Chemistry 1A Laboratories at U.C. Berkeley: Environmental Awareness Through Education

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Many of the scientists being educated in our colleges and universities today will move into professions from which society expects responsible, informed behavior in the disposal of hazardous chemical substances. The time to learn this behavior is in the high school and college or university laboratory (Committee on Hazardous Substances in the Laboratory, 1983).

Introduction

The students at the University of California, Berkeley who take the introductory class in chemistry receive an excellent overview of important chemical principles and laboratory techniques. The present method of teaching, however, does not allow sufficient time for the discussion of proper hazardous waste disposal. During most laboratory periods, the students have little time for proper clean-up due to the long and usually difficult experiments that they are expected to perform. The students are in the laboratory one day a week for three hours and are presently expected to complete the experiment and laboratory report within that time period. It is up to the teaching assistants to make sure the students understand what is happening and finish on time. There is little or no time for a discussion about the proper means of disposal of toxic and hazardous wastes that may be produced during the experiment.

The teaching assistants appear to be well trained for the job. Every semester all prospective laboratory assistants are required to attend a two-day seminar which mainly covers safety and emergency procedures. There is a mandatory meeting once a week during the semester for all assistants so that they can perform and become familiar with the experiments that are required of the students. In addition, the chemistry department has put together a substantial handbook entitled, "Who Does What and Where to Find It." It contains emergency phone numbers, information about chemical spills, where to find things around the laboratories, and information about disposal methods.

The purpose of this study is to assess the quality of the Chemistry 1A laboratory manual used by U. C. Berkeley students in regard to the disposal of hazardous wastes. Where I find the manual deficient, I formulate text inserts for the experiments, explaining hazard classes, special safety precautions and most importantly, proper disposal procedures. The knowledge students gain from chemical hazard classes may help them make the right decisions about waste disposal during future experiments. It may be that the laboratory assistants cannot realistically be expected to teach chemistry, monitor laboratory classes of twenty-seven people and also teach about environment awareness. If this is true, written instructions describing the environmental importance of proper waste disposal and the chemicals used and produced during the lab exercises will help preserve the valuable instruction time of the TAs.

Past Studies

Howard (1983) analyzes the problems many universities are having with hazardous waste disposal. The Committee on Hazardous Substances in the Laboratory (1983) published a handbook that recommends certain disposal methods and which focuses on the special problems that occur where many types of chemicals are used in relatively small amounts. The Office of Environmental Health and Safety at U.C. Berkeley maintains a database on the chemical wastes produced by the individual departments on campus which lists the amount and hazard class of each waste.

Background

Unlike manufacturing facilities that produce large quantities of wastes of just a few types, laboratories tend to produce smaller quantities of wastes with varying compositions. Typical of such wastes are mixed solvents, contaminated glassware, reaction products, heavy metals, and strong acids and bases. Because of the large amount of wastes produced, U.C. Berkeley is considered to be a large quantity generator (producer of greater than 1,000 kg/month of hazardous materials). Furthermore, hazardous wastes from laboratories can be as potentially damaging to the environment as hazardous wastes from manufacturing or other sources (American Chemical Society, 1983).

As a result of continual hazardous waste dumping to the sewers, there are now designated locations all over the San Francisco Bay Area considered to be toxic "hot spots." These areas, or outfall points along the shore of the Bay, are where high concentrations of toxic pollutants are suspected. These pollutants could pose a serious threat to aquatic life and, through bioaccumulation in the food chain, to human health as well (Citizens for a Better Environment, 1987). The sewage outfall from the East Bay Municipal Utilities District

(EBMUD) is included in that list of 39 hot spots. U.C. Berkeley drains contribute to this sewage facility.

Many of the toxic hazardous wastes that are produced by the freshmen chemistry laboratories contain mercury, silver and other heavy metal by-products. When these metals are introduced into the sewage treated at EBMUD's plant by way of drains from the laboratories, they kill the micro-organisms in the water that "eat" harmful substances. Consequently, the "treated" waste that is released into the San Francisco Bay remains contaminated (Kurt Ladensack, pers. comm., 1988).

