Analysis of the Use of Small Scale Chemistry (SSC) in a Community College Setting

(Front Range Community College; Larimer Campus (FRCC/LC); Ft. Collins, CO)

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A. **Introduction:** The following is a thumbnail sketch of an example of the use of Small Scale Chemistry in a community college setting. The NAES (Natural, Applied, and Environmental Science) Department on the Larimer campus of Front Range Community College has utilized Small Scale Chemistry almost exclusively in our first year chemistry classes for a number of years now. We have four sections of approximately 24 students each in our Chemistry 101 course (for non-science majors, total students < 96) for which we use E.L. Waterman and S. Thompsonís *Small-Scale Chemistry Laboratory Manual*. We also give a full year (2 semester) course for science majors (Chemistry 111 and 112) for which we use S. Thompsonís *Chemtrek: Small Scale Experiments for General Chemistry.* Chemistry 111 consists of four sections of about 24 students each (total students < 96) and Chemistry 112 consists of 2 sections of about 12 students each (total students < 24). Our total student population taking Small Scale Chemistry classes totals approximately 200-220/semester. We also give a year-long Organic Chemistry course which is not discussed here. This report will focus on the laboratories for our Chemistry 111 and 112 curriculum using the *Chemtrek* text.

B. **Small Scale Laboratories in Use at FRCC/LC**

1. SSC Laboratories Used Every Semester:
   a. Chem 111 (*Chemtrek*):
      Small Scale Techniques and The Absorption of Light
      Spectroscopy: The Interaction of Light and Matter
      Thermochemistry and Solar Energy Storage
      Solutions and Reactions
      An Introduction to Acids and Bases

   b. Chem 112 (*Chemtrek*):
      Kinetic Blues
      Acid-Base Equilibria
      Redox Equilibria and Electrochemistry
      Gas Chromatography
      Acid Deposition
      Semimicro Qualitative Analysis and Metal Ions (SMQA)
      Paper Chromatography and Liquid Chromatography

2. SSC Laboratories Used Some Semesters:
   a. Chem 111 (*Chemtrek*):
      The System
      Halogens and Their Compounds
      The Use and Abuse of Aluminum and Its Compounds
      Chemistry of Natural Waters
      Natural Products Chemistry: Anthocyanins as Food Dyes

   b. Chem 112 (*Chemtrek*):
      Vitamin C Analysis
      Surface Chemistry: Bubbles and Films
      Zinc Links: Coordination Chemistry and Nutritional Deficiency

C. **"Traditional"/Other Laboratories in Use at FRCC:**

1. Gases: Analysis of Baking Powder Using the Ideal Gas Equation (study properties of gases generated from several brands of baking powder). (handout)
2. "Molar Mass Determination Using Colligative Properties" (handout)
3. "Le Chatelierís Principle" (handout)

4. Working with Model Kits (we have a supply of molecular model kits for the students to check out and use in class)
5. Demonstrations: This is an area where we often use traditional chemistry glassware and volumes of chemicals and solutions. These enable all students to clearly see the demonstration and we keep a stock of standard glassware (volumetric flasks, beakers, graduated cylinders, etc.) for this purpose.

D. **Costs per Experiment**

1. Average number of students supplied in Chem 111:
   a. Number of Sections of Chem 111: 4
   b. Average number of students per section of Chem 111: 24
   c. Average total Number of students/ Semester in Chem 111: 96

2. Average number of students supplied in Chem 112:
   a. Number of Sections of Chem 112: 2
   b. Average number of students per section of Chem 112: 12
   c. Average total Number of students/semester in Chem 112: 24

3. Supplies Provided by Students:
   a. Chemtrek Laboratory Manual (suggested purchase of safety glasses by students; we do not require this and we make them available free of charge to borrow while in the lab)
   b. We do not have a "Breakage Card" for the students at present and since most of what they use is plastic and inexpensive and their lab fees appear to cover costs reasonably well.

