JOURNAL OF CHEMICAL EDUCATION

Commentary

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Undergraduates Need a Safety Education!

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ABSTRACT: Safety education is absent in the chemistry curriculum. This commentary discusses the consequences of the missing safety education for graduates and institutions that hire them. It suggests and discusses the application of the theory of Normalization of Deviance to explain why safety education is missing. It suggests ways to fix the shortcoming by involving not only chemistry but other departments and top administrators. It suggests ways to incorporate safety education, the "why" of safety, into the curriculum.

KEYWORDS: *Safety/Hazards, Laboratory Instruction, First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, High School/Introductory Chemistry, Curriculum*

Undergraduate faculty have made substantial efforts to reduce risks in teaching laboratories, often using less hazardous chemicals and procedures, and experimentation is often very controlled, with the exception of undergraduate research. While these efforts have made teaching laboratories much safer, graduates are likely to encounter much less controlled, riskier laboratory operations in their new endeavors without the benefit of a safety education. Safety education is absent in undergraduate chemistry curriculum in most colleges and universities. This commentary discusses the consequences, suggests reasons for this shortcoming, and suggests ways to get safety education into curriculum.

CONSEQUENCES OF MISSING SAFETY EDUCATION

The consequences of this missing element in the chemical education process are far-distanced, unfelt directly (if at all) by the undergraduate academic community, but the impact is significant to past graduates and institutions that hire them. New graduates do not have adequate safety knowledge and safety ethics (the dual products of safety education), but they do not know that they do not know about safety until they are faced with the safety responsibilities of their new endeavors that require them to understand and employ safety knowledge and have strong safety ethics. Evidence of inadequate safety knowledge is found in numerous incidents occurring in laboratories: estimated at 2.5 laboratory incidents weekly in academic settings[1] (media-reported incidents only, so actual rates are much higher). The Centers for Disease Control and Prevention (CDC) reported that the Educational Services (ES) industry ranked second out of the top industries with injuries from chemical events; two-thirds of reported injuries in ES were among students.[2] These high rates reflect an unmet need for safety education.

There are consequences for middle and high school chemistry/science teachers who become responsible and accountable for safe conduct of chemistry/science—yet without safety educations, they are not adequately prepared. Ask high school science teachers what they need and you are likely to hear "more knowledge of safety". Clearest examples of inadequate safety education are found in the repeated incidents within secondary chemistry classes involving demonstrations with methanol that have seriously burned numerous students and teachers.[3−7] Each incident demonstrated a basic lack of understanding of flammable properties.[8] It is easy to decide these incidents were results only of personal poor decision-making, but repetition of the same error points to another conclusion. These incidents are symptoms of an underlying cause, the lack of safety education (inadequate safety knowledge and weak safety ethics).

Consequences of the lack of safety education accrue to graduate students who conduct research to earn advanced degrees. Their research often involves managing new reactions and highly reactive chemicals without adequate safety education, and graduates are under pressure to perform this research as a requirement to achieve their advanced degrees.[9] Evidence for effects of a missing safety education is found in the many incidents in academic research laboratories. The U.S. Chemical Safety and Hazard Investigation Board (CSB) was concerned about laboratory safety in academic institutions before it investigated the explosion at Texas Tech University.[10] CSB found researchers were not adequately prepared to address the safety aspects of research, and their findings apply to academia as a whole. The death of a UCLA laboratory researcher brought the face of recurring serious laboratory incidents to the public's attention—and there are valuable lessons about the importance of safety education learned in this event and its aftermath.[11] The American Chemical Society (ACS) responded with a report providing recommendations to strengthen safety cultures of academic institutions, including providing safety educations to undergraduates.[12]

Consequences of the lack of safety education accrue to graduates who go into laboratory work for industry or government only to be astounded that there is so much emphasis on safety—and yet these graduates have inadequate knowledge of safety and weak or missing safety ethics. A distinguished professor from a large university perhaps expressed this best: "It has been said that the greatest hazard

Received: October 12, 2015
Revised: July 6, 2016

DOI: 10.1021/acs.jchemed.5b00825
J. Chem. Educ. XXXX, XXX, XXX−XXX

in an industrial laboratory is a fresh chemistry Ph.D. graduate."[13] Industry is a strong supporter of safety,[14] has long complained of inadequate safety education,[15,16] and has even devoted its own resources to help universities improve on academic efforts in laboratory safety.[17,18] Students with strong safety education and safety ethics would likely be viewed as stronger candidates for jobs in industry and government.

