2000

Introducing Proper Chemical Hygiene and Safety in the General Chemistry Curriculum

Gordon J. Miller
Iowa State University, gmiller@iastate.edu

Stephen A. Heideman
Iowa State University, saheidem@iastate.edu

Thomas Greenbowe
Iowa State University, tgreenbo@iastate.edu

Introducing Proper Chemical Hygiene and Safety in the General Chemistry Curriculum

Abstract
Chemical safety is an important component of science education for everyone, not just for chemistry majors. Developing a responsible and knowledgeable attitude towards chemical safety best starts at the early stages of a student's career. In many colleges and universities, safety education in undergraduate chemistry has been relegated primarily to a few regulatory documents at the beginning of a laboratory course, or an occasional warning in the description of a specific experiment in a prelaboratory lecture. Safety issues are seldom raised in general chemistry or organic chemistry lecture-based chemistry courses. At Iowa State University we have begun to implement a program, Chemical Hygiene and Safety in the Laboratory, into the undergraduate chemistry curriculum. This program is designed to increase the awareness and knowledge of proper chemical hygiene and laboratory safety issues among all students taking general chemistry and organic chemistry courses. Laboratory protocol, use of safety equipment, familiarity with MSD sheets, basics of first aid, some specific terminology surrounding chemical hygiene, EPA and OSHA requirements, and the use of the World Wide Web to search and locate chemical safety information are topics that are applied throughout the chemistry curriculum. The novelty of this approach is to incorporate MSD sheets and safety information that can be located on the World Wide Web in a series of safety problems and assignments, all related to the chemistry experiments students are about to perform. The fundamental idea of our approach is not only to teach students what is required for appropriate safety measures, but also to involve them in the enforcement of basic prudent practices.

Keywords
first-year undergraduate/general, curriculum, safety tips, internet/web-based learning

Disciplines
Curriculum and Instruction | Higher Education | Other Chemistry | Science and Mathematics Education

Safety Tips

edited by
Timothy D. Champion
Johnson C. Smith University
Charlotte, NC 28216

Introducing Proper Chemical Hygiene and Safety in the General Chemistry Curriculum W

Gordon J. Miller, Stephen A. Heideman, and Thomas J. Greenbowe*
Department of Chemistry, Iowa State University, Ames, IA 50011; *tgreenbo@iastate.edu

According to *Prudent Practices in the Laboratory*, "the new culture of laboratory safety implements the priority of 'safety first' through a greatly increased emphasis on experiment planning" (*1*). Of course, knowledgeable attitude toward chemical safety starts best at an early age, for it affects all members of the chemistry laboratory community. In many universities, safety education in chemistry has been relegated primarily to a few regulatory documents at the beginning of a laboratory course, or an occasional warning in the description of a specific experiment in a prelaboratory lecture. Moreover, safety issues are seldom raised in general chemistry or organic chemistry lecture-based chemistry courses. A review of the literature reveals that these concerns have been discussed over the past 20 years.

Previous articles have described specific steps or procedures that could be implemented to enhance chemical safety. Kaufman (*2*, *3*) listed 38 steps for improving laboratory safety and he stressed the need for chemistry faculty to make "chemical safety an integral and important part of the chemical education process, and to realize that the basic component in an effective program is commitment not money" (*2*, p A337). Hanssmann provided a checklist for general laboratory safety and discussed some of the common safety hazards observed in secondary schools (*4*). Chiad and Hardy discussed specific safety procedures that were implemented in their undergraduate laboratory courses (*5*).

Several articles described specific safety courses or lectures for beginning chemistry majors. Nicholls (*6*) described a separate safety course for junior and senior chemistry majors interested in industrial chemistry, teaching, or graduate research. Examples of problems requiring problem solving and calculations that help students understand safety concepts, safety rules, and regulations are presented and discussed. Carpenter, Kolodny, and Harris described a chemical safety lecture course for junior and senior chemistry majors that included five projects involving literature searches, fire fighting demonstrations, and industrial guest speakers (*7*). Irving proposed a laboratory safety orientation lecture for the first chemistry laboratory course (*8*). Fawcett was one of the first to argue for integrating safety in college chemistry courses (*9*). This current article describes our attempt to integrate chemical safety in our introductory chemistry course using a variety of strategies, including use of the World Wide Web (WWW).

