Journal of Hazardous Materials, 36 (1994) 159–164
Elsevier Science B.V., Amsterdam

Laboratory safety course in the chemistry curriculum*

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Abstract

Although laboratory safety is considered an important component of undergraduate training, less than 5% of U.S. colleges and universities offer a required course for chemistry majors. A successful one-credit Laboratory Safety Course has been instituted with the objective to develop skills and attitudes for working with chemicals in a safe and responsible way. The general design of the course including topical information, demonstrations, student projects, and other unique course requirements will be discussed. Outcomes of the course include positive student evaluations, and an increased student awareness for applying safety practices in the laboratory.

1. Introduction

In the process of revamping the undergraduate chemistry curriculum, the Chemistry Department at Salisbury State University included a required Laboratory Safety Course for all chemistry majors. Although students receive safety instructions in the prelab discussions in a variety of chemistry courses, these are often too specific for the laboratory work at hand or too fragmented and disjointed to give a good comprehensive introduction to laboratory safety. Many safety issues such as legal implications, storage and disposal of chemicals, and other safety practices that are not the direct responsibility of the laboratory student could more effectively be covered in a laboratory safety course.

The safety course has been taught 3 years and is a one-credit course which is part of the 128 credits required for the recently American Chemical Society (ACS) accredited undergraduate chemistry curriculum. It has a prerequisite of general chemistry and therefore, the majority of students are sophomores

*Presented at the ACS-CHAS Symposium on Fire and Explosions, Washington, DC, August 27, 1992.

0304-3894/94/$07.00
SSDI 0304-3894(93)E0070-I

concurrently enrolled in organic chemistry. Only 6% of all colleges and universities offer such a safety course [1], with only 1–2% requiring it for all chemistry majors [2].

2. Course objectives

The primary purpose of this course is to develop skills and attitudes for working with chemicals in a confident and responsible way. Based on that purpose there are four general course objectives. Firstly, students must be motivated to think about safety. This could also be called "safety awareness". Students must be aware of both the risks and benefits of using hazardous chemicals. Secondly, students must be aware of the appropriate sources of information about hazardous equipment/chemicals. It is impossible to know or teach all chemical hazards. Students need to be aware of how to get the appropriate information such that they can evaluate the risks/benefits of a chemical procedure. Thirdly, general chemistry principles are incorporated in explaining safety topics. The "Dos and Don'ts of Safety" are explained through chemistry principles. Lastly, it is important to emphasize the common sense approach to safety. Once the hazards have been determined, many safe practices in the laboratory are common sense.

3. Texts/materials

As often noted by others teaching safety courses [3–5], there are no suitable textbooks for this course. Students are required to purchase a notebook containing copies of journal articles that coincide with lecture material. The majority of these articles are from the *Journal of Chemical Education*. Students are also required to purchase the textbook *Safety in Academic Chemistry Laboratories*, published by the American Chemical Society [6]. This is an excellent compact source of general safety information and guidelines.

4. Course requirements

Student grades are determined from five equally weighted course requirements: (1) a laboratory safety analysis/survey, (2) completion of a cardiopulmonary resuscitation (CPR) course, (3) quizzes, (4) a safety paper, and (5) a final comprehensive examination. The laboratory safety analysis/survey is basically an inspection of one of our laboratories after having discussed related topics in the lecture. Because of the possibility of a variety of types of accidents in the laboratory, students are required to pass a CPR/First Aid course. Frequent quizzes (3–5) are given on announced topics. Students are

required to prepare a 4–8 page report on a safety topic not directly covered in class. The final comprehensive exam includes both short answer and essay questions.

5. Course content

The course content is described in Table 1. There are four major topical areas covered in the course: (1) general laboratory safety and equipment, (2) information on chemicals, (3) properties of hazardous chemicals, and (4) hazardous chemical wastes. Since the topics are similar to other safety courses, only features that make this course unique will be discussed.

Several subtopics are discussed under general laboratory safety and equipment. They include general laboratory design, safety equipment in the laboratory, personal protective equipment, and general procedures in case of an accident. The lectures are intended to not only state but explain safety policies/procedures and use of safety equipment. In discussing fire extinguishers, the process of combustion is explained as related to the so-called Fire Tetrahedron. This allows for a better understanding of how fire extinguishers work and why only certain types of fire extinguishers are used on some classes of fires.

