste disposal and transport, seismic safety, and mechanical and electrical safety. Appendix D categorizes different inspection findings as behavioral, environmental, and personal. Data analysis was centered on experimental research groups in various areas of Chemistry and Biochemistry leaving out theoretical and computational research groups as well as instructional laboratories and core facilities. It should be pointed out that inspection-finding data analyzed is not homogeneous because the number of laboratories, the number of researchers and their expertise, the range of activities, and the types and levels of risk vary widely from group to group. While these variations contribute to the limited statistical significance, the trends are clear and worth sharing.

COMPARISON TO DEPARTMENTAL AVERAGE

The effectiveness of the three measures adopted in the study are exhibited when comparing the GG group inspection records with respect to the average number of inspection findings for the Department of Chemistry and Biochemistry at UCLA (Figure 2). This average is calculated from 30 different active

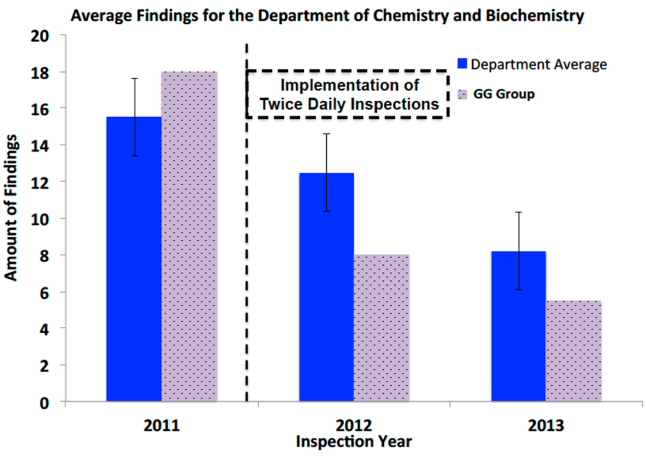

Figure 2. Total number of findings from the GG group compared to the average number of inspection findings per research group in the Department of Chemistry and Biochemistry. (Two inspections were done in 2013 and the average was taken for the GG group.)

research groups with data collected by EH&S between 2011 and 2013. In 2011, the GG group had a total of 18 findings while the department showed an average number of inspection findings of 15.2 per research group. When the twice-daily inspections were implemented in early 2012, the number of inspection findings in the GG group decreased to 8 while the departmental average decreased to 13.1. This number decreased further in 2013 when the GG group showed an average of 5.5 inspection findings per inspection and the department had an average of 7.8 findings per research group (in 2013 there were two inspections documented for every group).

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It is clear from Figure 2 that increased awareness and institutional support had a very significant impact on the overall safety performance of the Department of Chemistry and Biochemistry at UCLA,[2] as revealed by the sustained and systematic decrease in the average number of inspection findings from 2011 to 2013 (Figure 2). Notably, the decrease in the number of inspection findings in the GG group is greater than that in the department, and beyond one standard deviation indicated by the bars. Another perspective of this change can be appreciated by analysis of Figure 3, which summarizes the range of inspection findings from 2011 to 2013, with each line representing the findings history of a different research group and the red bars indicating the range in the number of inspection findings for each year.

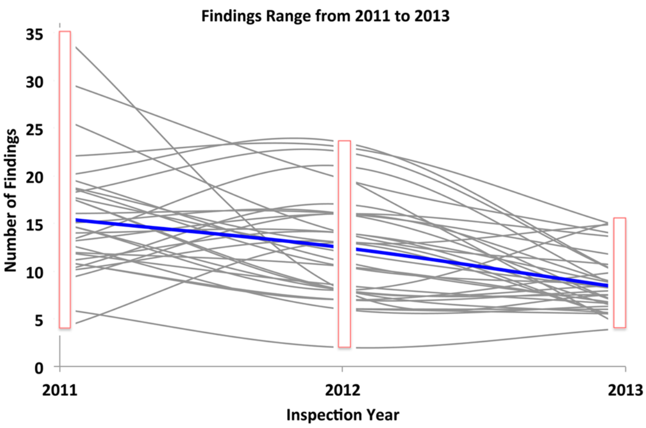

Figure 3. Illustration of finding ranges from 2011 to 2013 by red bars. Average number of inspection findings shown by blue line.