4. Supplies Provided by FRCC[1]
   a. Supply kits (24 kits (total) available in supply drawers for all 6 sections of Chem 111 and112) in plastic "shoe boxes" with hinged lids from WalMart (approx. $5.00 each) each containing:
      1 pair scissors
      1¼" paper punch
      1½" plastic ruler, clear, inch/metric
      1 pair forceps (tweezers)
      2 96 well plates (one round-bottom type and the other flat-bottom type)
      3 microstrips, 1x12 wells
      2 24 well plates
      1 petri dish with cover, 100 x 15 mm
      Sharpie marker (extra fine point)
      Hand lens
      (**Note:** total cost of each kit (including the plastic shoe box) is approximately: $23.40)

   b. Other Supplies in Supply Drawer (24 drawers available):
      Spectroscope (as described in Lab #2 "Spectroscopy. . .")
      8½" x 11" laminated Periodic Table
      "Lab Top" (with sheet protector and white plastic insert for stiffening)

   c. Chemicals, supplies[1]
      Chemicals (liquid and dry), thin stem pipets, straws, "Micro towels", Styrofoam cups, Sep-Cap vials, pH paper, filter paper, and any other supplies specific to a particular laboratory are supplied on a rolling cart (1 cart is set up for Chem 111 and one for Chem 112 at the beginning of each weekóthese carts are comparable to Dr. Thompsonís "Reagent Central"). Liquid reagents are supplied in pre-filled and labeled micropipets which are easily recycled for other labs and between semesters. Stable reagents are actually stored in the pipets between experiments, in addition to having stock bottles of reagents. Acids, bases and corrosives are stored in appropriate bottles in approved storage cabinets when not in use.

   d. Large Equipment Available to Instructors and Students:
      Stir/hotplates (5)
      Hotplates (8)

Waterbaths (2)
Drying Oven (1)
Centrifuge (1)
Spectrophotometers (6)
Triple beam balances (9)
Electronic Top-Loader Balance (2)
Power sources (4) and gas emission tubes (10) for spectroscopy
Multimeters (12)
Refractometer (1)

e. Replacement/semester for both Chem 111 and Chem 112 (%)
    1. Supply Drawer:
        a. Shoe box contents generally require no more than 25% replacement from semester to semester
        b. Spectroscopes, periodic tables, and Lab-tops (out of 24 drawers) about 3-4 of each (maximum) may need replacing
    2. Pipets and Solutions (supplied on cart for students); require about 10% replacement/semester
    3. Supplies specific to individual experiments-most are quite durable and require replacement no more than every few years with about 10% replacement required each semester.
    4. Our major financial outlays would be:
        a. Thin stem pipets which the students use (not the ones filled with stock solutions and supplied on the top shelf of the cart). We use about 2-3 boxes per semester ($21.00/bx) for a total of $42-$63/semester
        b. micro-towels, straws, sample cups, foil, etc. (about $10.-$20/semester)
    5. Supplies recycled each semester (%)
        1. Supply Drawer:
            a. Shoe box contents can generally be recycled at the rate of about 75% from semester to semester.
            b. Spectroscopes, periodic tables, and Lab-tops (out of 24 drawers) about 20-21 of each can be reused the next semester.
        2. Pipets and Solutions; are recycled at the rate of about 90% of the stock pipets and solutions per semester.
        3. Supplies specific to individual experiments-most are quite durable and we do not experience a great deal of breakage such that about 90% can be reused each semester.

5. **Time Expenditures:**
    1. Preparation time/experiment (setting up the lab cart):
        a. Depends on experiment, but generally it takes about 1-1.5 hrs. to select and set up pipets in 24 well trays (which are used as racks for the pipets) and make any solutions that need to be fresh. We make up 1 rack for each team of two students. These are usually sufficient for several classes.
        b. Another 0.5-1.0 hr is usually required for collecting other items such as multimeters, dry chemicals, metals, etc. that are specific to the particular laboratory and are to be supplied on the cart.
        c. Other items that are routinely used in most experiments such as thin-stem pipets, cotton-tipped swabs, "micro towels", styrofoam cups, drinking straws, etc. are stored on the second and third shelves of the cart and are always available. These are restocked as needed on a regular basis.
        d. Total average prep time: 1.5-2.5 hrs

    2. Clean up/Breakdown (after the weekís laboratories):
        a. Chemical waste generated is either pHíd and sink disposed if the chemicals used in the experiment are allowable for sink disposal. Other wastes are stored in proper waste containers, logged, and ultimately removed by FRCC Environmental Health and Safety (FRCC/EHS). This requires about 0.5-1.0 hrs. time.
        b. Pipets are returned to storage racks (0.5-1.0 hrs time)

c. Cleaning of glassware is minimal because of the design of Small Scale Chemistry laboratories. Students clean items used out of their kits in the drawers and the only dirty glassware and plasticware requiring prep staff attention are those used in preparing solutions. Cleanup requires a maximum of 1 hr (usually less).
d. Total average clean-up time: 2-3 hrs.