Methodology

My research began by listing all the chemicals used in the Chemistry 1A laboratory experiments so I could categorize them into the various hazard classes. The U.S. Environmental Protection Agency regulations classify hazardous wastes by specific characteristics of the materials. Based on this information, I have written text inserts for the lab manual which present the chemical products and reactants, safe handling procedures and disposal methods.

In addition, I conducted a written survey of students who have taken freshmen chemistry at U.C. Berkeley (see Appendix I). The survey has given me an idea of the attitudes that prevail about hazardous waste disposal, and the amount of confusion felt during the experiments.

A specialist on waste management employed by the Office of Environmental Health and Safety spoke to me about the ambiguous drain disposal policies and the difficulty of monitoring the laboratory drains (Belk, pers. comm., 1988). Various other interviews with professors, teaching assistants and students gave me even more incentive to create the additions to the laboratory experiments.

Data

The laboratory manual uses chemical names and chemical formulas interchangeably throughout the experiments and I think this adds unnecessary confusion to them. Instead of paging through the manual to find a formula, the students could refer to a quick reference list such as is presented here in Table 1. The hazard classes are listed to give the students an idea of the types of chemical they are handling. Hazard classes include, among others, ignitables

CHEMICAL NAME	FORMULA	HAZARD CLASS	EXERCISE NUMBER
Acetic Acid	CH_3COOH	Corrosive	6, 10, 13
Aluminum Chloride	$AlCl_3$	Corrosive	17
Aluminum Hydroxide	$Al(OH)_3$	Corrosive	17
Ammonia	NH_3	Non-flammable gas	5
Ammoniacal Silver Nitrate	$Ag(NH_3)_2$	Explosive	14
Ammonium Chloride	NH_4Cl	ORM-E	5, 9, 12
Ammonium Hydroxide	NH_4OH	Corrosive	6
Barium Carbonate	$BaCO_3$	Poison-B	16
Barium Chloride	$BaCl_2$	Poison-B	16
Barium Hydroxide	$Ba(OH)_2$	Poison-B	16
Barium Nitrate	$Ba(NO_3)_2$	Oxidizer	16
Bromine	Br^-/Br_2	Corrosive	15, 17
Chromium (II)	Cr^{+2}	ORM-E	17
Chromium (III)	Cr^{+3}	ORM-E	17
Chromium Chloride	$CrCl_3$	ORM-E	17
Chromium Hydroxide	$Cr(OH)_3$	ORM-E	17
Copper (wire)	Cu	Combustibe solid	2
Cupric Nitrate	Cu_2NO_3	ORM-E	15
Cupric Sulfate	Cu_2S	ORM-E	2
Ferrous Sulfate	$FeSO_4$	ORM-E	17
Hydrochloric Acid	HCl	Corrosive	4, 5, 11, 9, 16, 17
Lead Nitrate	Pb(NO)	ORM-E	16
Lead Sulfide	PbS	ORM-E	16
Magnesium	Mg	Flammable	4
Magnesium Chloride	$MgCl_2$	ORM-E	17
Magnesium Hydroxide	$Mg(OH)_2$	Corrosive	17
Manganese Dioxide	MnO_2	Oxidizer	17
Nitric Acid	HNO_3	Oxidizer	2, 10, 14
Performic Acid	CH_2O_3	Explosive	17
Potassium Carbonate	K_2CrO_4	Poison-B	16
Potassium Chromate	K_2CrO_4	ORM-A	14
Potassium Cobaltinitrate	$K_3CO(NO_2)_6$	–	16
Potassium Dichromate	$K_2C_{r2}O_7$	ORM-A	17
Potsssium Iodide	KI	ORM-A	15
Potassium Nitrate	KNO_3	Oxidizer	15
Potassiumthiocyanate	KCSN	Toxic	10
Silver:			
Acetate	AgOAc	Toxic	10
Chloride	AgCl	Toxic	6
Chromate	$AgCrO_4$	–	14
Nitrate	$AgNO_3$	Oxidizer	6, 10, 12, 15, 16
Sodium:			
Acetate	CH_3COONa	Non hazardous	6
Bicarbonate	$Na2CO_3$	Oxidizer	9, 16
Chloride	NaCl	ORM-A	6
Dichromate Oxide	$Na_2Cr_2O_7$	ORM-E	15, 17
Hydroxide	NaOH	Oxidizer	7, 8, 10, 11, 13
Oxalate	C_2O4Na_2	ORM-E	12
Permanganate	Na_2MnO_4	Oxidizer	17
Sulfide	NaS_2	Corrosive	16, 17
Sulfuric Acid	H_2SO_4	Corrosive	15, 16, 17
Zinc Nitrate	$Zn(NO_3)_2$	Corrosive	15

Table 1: Chemical Products and Reactants from Chemistry 1A Laboratories.