A Chemistry Safety Program for Colleges and Universities

At Iowa State University we have begun to implement a program into the undergraduate chemistry curriculum that will increase the awareness and knowledge of proper chemical hygiene and laboratory safety issues among all students taking chemistry courses. Although this program targets the general chemistry and organic chemistry courses, it will be expanded to all areas to insure that issues of chemical hygiene are treated throughout the undergraduate chemistry curriculum. Within general chemistry, this program, which we call "Chemical Hygiene and Safety in the Laboratory", is intended to work with the existing topics in the syllabus of any general chemistry course so as to complement the concepts and skills the students are expected to learn. Since chemistry, the central science, plays a key role in the curriculum of any scientific discipline, many of these students will go on to scientific leadership positions in industry, academia, and government. Not only will these individuals carry scientific research into the 21st century, but they must also confront the responsibility for dealing with experimental risks as well as the increasing regulatory actions designed to minimize hazardous situations.

Chemical Safety Books

To accomplish the goal of chemical safety education, students could be required to purchase and read a chemical safety book. There are several chemical safety books available, but each has its drawbacks. *Prudent Practices in the Laboratory* (*1*) is a detailed account of proper chemical hygiene and safety measures for laboratory settings. Although it is inappropriate for the typical general chemistry student, it is an important resource for chemistry instructors. *Safety in Academic Chemistry Laboratories* (*10*) provides succinct descriptions and definitions of many health and safety issues relevant for individuals working in a chemistry teaching or research laboratory. However, this reference does require some familiarity with chemical principles, and is not entirely appropriate for many general chemistry students. *Working Safely with Chemicals* (*11*) provides relevant information for introductory chemistry students, but, according to our student evaluations when this book was used, the writing style created a barrier towards how seriously the students treated this material. Some of the prose involves a cartoon character's conversation with the reader that carries on throughout the book. Although this style may be engaging for some readers, it did not attract or motivate our students. Heindel (*12*) provides a book to accompany a video course for chemists engaged in research.

Nevertheless, these books do contain a substantial amount of useful information, and an instructor could create a chemical safety unit around them. This analysis and previous reviews (*6*, *7*) reveal that there is no one single book on chemical safety that is appropriate for students enrolled in an introductory college chemistry course. With these limitations on the current resources, chemical hygiene and safety can be incorporated in the curriculum through a series of prelaboratory problem assignments and World Wide Web search assignments related to the specific laboratory experiment to be undertaken by the students.

Material Safety Data Sheets: Part of Chemical Safety Training

One of the many roles of an undergraduate chemistry curriculum should be to promulgate proper chemical hygiene and safety practices for working in a laboratory environment. Of course, these "concepts" are often hidden among myriad topics treated in general, organic, physical, analytical, inorganic, and other courses (both lecture and laboratory-based) offered to fulfill the curriculum. Laboratory management, however, expects and anticipates chemical safety issues to be part of the chemistry curriculum. Furthermore, other scientific and engineering disciplines require their students to take at least one year of chemistry, which would be the general chemistry sequence. As these students move on to their scientific careers, they confront the same standards, regulations, and policies for proper laboratory hygiene and safety as do those with chemistry degrees. For example, nearly all jobs expose workers to Material Safety Data Sheets (MSDSs). These forms generally contain much more information than anyone is really required to know, and often the information presented corresponds to a worst-case scenario (e.g., compare MSDSs for solid sodium hydroxide and 0.1 N sodium hydroxide). Learning how to read and to extract useful and meaningful interpretations of the information in MSDSs is just one measure of proper chemical hygiene and safety that needs to be addressed in the chemistry curriculum. Therefore, it is imperative that general chemistry begins to treat proper chemical hygiene and safety in the laboratory. In this age of learning chemical concepts and critical thinking skills, where do issues of chemical hygiene fall? Must other topics traditionally covered in a general chemistry course be set aside to make room for this subject? Since chemical hygiene and safety does not occur as a distinctive "chapter" in any current general chemistry textbook, how can the topic be introduced to the students?

A New Type of Safety Assignment

Our Chemical Hygiene and Safety in the Laboratory program is attached to general chemistry via the laboratory courses. During the first-semester course, students are assigned 10 safety problems, which are available on the World Wide Web at *http://avogadro.chem.iastate.edu/chem177*. Each assignment treats a different aspect of chemical hygiene, has students use the WWW to search and locate safety information, and requires students to complete a short writing assignment to be handed in at the start of the following week's laboratory period. The problems range from summarizing pieces of information in MSDSs, to numerical problems involving exposure limits, to extracting all information from chemical reagent labels. Together these assignments weigh 15–20% of the final laboratory grade and are graded with severe restrictions: no late assignments are accepted and the student receives zero credit for any missed assignment.