Starting with a difference of 31 inspection findings between the research groups with the largest and smallest number of inspection findings in 2011, one may infer a rather large range of safety practices among different research groups. The 2012 data corresponds to a range of 21.5, which is a 30% decrease in the inspection-finding range. The range becomes more localized in the 2013 data with a range of 11.5 that corresponds to an overall decrease of 63% with respect to the one revealed by the 2011 data. This corresponds to the Department of Chemistry and Biochemistry at UCLA improving as a collective unit. The solid blue line represents the average number of inspection findings for all experimental research groups in the Department of Chemistry and Biochemistry at UCLA, which also shows a decrease in the number of safety findings from 2011 to 2013. A general measure of safety progress in the department can also be appreciated by analyzing the percent decrease in the number of inspection findings within the three-year period for all research groups considered in the data set. As shown in Figure 4, 22 out of the 30 research groups fall within a range of 20−60% decrease in the total number of inspection findings, and there were only three groups who had an increase in the number of inspection findings between 2011 and 2013 as shown in the <0% bar in Figure 4.

Considering that most of the environmental and personal issues of the safety triad (Figure 1) are dealt with by EH&S and campus-wide regulations, it seems clear that addressing the more challenging behavioral aspects should be the most effective way to improve the safety culture within an academic research setting. Figure 5 breaks down the inspection-finding categories from 2011 to 2013 as behavioral (orange),

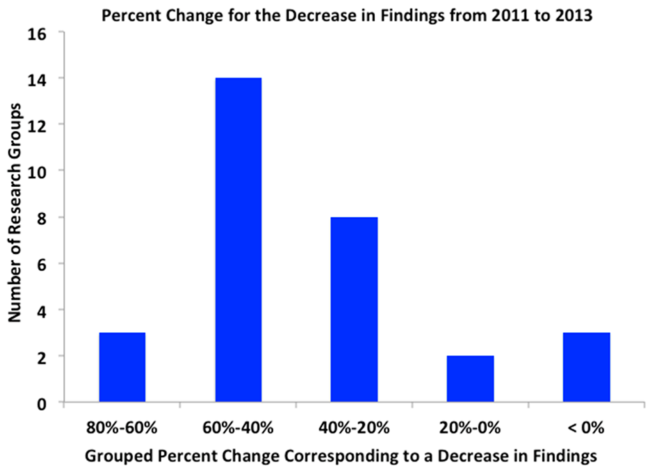

Figure 4. Percent change corresponding to a decrease in the number of inspection findings from 2011 to 2013 among active research groups in the Department of Chemistry and Biochemistry.

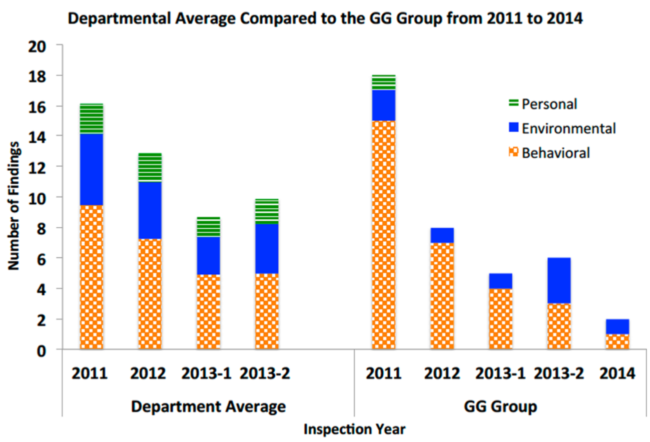

Figure 5. Breakdown of the inspection findings as behavioral, environmental, and personal from the GG group and the average for the department from 2011 to 2013. (2014 was unavailable for the department at the time of manuscript preparation; however, it illustrates that this trend continues).

environmental (blue), or personal (green) within each bar, in a manner that makes it possible to compare changes in the departmental average, illustrated by the bars on the left, with those occurring in the GG research group, which are grouped on the right. For the year 2013, inspection-finding data was available for two inspections for all research groups, and the data has been analyzed accordingly as 2013-1 and 2013-2. It should be pointed out that behavioral aspects listed in Appendix D are reflected in a number of inspection findings that can be easily prevented with simple actions that require awareness and proactive attitudes. Those behavioral aspects can be characterized as depending on personal choices of doing the right thing, or not, during the executions of one's routine work. Ideally, these behavioral aspects should become as second nature as putting on a seat belt when one gets into a car.