Because most undergraduates do not know where they will end up in the future, it is important that safety education explain in the broadest sense the kinds of chemical and laboratory hazards they might encounter.[19,20] This education should be principle-based safety—RAMP: **R**ecognize hazards; **A**ssess the risks of hazards; **M**inimize the risks of hazards; **P**repare for emergencies.[19] Safety education should emphasize understanding hazards in terms of chemical and scientific principles, including, for example: formulas; reaction equations and profiles; thermodynamics; structure−activity relationships; assessment of risks of hazards; safe practices to minimize risks of hazards; and preparations for responding to emergencies. This safety education should answer the "*why*" behind safety—Why is this flammable?—because it is the *why* that creates the value and understanding of safety needed by graduates in new endeavors.

■ WHY IS SAFETY EDUCATION MISSING?

I have long pondered why safety education is missing from the curriculum. After talking with many faculty, I talked with one faculty member who remarked, "If I knew what to teach, I would." So I coauthored a textbook on lab safety, thinking this could help if educators knew what students needed to know.[19] But in time I began to suspect that something else was going on. I believe that the lack of interest in safety education has its roots in a decision concerning safety made many decades ago within the academic community itself and its culture. Perhaps these roots lie in past risk taking to achieve important research goals, or not educating generations of chemists in safety, which resulted in less caring attitudes and prioritization for safety—we are not likely to determine these reasonings.

Perhaps a better understanding can be found in considering a theory proposed by Diane Vaughn: the Normalization of Deviance (NOD).[21] Vaughn derived this theory after extensive study to explain the *Challenger* NASA disaster (and later the *Columbia* disaster), because she did not accept the reasoning of reports that placed the blame on intentional management decisions that put program and costs over safety. Rather, NOD explains that decisions were driven by an organizational culture that accepts greater and greater risks as normal. Others used this theory to explaining serious incidents from organizational cultures.[22] Still others have recognized that personal behaviors result from learning to be at risk.[23] Briefly, NOD means that within an organization people become so accustomed to a deviant (risky) behavior that they no longer considered it deviant within the organization (outsiders see the increased risks). Applying NOD theory to the academic community, the deviant behaviors that seem to have become accepted include the following:

- Deciding that teaching safety to students is not important
- Prioritizing safety education far below other aspects of chemistry
- Viewing safety training as an adequate substitute for safety education

These decisions have produced professional chemists uneducated in chemical and laboratory safety and without strong safety ethics. Safety is viewed as sets of rules and procedures, rather than a principle-based science that requires chemists and chemistry students to understand "why". Every educator knows that to teach and effectively understand something, you need to know "why". Today's chemistry curriculum evolved focusing on comprehensive courses explaining the "why" of inorganic, organic, physical, analytical, and biological chemistries, but without including safety education as an integral part of these. Yesterday's and today's graduates apply their chemistry knowledge in their endeavors without adequate safety knowledge and safety ethics, and the risks of adverse incidents are increased and realized in future generations—the result of NOD.

The perception of safety outside of the academic community is vastly different from within this community. Outside, safety is highly valued and an utmost priority, while to those outsiders, safety within the academic community does not seem to have the same value or priority (a result of NOD). Outside organizations, especially businesses, learned long ago that ignoring safety directly affects them by severely injuring their valued employees (or worse), by damaging reputations, by disrupting or destroying businesses, or by initiating civil suits, governmental investigations, or criminal charges. These effects are not felt directly in the undergraduate academic community even though missing safety educations were important contributing factors to safety issues in outside organizations.

■ HOW CAN WE FIX THIS?