6. **Wastes Generated**
   1. Chemical waste:
      a. Volumes generated average less than 200 ml/experiment
         1. Many can be pHíd and then sink disposed
         2. Some require storage in a proper chemical waste container (brown glass with good cap). Once a semester they are removed by FRCC/EHS.
         3. SMQA poses some problems but we collect that waste separately and handle it as detailed in "**Attachment A**". We have rewritten this laboratory to eliminate use of mercury and chromium which pose special disposal problems.

      b. Much of our solutions are recycled since the pipets do not normally become contaminated and the remaining solutions in them can be re-used.

   2. Solid waste:
      a. Paper, straws, thin stem pipets, etc. are disposed of in the regular trash
      b. Pasteur pipets are always disposed of in hard red plastic tubs to prevent injuring staff (and students).

7. **Summary and Observations:** My role as Laboratory Coordinator here at FRCC includes overseeing the set-up and break-down of a large number of biology, anatomy and physiology, and microbiology laboratories, in addition to our chemistry laboratories. As such, the ease of preparation and clean-up for the Small Scale Chemistry classes is greatly appreciated. The costs are well-within our budget, many of the solutions are stable for a long period of time and can be stored in the pipets which the students use. Further, the waste generated is mostly minimal and easily dealt with. The materials do not take up too much room, another positive aspect in a busy prep room with less than ample storage space. We have utilized Small Scale Chemistry for a number of years and with dozens of instructors and hundreds of students and have found that the students have an enjoyable and motivating learning experience. One of our college-wide goals is to be a "Learner-Centered" institution and Small Scale Chemistry ably rises to this endeavor. Students learn by doing and this program is designed to accommodate this goal.

[1] Actual prices for supplies are not itemized here. A complete breakdown of costs per item are delineated in **the report** (in **Microsoft Excel format**) by Ms. Lynne Judish. Many of the supplies are obtained from her distributorship ("Small-Scale Science Supplies") and the rest are obtainable from well-know sources such as Fisher Scientific and VWR which provide us with State of Colorado contract pricing.

Attachment A:

Protocol for Disposing of SMQA Aqueous waste:

1. Treat liquid waste with ~1.0 M NaOH to precipitate out silver, copper(II), cadmium, iron(III), chromium(II), nickel(II), manganese(II), lead(II), and zinc hydroxides ($AgOH$, $Cu(OH)_2$, $Cd(OH)_2$, $Fe(OH)_3$, $Cr(OH)_2$, $Ni(OH)_2$, $Mn(OH)_2$, $Pb(OH)_2$, and $Zn(OH)_2$); filter out any solids.

2. Repeat Step 1 at least twice or until no new solids are formed.

3. Save solids and record mass for EHS removal, and mark as "silver, copper(II), cadmium, iron(III), chromium(II), nickel(II), manganese(II), lead(II), and zinc hydroxide waste."

4. Add ~1.0 M HCl until remaining liquid waste is pH ~7 and sink dispose with copious amounts of cold water.

This procedure is based on the very low solubilities (large pK_{sp} values) of the respective hydroxides of Ag^{+}, Cu^{2+}, Cd^{2+}, Fe^{3+}, Cr^{2+}, Pb^{2+}, Ni^{2+}, Mn^{2+}, and Zn^{2+} as determined from the data in "Langeís Handbook of Chemistry." pK_{sp} values for the metal hydroxides are shown below.

Remaining liquid waste will contain less than ppb concentrations of all metal ions.

Nominal percentages by mass (assuming an equimolar mixture) for each metal hydroxide in the metal hydroxide mixture are shown below.

	pK_{sp}	mass %		pK_{sp}	mass %
$Cu(OH)_2$	19.66	9.04	$Ni(OH)_2$	14.7	8.58
$Cd(OH)_2$	13.6	13.47	$Mn(OH)_2$	12.72	8.21
$Fe(OH)_3$	37.4	9.87	$Pb(OH)_2$	14.93	22.22
$Cr(OH)_2$	15.7	7.93	$Zn(OH)_2$	16.92	9.13
AgOH	7.71	11.53			

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