As shown in Figures 2 and 5, the GG group had more total inspection findings than the department-wide average in 2011. Figure 5 specifically discloses that the number of behavioral-related findings for the GG group was 15 compared to 9.5 for the departmental average. The three measures described and analyzed in this article were implemented in the second half of 2011, at a time that is indicated by the vertical dotted line. The

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effect of these measures was immediately apparent. As the total number of inspection findings for the GG group decreased in 2012, the number of findings related to behavioral issues displayed the most significant reduction, by more than a factor of 2 compared to the corresponding 2011 data. It is reasonable to attribute this decline primarily to the implementation of the twice-daily safety inspections, which helps every group member keep a number of seemingly simple regulations in mind. It is also worth noting that the GG lab has not had a personal-related inspection finding since 2011, reflecting the fact that the head safety coordinator has taken responsibility for making sure that all co-workers maintain their training as up to date, and that every researcher is willing to comply. A consistent decrease in environmentally related findings continued through the two inspections in 2013, going from 4 to 3, and the most recent EH&S safety inspection in early May 2014 has only 2 inspection findings, with only one of them being environmental. We interpret this to an exceptional advance in the safety culture of the GG group from 2011 to 2014, with an overall decrease in the number of inspection findings of 89%.

A similar analysis of the changes in behavioral, environmental, and personal issues for all research groups in the department, on the left half of Figure 5, indicates that behavioral issues decreased from 2011 to 2013 while environmental and personal issues showed comparable numbers. A decline in the number of inspection findings related to behavioral issues correlates very well with the number of safety findings in the Department of Chemistry and Biochemistry consistently decreasing. One can see from Figure 5 that the departmental average for behavior-related findings decreased in a linear fashion from 2011 to 2013, but seems to have leveled off during the 2013-1 to 2013-2 inspection data. This can be compared with the GG group data, which appears to follow an exponential decay function for changes in behavioral components from 2011 to 2013-2. Examples of some common behavioral components include waste tag not affixed, no secondary containment of waste, improper chemical segregation, and improper chemical labeling. The intent of the twice-daily checklist has been to address the behavioral issues present in the GG laboratory, and the data in Figure 5 supports the strategy's success. Since the implementation of the twice-daily inspection, trends in the GG group are consistent with improvements in safety culture and a better understanding of safety by all researchers.

■ CONCLUSIONS

Striving to be "Best in Class" in laboratory safety, and based on the interpretation of the safety culture triad proposed by Geller, based on the roles of environmental, personal and behavioral components, the GG research group implemented three simple safety practices intended to address behavioral aspects. These include (1) the implementation of twice-daily safety inspections that rotate weekly among all group members and are intended to sensitize all researchers on the importance of best practices that are generally simple to execute but that many researchers may overlook during day to day research, (2) frequent safety quizzes to give researchers an opportunity to recognize the level of safety knowledge expected within the institution, and (3) the use of an overnight reaction form that helps create a proactive mindset and potential communication with other workers and first responders. To determine the effects of these measures we analyzed inspection-finding data from periodic inspections carried out by EH&S over a three year period that covers the time frame before and after the adoption of these measures. While there is limited statistical significance, a systematic and sustained reduction in the number of inspection findings for the GG research group as compared to the departmental average suggests that these adopted measures have had a substantial impact. Furthermore, a detailed analysis of the nature of the inspection findings shows that the greatest progress, both in the department and in the GG research group, is related to behavioral aspects, suggesting that institutional support for environmental and personal aspects has been very effective. However, a greater rate of improvement in the GG group suggests that the implementation of strategies that address behavioral factors, which involves the participation of all group members, has a very positive impact. Ultimately, an ideal behavioral component would lead to a safety culture where proactive and immediate action of every aspect of safety that requires attention becomes second nature to every researcher in the academic laboratory. Under these conditions, compliance becomes spontaneous, as it becomes a byproduct of a good safety culture.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00299.

Safety inspection checklist,overnight reaction form, and categorized safety citations (PDF)

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: j.gibson@usc.edu.
*E-mail: mgg@chem.ucla.edu.

Present Address

[†]Environmental Health and Safety, University of Southern California, University Park Campus Los Angeles, CA 90089-0011

Notes

The authors declare no competing financial interest.

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