First, understanding and being aware that past choices (NOD) have put our academic institutions in the present state is important. The academic community should acknowledge that safety education is missing because of a system that "normalizes" the omission of safety education, the low prioritization of safety, and the acceptance of safety training as a substitute for safety education. All laboratory-based sciences involve safety, so safety education should be integrated with each of these areas as part of the normal course of study. Clearly some past views of safety need to go away and be replaced with a newer vision of the importance of safety and innovative ways to include safety education in the curriculum. Today's sciences are more integrated and interdependent upon other disciplines, so all students need chemical and laboratory safety education. We need to be looking at all places where laboratory-based sciences are used: chemistry (teaching, research laboratories); biology (microbiology, molecular biology); education (teaching science); art (heavy users of chemical products); and so forth. While chemistry departments need to be leaders in developing safety education, other departments need to be part of the solution, too. This effort should include safety education in all laboratory-based sciences and must involve the highest levels of the administration.[24−26]

Principle-based safety education for undergraduates needs to start at the very beginning of chemistry, explaining the "why" of safety. Many undergraduates take chemistry for a year or two then move into their preferred areas of learning (education, biology, art, premed, etc.), so they need to begin learning the basics of chemical and lab safety before they move on. A layered approach has been developed for first-year, second-year, and advanced undergraduates with short sections that could be used in lab or classroom discussions.[19] Approaches and options for teaching safety could include the following:

DOI: 10.1021/acs.jchemed.5b00825
J. Chem. Educ. XXXX, XXX, XXX−XXX

- Prelab assignments with testing as a requirement for entry
- Incorporation of safety into each and every course with emphasis on safety related to that topic; this requires reprioritization of course content
- Teaching stand-alone courses for early students and later for advanced students (Note that early students may not know enough chemistry to learn from a course)
- Developing new approaches and texts for teaching safety that require textbook authors to include safety education in their textbooks

Testing of safety knowledge must be required. A few institutions have successfully incorporated safety education into their chemistry curriculum, including Wittenberg University (Ohio) and St. Olaf College (Minnesota). Still others have reported their unique approaches in teaching safety to undergraduates.[27−29] Perhaps other institutions are also doing this: if so, share your experience with all of us through the ACS Committee on Chemical Safety, which solicits such information.[30] Industry organizations, the American Institute of Chemical Engineers and the Center for Chemical Process Safety, established an alliance to form a program for Safety and Chemical Engineering Education that collaborates with universities to develop materials to incorporate undergraduate safety education focusing on process safety into the curriculum.[31] *ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs* recommends that the promotion of safety awareness and skills must begin with the first laboratory experience and should be incorporated into each lab experience, and that safety understanding should be assessed throughout study.[32] Finally, teaching safety to faculty and staff is just as important because most never received formal safety educations.

Incorporating safety education may require considerable effort, however this need may be assisted by recent recommendations by the influential Association of Public & Land-Grant Universities (APLU).[33] APLU seeks a proactive approach to address safety issues by getting university leadership involved in a top down approach to implementing safety cultures in academia, including safety education.

Chemists struggle to create positive values of chemistry. Providing strong safety educations for undergraduates (the public) could help people better understand about chemical risks and steps that can minimize risks through an organized application of safety knowledge. Furthermore, chemists care enough about safety to teach it in the curricula. Teaching safety at the earliest exposure to chemistry can help instill the value that chemists and other scientists place on safety and highlight balance between benefits and risks. Incorporating safety education may be a challenge, yet unlike other areas of chemistry, being uneducated in safety can result in injury or death. Undergraduates need a safety education!

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Notes

The author declares the following competing financial interest(s): I am the coauthor of the textbook "Laboratory Safety for Chemistry Students", 2nd ed., John Wiley & Sons, Inc., 2016. This is the one and only textbook on laboratory safety for undergraduate students. The only other reference lab safety book is "Prudent Practices in the Laboratory", by the National Research Council (it is not a textbook). I welcome other lab safety textbooks and/or incorporation of safety education into college textbooks and suggest this in the Commentary.
Opinions expressed are those of the author and do not necessarily reflect those of Battelle or its employees.

ACKNOWLEDGMENTS

I would like to thank Battelle Memorial Institute for their strong support of my efforts to improve laboratory safety. I would also like to thank the myriad of other supporters within the American Chemical Society who have been working together to make safety education and safety an important value for chemists. And last I would like to thank all of those educators who are finding ways to incorporate safety education into their teaching.

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DOI: 10.1021/acs.jchemed.5b00825
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