It is important that students understand where to get and how to utilize information about chemicals. A brief introduction to federal regulations

TABLE 1

Topics for laboratory safety course

Lecture hours	Topic
1	Introduction to laboratory safety
1	Laboratory design/organization safety equipment in the laboratory
1	Personal protective equipment
1	Information on chemicals RTK/MSDS/labelling of chemicals
1	Properties of toxic chemicals
1	Properties of reactive chemicals
1	Properties of flammable chemicals
1	Demonstration of fire extinguishing
1	Properties of corrosives
1	Cryogens and compressed gases Monitoring of airborne chemicals
1	Incompatibles/storage of chemicals
1	Radiation safety
2	Hazardous wastes in the laboratory Concluding remarks on lab safety

leads to a discussion of the Hazard Communication Standard. The purpose of Material Safety Data Sheets (MSDSs) is explained and examples of MSDSs of common laboratory chemicals are reviewed to focus on pertinent information. Common labelling schemes for chemicals (number and color codes) are discussed and several manufacturers' labels are reviewed. The Chemical Hygiene Plan for laboratories is also introduced in this section.

A major block of lecture time (approximately 40%) is used on discussing the major classes of hazardous chemicals. This topic is introduced by commenting on the significance of hazard control as it applies to working with chemicals which is discussed in an excellent article by Zwaard et al. [7]. Properties of toxic chemicals, corrosives, reactives, and flammables are primarily discussed in this section. In discussing measurements of toxicity/safe exposure levels, general chemistry principles are applied (gas laws) to convert from the TLV (threshold limit value) of mercury vapor to its actual vapor pressure. In the discussion of reactives, properties of oxidation and reduction are reviewed as applied to violent redox reactions. The nature of the hazards, the reason for the hazards, precautionary measures, and emergency procedures are discussed for each class of chemicals. Once hazards are understood, it is emphasized that precautionary measures are often common sense. A discussion of incompatible classes of chemicals introduces the lecture on proper storage of chemicals. Compressed gases, cryogens, and radiation safety are also discussed in this section.

The last topical information section is on chemical waste management. A historical approach introduces the need for federal regulation of hazardous waste with an emphasis on the Resource Conservation and Recovery Act (RCRA) of 1976. Methods of minimizing, handling, and disposing of hazardous waste such as in an academic institution are discussed.

6. Teaching tools

Since some safety information may be somewhat dry and perhaps not seem relevant to the student, a variety of teaching tools have helped to stimulate and maintain enthusiasm.

Each lecture begins with an example of "Learning By Accident". Examples of actual accidents in both industry and academic institutions are utilized to stimulate interest, discussion, and act as an introduction to the related lecture material. Excellent sources of these examples are "Speaking of Safety" [8] and "CHAS Notes" [9].

The use of relevant demonstrations enhances the presentation of many safety topics. After discussing fire extinguishers, students are given an opportunity to extinguish a flammable liquids fire with a variety of types of extinguishers (under supervision of the local fire department). A flashback apparatus [10] is utilized to demonstrate how a flammable liquid such as pentane can flashback and create a fire hazard. The explosive characteristics of ethanol can

be demonstrated by comparing the slow burning of ethanol in a watch glass versus its combustion after vaporizing a small volume (5 mL) in a plastic gallon milk jug. The charring of table sugar with concentrated sulfuric acid clearly demonstrates its dehydrating ability and possible hazards when in contact with skin. The ignition of paper towels (sprinkled with sodium peroxide) by adding a few drops of water demonstrate a strong oxidizing agent. The "Non-Burning Paper" demonstration [11] is a good example of the ability of water to act as a fire extinguishing agent. When paper (such as a dollar bill) is wet with a mixture of about 50% alcohol and water, the alcohol will burn, but there is sufficient water absorbed by the paper so that it will not burn.

Students have expressed an interest in field trips to evaluate safety programs at industrial settings. The class has visited a metal plating facility in our area and has seen both good and poor safety practices.

Audiovisuals (films and slide-tape presentations) have also been utilized, but to a more limited extent. "The Laboratory Safety Workshop" at Curry College, MA, has an excellent library of audiovisuals which may be utilized.

7. Assessment of course

This course has become a valuable component of the chemistry curriculum and students taking the course have become more safety conscious. The students have developed a healthy respect for chemicals, yet not becoming paranoid and afraid in the laboratory. Chemistry majors that have taken the course and are lab assistants, initiated rearranging our inorganic chemical storage system and reorganizing stockrooms for safer working conditions. The students ask more questions relative to safety in their laboratory experiments. Several changes such as removal of unsafe laboratory storage shelves and cleanup of work areas have occurred partially because of the laboratory safety surveys/reports prepared by the students in the course. A concern of the instructor has been trying to appropriately cover the important safety issues in the allotted time.

Evaluations by students have been positive and suggest that the course has increased the students' awareness of safety. Students appreciated the demonstrations, especially the individual use of fire extinguishers. The major student concern was that the course should be worth two credits, especially because of the requirement for CPR certification.

8. Conclusion

A laboratory safety course can be a worthwhile and integral part of the chemistry curriculum. A one-hour credit course is sufficient to make students more safety conscious, yet not burden an already replete curriculum. Safety must be an integral part of the student's chemical education.

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