The assignments examine topics according to the following plan (the first two are basic necessities and should be covered in any laboratory course; the remaining eight cover proper chemical hygiene and safety principles).

1. *Safety Equipment and Emergency Procedures* (first week). Students must be informed of these issues of their working laboratory environment, and are required to sign a statement of this "training". Each student draws a plan of the teaching laboratory and points out all safety features, which include exits, routes to exits, telephones, fire protection equipment (blankets and extinguishers), showers, spill kits, first aid kits, etc. If an experiment is carried out, the operations do not require personal protective equipment.

2. *Personal Protection and Laboratory Protocol* (second week). By this time, students must have safety goggles or glasses to carry out experiments. Laboratory aprons and gloves are available, and aspects of laboratory notebook management, data recording, protocols for using community spaces (balances and chemical reagent cabinets, for example) are summarized.

3. *Toxicology—Routes of Entry, Dose*. Defines toxicity and dose and addresses the four main routes by which hazardous chemicals enter the body. The term *hazardous* is also discussed. The written assignment gets the students to examine other definitions of various terms found throughout the chemical hygiene literature.

4. *Toxicology—Exposure Limits*. Addresses types of toxic effects and exposure limits using OSHA and ACGIH values. Conversions between ppm and Mg/m^3 and the meaning of the terms LD_{50} and LC_{50} are introduced. The written assignment addresses exposure limits to chemicals in the laboratory (see the next section of this article for an example problem).

5. *Toxicology—Hazard Warnings, NFPA Signs and Other Symbols*. Introduces symbols found on chemical reagent containers students will see in the lab and provides further definitions of important terms. Describes the NFPA signs found on all doors. The assignment gets students to carefully examine, read, and interpret labels on reagent bottles and provides them the opportunity to interpret NFPA signs.

6. *Material Safety Data Sheets—Overview*. Introduces the basics of MSDSs, pointing out why they exist and how they should be used. The unit on MSDSs extends over four weeks. The written assignments are all the same: students compare the MSDSs for two chemicals, one a laboratory reagent and the other a substance known to them outside a laboratory. For example, our first MSDS assignment compares nitric acid with sodium chloride (table salt).

7. *Material Safety Data Sheets—Sections 1–5*. Focuses on the first five sections of MSD sheets. The assignment compares aspirin with sulfuric acid.

8. *Material Safety Data Sheets—Sections 6–10*. Focuses on the second five sections of MSD sheets. The assignment compares bleach with sodium hydroxide.

9. *Material Safety Data Sheets—Sections 11–15*. Focuses on the third five sections of MSD sheets. The assignment compares denatured ethanol with caffeine.

10. *Federal Agencies: OSHA, EPA*. Brief history and missions of these two organizations. The written assignment requires the students to do some literature searching in the library and to write about various federal initiatives.

During the second semester of general chemistry, students were required to examine the MSDSs for various chemicals they would be using during the following week's laboratory experiment and to summarize various aspects. The first four assignments guided the students to address certain questions in preparing for an experiment: (i) identify three hazards most relevant to the compound as used in the described laboratory procedure; (ii) specify whether the hazardous effects are

the result of acute or chronic exposure; (iii) briefly outline the methods you will use to limit your exposure to the substance. The last two assignments expected each student to draw his or her own conclusions from the MSDSs and to summarize aspects of use, disposal, cleaning, and possible emergency situations.

Sample Safety Problems

To enable this safety unit to coalesce with material presented in the general chemistry course, problems were designed that made use of various chemical principles. For introductory students, two important fundamental concepts are chemical reactions and concentration. In the section on MSDSs, students were asked to think about a substance's reactivity with respect to significant hazards, the nature of personal injury that may occur, and the first aid measures that must be applied when an accident involves the substance.

With respect to concentration, exposure limits offer a wonderful (and necessary) application from which numerous chemistry-based calculation problems can be written. We have used the following two examples.