Sources: McLoone, 1987.
The Merck Index, 1976
Sittig, 1985.

(liquids or solids); oxidizers (which readily stimulate the combustion of organic matter); corrosives (aqueous solutions that have a pH greater than 12.5 or less than 2); toxics (chemicals which exhibit high concentrations of any of eight elements of ions [As, Ba, Cd, Cr(VI), Pb, Hg, Se, Ag]); explosives (the primary purpose of the compound or mixture is to function by explosion); flammable solid (liable to cause fires through friction or retained heat); combustible solid (solid which may undergo spontaneous heating or self-burning under normal conditions); poison B (less dangerous than poison A substances, but presumably so toxic that they are a hazard to health); ORM ("other regulated materials" which are divided into five different classes, A-E. These materials may pose an unreasonable risk to health and safety or property, and do not meet any of the definitions of the other hazard classes) (Committee on Hazardous Substances in the Laboratory, 1983). I have defined only the hazard classes that are used in the Chemistry 1A laboratories and which appear on Table 1.

Using the data on Table I, I have written individual text inserts for many of the lab exercises, consisting of chemical names and disposal procedures for each product and reactant (see Appendix I). Some inserts contain cautionary statements or recommendations that may alleviate confusion. From personal experience, I know that it is difficult to remember all the chemical reactions and resulting formulas of products. Therefore, I added a column in the inserts that indicates whether it is a reactant or product. Experiments 1-3, 13 and 18 did not need inserts due to the nature of the chemicals (such as HCl and NaOH solutions that are neutral or very dilute) or of the experiment itself (experiment 3 has only gaseous products and requires very little reactant).

The survey data I have gathered reveal the responses of 20 students who have taken this chemistry course. About one third of the sample was comprised of Environmental Science majors and the other two thirds were acquaintances of mine, both men and women. I have supplied for my reader a non-biased report of all answers. See Appendix II for survey form and tabulations of responses.

Some estimates of the amount of waste produced in the labs and suggestions on how to separate and store the wastes safely were provided by a teaching assistant. He says that for every lab period, there are approximately two liters of waste produced (of significant concentrations). There are about 16 lab sections per week, so by simple multiplication we see that there are roughly 32 liters of waste produced every week (Czerwinski, pers. comm., 1988).

Discussion

It is apparent from the respondents' answers to the survey that proper hazardous waste disposal is not regarded as a priority during the laboratory period. The quality of instruction is already reduced due to time constraints place on the teaching assistants to finish in three hours (Czerwinski, pers. comm., 1988). Due to this rushed atmosphere, some students either were confused at the end or felt it was not bad to throw chemicals away improperly. Students who remember throwing waste away improperly usually attributed their actions to being rushed and out of time (see questions five and six).

Almost three-fourths of the respondents felt that written instructions would be helpful. Written instructions would benefit both students and instructors because actual laboratory experience would not have to be reduced in order to explain disposal procedures. Ken Czerwinski, a teaching assistant for Chemistry 1A , agreed with me on that point and feels that laboratory instructors do not want to spend the time to discuss hazardous wastes. He also said that there would be less confusion about disposal procedures if the students had a better understanding of toxic chemicals. The students in his lab may think twice about pouring silver products down the drain if they were educated about the consequences of doing so. Although 86 percent of the sample feels that their teaching assistant had a clear understanding of disposal procedures, 100 percent feel that he or she was ineffective in terms of relating the importance of proper waste disposal (questions two and eight). Hazardous waste disposal procedures should never be confusing or ambiguous; questions three and four, however, show that this is not always the case. It seems that verbal instructions at the beginning of a three hour lab are not always clear at the time of clean-up.

The way to separate the wastes safely is first to segregate the metals from the non-metals. The students use lead, mercury, silver and chromium in the experiments. Silver products, because they are expensive, are kept separate. The non-metals are further divided into inorganics or organics, the organics into halogenated or non-halogenated. Halogenated substances are chemicals with carbon and one or more of the following: fluorine, chlorine, bromine, iodine, or astatine. The 32 liters of waste per week would be divided up among 16 two-liter bottles and picked up once a week by the Office of Environmental Health and Safety. It cannot get much simpler.

Recommendations and Conclusion

The Chemistry Department at U.C. Berkeley should look into improving the existing waste-disposal program used within the instructional labs, and see that it is implemented with the proper disposal equipment. The author of the laboratory manual should deal with the problems of disposal explicitly and should include as part of each experiment procedures that the student can carry out to minimize disposal problems. Much of the work that is necessary to comply with such a suggestion has been included in the report.

Although these students are learning valuable chemistry, it is unnecessary to design such long experiments which force the students to use bad judgment and "forget" to clean up properly. The experiments should either be shortened or the laboratory time should be lengthened. Furthermore, every laboratory period should have an allotment of time designated specifically for clean-up.

The data collected in this study indicate that an unknown amount of potentially harmful chemicals and wastes go down the drains in the freshman chemistry labs. This could be avoided if the Chemistry Department were to employ a no-drain disposal policy, to eliminate the possibility that it is adding to the pollution of the Bay. Once the program is implemented, it may possibly serve as an example for other departments to follow.

Lastly, I recommend that the Chemistry Department invest some time in an overall training program regarding the significance of proper hazardous waste disposal. The orientations and the weekly experiments that the teaching assistants take part in should have the topic of waste disposal as one of the priorities for discussion. In return, the teaching assistants should relate this information with clarity and vigor to all beginning chemistry students.

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Appendix I: Proposed Inserts for Laboratory Manual.

Disposal Methods for Experiment 4:

Once you have completed the experiment, discard the products under the fume hood in the bottle labeled "Metal Products." Metals, when introduced into the sewage system, kill biological micro-organisms in the water which break down harmful substances. These untreated materials then get deposited into the Bay and pollute it.

Disposal Methods for Experiment 5:

Ammonia is a non-hazardous substance and may be poured down the drain. However, the HCl and NH_3Cl product must be poured into the bottle labeled "Chlorine Products."

Disposal Methods for Experiment 6:

CH_3COONa	R•	These can go down drain.
NaCl	R	
CH_3COOH	R	These two reactants go in bottle labeled " Hydroxides."
NH_4OH	R	
AgCl	R	Pour ALL SILVER PRODUCTS in the SILVER WASTE CONTAINER under the hood.
$AgNO_3$	P	

• R = Reactant P = Product.

Hint: Label a beaker at the beginning of the lab "Silver products."

Disposal Methods for Experiment 7:

The HCl and NaOH neutralize and become non-hazardous. All products from this experiment may be thrown down the drain, but any excess reactants must be poured into the bottle labeled "HCl/NaOH."

Disposal Methods for Experiment 8:

H_2SO_4	R	All products and reactants from this cxperiment must be poured in the bottle labeled " Acids/Bases."
HCl	R	
NaOH	R	

Disposal Methods for Experiment 9:

NH_4Cl	R	All products from this lab can be poured into a single bottle labeled "Inorganics."
HCl	R	
Na_2CO_3	R	

Disposal Methods for Experiment 10:

CH_3COOH	R	These reactants can be poured into the same bottle, labeled "Acids/Bases."
HNO_3	R	
NaOH	R	
$AgNO_3$/NaOAc	R	Once again, always put silver waste into the SILVER WASTE CONTAINER.
AgOAc/KCSN	R	

Caution: $AgNO_3$ may cause burns; handle carefully.

Disposal Methods for Experiment 11:

You need only put the 1M and .1M solutions of HCl in the "HCl" labeled bottles. The dilute solutions (< .1M) can be thrown down the drain.

Disposal Methods for Experiment 14:

AgCl	P	All silver reactants and products must be thrown in the SILVER WASTE BUCKET.
$AgNO_3$	R	

Ag_2CrO	P	
$AG(NH_3)_2$	P	
NaCl	R	Can be poured down drain.
HNO_3	R	Pour into "HNO_3" bottle.