Example 1

In Experiment #4, you treated a metal with concentrated nitric acid to form a metal oxide. The reaction produces some nitrogen dioxide gas. The OSHA PEL for nitrogen dioxide gas is 5.00 ppm. Using the dimensions of your laboratory (see below), what is the maximum number of moles of nitrogen dioxide that could be generated in a three-hour laboratory period according to OSHA regulations? (NOTE: air circulates continuously into and out of the room. In a three-hour period, there are 30 complete "air changes" in this room.)

According to your lab manual, the amount of metal recommended for each team to use would produce approximately 0.034 mol of nitrogen dioxide per team. Count the number of teams in your lab, and compare the total number of moles of nitrogen dioxide produced in your lab with your answer to the question above.

Room Information:	0272 Gilman	21' × 37' × 12'
	1272 Gilman	21' × 37' × 14'
	1284 Gilman	24' × 27' × 14'

This example requires students to apply the ideal gas law as well as to address conversions between ppm and Mg/m^3 and from ft^3 to m^3. It also exposes them to an aspect of laboratory work that is generally neglected in many chemistry courses: room utilities. How many instructors discuss air flow in laboratory settings?

Example 2

Using the data given in section 11 [of the MSDS] for caffeine, approximately how many 12-oz cans of Coca-Cola would you need to ingest to reach the LD_{50} value for caffeine? (One 12-oz can of coke contains about 32 mg of caffeine.)

This example is designed to get students to think critically about MSDSs. What do the exposure limits and OSHA regulations mean with respect to commonly used dosages of caffeine? These problems are fundamentally similar to basic exercises in introductory chemistry books, but they address safety. These two problems, as well as others we have used, the complete narratives for all the general chemistry safety assignments, and a list of the general chemistry laboratory experiments performed by our students that correspond to the safety assignments are available online.[W]

Discussion and Summary

In this article we introduce a different type of approach to chemical safety: infusing safety within an existing course rather treating it as a separate course. Since the introductory course enrolls students who are not chemistry majors, we start chemical safety training here, rather than later in a separate course for juniors and seniors, because it is important that *all* science and engineering majors receive chemical safety training. Examples of the safety problems and other safety information we have assigned to our students are available on the *JCE* Web site.[W] Our students have accepted these safety assignments and rate them on average as a "3" on a scale of 1–5. However, too many students still view the assignments as something that must be done for points, rather than as an important component of their education and training.

The fundamentals of prudent laboratory practices must be included in the general chemistry curriculum. Laboratory protocol, use of safety equipment, familiarity with MSDSs, basics of first aid, some specific terminology surrounding chemical hygiene, and the use of the WWW to search and locate chemical safety information are appropriate topics that must be continuously applied throughout the chemistry curriculum. The objective of making safety assignments a relevant, interesting, and important part of safety training must be addressed. Students' opinions and perceptions about laboratory safety and training need to be investigated and the results incorporated into the safety program. The fundamental idea of our approach is not only to teach students what is required for appropriate safety measures, but also to involve them in the enforcement of basic prudent practices.

[W]Supplemental Material

Supplemental material for this article is available in this issue of *JCE Online*.

Literature Cited

1. National Research Council. *Prudent Practices in the Laboratory*; National Academy Press: Washington, DC, 1981.
2. Kaufman, J. A. *J. Chem. Educ.* **1978,** *55*, A337–A340.
3. Kaufman, J. A. *J. Chem. Educ.* **1987,** *64*, 161–162.
4. Hanssmann, C. O. *J. Chem. Educ.* **1980,** *57*, 203–205.
5. Chlad, F. L.; Hardy, J. K. *J. Chem. Educ.* **1983,** *60*, A117–A119.
6. Nicholls, L. J. *J. Chem. Educ.* **1982,** *59*, A301–A304.
7. Carpenter, S. R.; Kolodny, R. A.; Harris, H. E. *J. Chem. Educ.* **1991,** *68*, 498–499.
8. Irving, J. R. *J. Chem. Educ.* **1967,** *44*, A215–A225.
9. Fawcett, H. H. *J. Chem. Educ.* **1949***, 242*, 108.
10. American Chemical Society Committee on Chemical Safety. *Safety in Academic Chemistry Laboratories,* 5th ed. American Chemical Society: Washington, DC, 1990.
11. *Working Safely with Chemicals in the Laboratory,* 2nd ed.; Gorman, C., Ed.; Genium: Schenectady, NY, 1995.
12. Heindel, G. D. *Introduction to Chemical Laboratory Safety*; American Chemical Society: Washington, DC, 1991.