Disposal Methods for Experiment 15:

$Zn(NO_3)_2$	R	Zinc and copper harm the environment. Pour them both in the "Cu/Zn" bottle.
Cu_2NO_3	P	
$Br2/Br^-$	R	Very toxic and corrosive substance. Pour in bottle labeled "Bromine water."
KI	P	Potassium iodide can also go in this bottle.

Disposal Methods for Experiment 16:

NaCl	R	Can go down the drain.
NaOH	R	All of these substances can go into the same bottle labeled "Acids/Bases."
$Na2CO3$	R	
$Na2SO4$	R	
$Na2S$	R	
$HNO3$	R	
HCl	R	
$Ba(NO3)2$	R	Due to the extreme toxicity of Barium compounds, these substances go in a separate bottle labeled "Barium ."
$Ba(OH)2$	R	
$BaCO3$	P	
$Pb(NO3)2$	R	All lead solutions and lead impregnated paper must go in the LEAD WASTE CONTAINER under the fume hood. Lead is very toxic to the environment.
AgCl	P	All silver products and reactants must go in the SILVER WASTE BUCKETS provided in every lab.
$AgNO3$	P	

Disposal Methods for Experiment 17:

HCl	R	All of these inorganic materials must be poured into the same containers labeled "Inorganics."
H_2SO^4	R	
NaOH	R	
$NaHSO_3$	R	
NH_3	R	
Bromine water	R	Bromine reactants and products go in the bottle labeled Bromine" due to the toxicity of the chemical.
$CrCl_2$	P	All of these solutions containing trace metals should be poured into the same waste bottle labeled "Cr/Al/Mn."
$CrCl_3$	P	
$KCr(SO_4)_2$	R	
$MnCl_2$	R	
$Mn(OH)_3$	p	
$AlCl_3$	R	
$Al(OH)_3$	P	

Appendix II: Survey of Chemistry 1A Students and Results.

Question #1:

Describe the disposal practices employed by your laboratory on a typical day.

100% of the answers stated that a few things went in containers, but most of it went down the drains under the fume hoods.

Question #2:

Did your t.a. seem to have a clear understanding of proper disposal procedures?

86% yes; 14% I don't know.

Some comments were:

a) He didn't always stress how or why we were supposed to follow certain instructions.
b) He didn't say anything if we just put stuff down the drains.
c) He didn't emphasize anything.
d) Only stressed disposal procedures for most hazardous chemicals.

Question #3:

Did you usually know how to dispose of your waste?

71% yes; 29% No.

Some comments were:

a) Plenty of times I forgot what was correct or incorrect.
b) Sometimes it was confusing.
c) T.a. told us at the beginning of the lab.
d) Basically everything goes down the drain. It wasn't that hard to remember.

Question #4:

How did you know what to do with it?

Comments were:

a) Sometimes it was in the lab book.
b) By the label on the jar. If there was no jar, I just put it down the drain.
c) The t.a. touched on it lightly at the beginning of the lab.

Question #5:

Did you ever throw products down the drain that, looking back, were not supposed to go down?

71% yes; 19% I Don't remember.

Question #6:

If yes to #5, why?

Answers were:

a) Not a strongly enforced idea that dumping was bad.
b) I was always rushed.
c) I would forget.
d) Not enough time; I misunderstood.

Question #7:

What do you think the general attitude was in the lab about hazardous waste disposal?

Answers were:

a) People weren't serious about it, even in the supply office.
b) No problems; safety was stressed more.
c) At this point in education, students don't understand, or want to.
d) We never really talked about hazardous waste disposal.
e) We were just given instructions without explanations; we were just robots.
f) Hazardous waste disposal wasn't a priority because there were too many other things to worry about.

Question #8:

Was the t.a. ineffective in terms of relating the importance of proper waste disposal?

100% Yes.

Question #9:

Do you think more written instructions, as opposed to verbal instructions,would be helpful for describing disposal procedures during the lab?

71% yes. 19% No.

Some comments were:

a) Easily readable and short written instructions would be effective.
b) Verbal would be a lot better if they could be heard across the room.
c) Both would be good.
d) More verbal instructions would have a greater emphasis on the importance of hazardous waste disposal.
e) Verbal instructions are likely to be forgotten.