A New Approach to the General Chemistry Laboratory

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Background

Canisius College is a medium-sized liberal arts college with a long-standing tradition of maintaining an excellent chemistry program. We realized a few years ago, however, that this tradition was not being sustained by our General Chemistry laboratory course, which had not changed significantly in years. With the help of a grant from the National Science Foundation, our department has been able to design a new laboratory course built around several guiding principles. The design called for experiments to be grouped in units or clusters. Each cluster has a unifying theme or common thread, which gives some coherence to the experiments. The clusters and experiments are listed in the appendix and briefly explained below.

Course Design

Cluster A’s topic is organic and polymer chemistry, and its main objective is to show that chemistry can be enjoyable and relevant to common experiences. Data collection is minimal and hands-on manipulation with observable products is emphasized. Cluster B is a case study of the chemistry of maintaining a swimming pool. The common theme is solution chemistry, and the experiments are designed to promote critical thinking. Cluster C encompasses both oxidation–reduction reactions and electrochemistry, and attempts to show the commonality of these important topics. Cluster D is a series of experiments on methods and techniques of analytical chemistry; in this group the analysis of unknown materials is undertaken. Cluster E is covered last in the second semester, and it stresses important concepts in chemistry at a slightly more advanced level. The emphasis is on the relationship of experiment to theory, and the cluster involves experiments in kinetics, equilibrium, and synthesis.

Other guidelines that we considered important in our design were the use of computers (when appropriate), the introduction of microscale chemistry, and the use of instrumentation whenever possible. A separate cluster, labeled Mac, was developed to provide all students the opportunity to become proficient with Macintosh computers, which are used for data manipulation in some experiments. Another feature of the laboratory design is worthy of note. The experiments do not necessarily follow the topic chronologically as it is presented in the lecture. Instead, each cluster has a fairly extensive introduction, which summarizes the chemistry in that cluster. We had a reason in mind when we did this. In the past we have been content to cover the material in the lectures and to use the laboratory for confirmation of what the student had already learned. The results of laboratory experiments are known beforehand, and the students expect these results. An “unknown” given to the student merely allows the teacher to assess the student’s lab technique and/or ability to calculate from the data a particular parameter of the unknown, such as its molar mass or its concentration. This, of course, is not the way science is done; the answers are not known before the experiment. In the normal course of scientific investigation, experiments are carried out to provide information needed for advancing knowledge, and not simply to confirm what is already known. In our design, ideally the students do the experiments to generate useful data. It is clear to them from the outset that there are no “correct answers.” Data sampling and statistical analysis of the results are part of the experiments. In the course of developing these clusters, some questions arose that required further research. Several more advanced students have become involved in addressing these problems. One study on the “golden penny” demonstration resulted in a recent publication in this Journal (1).

Student Evaluation of the Course

An evaluation instrument was developed by two professors of the Psychology Department at Canisius College. It was administered at the end of each semester to all students taking General Chemistry. In addition, at the end of the second semester, the same professors engaged a group of 14 students (representing a cross section of the whole class) in a 75-minute discussion of many aspects of the courses.

As presented above, we made no attempt to perfectly synchronize the lecture and lab. In spite of our rationale, students invariably found this unappealing. They clearly prefer to have the matter covered in lecture before they perform an experiment on the particular subject.

In general, students expressed a positive view of the lab experiments, particularly the “experiment and observation” component. Somewhat more than half agreed or strongly agreed that the lab course stimulated their interest in chemistry. Most (80%) thought the number of experiments that we attempted to do was “about right”, and they considered the experiments well written with clear directions (86%). As regards the use of microscale techniques, the overriding response was neutrality, both in the enjoyment and in the perceptions of this as “new and different”. The use of computers in some experiments was not perceived as difficult, nor was it seen as especially helpful in increasing understanding.

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of chemistry. The component of the experiments most disliked by students and considered most difficult was the data-sheet reports. (Because these contain the observed data and the calculated results, this is probably not surprising.) The students were required to keep a notebook, and 68% found this an aid in taking tests on the lab work.

Instructors’ Observations

The instructors consider these experiments to be an improvement over the experiments they replaced. Students showed an interest in doing the experiments without the usual activity of trying to determine from other students the “correct” answers. One prelab presentation can cover an entire cluster, and weekly prelab directions take minimal time. The students learned to keep detailed notebooks, since they could use the notes for the exam at the end of each cluster.

In summary, we believe this laboratory course meets most of our objectives. Student dissatisfaction with doing experiments at a time different from lecture coverage of the material must be weighed against their acceptance of other beneficial aspects of the laboratory: doing experiments without predetermined or expected results; keeping a detailed notebook; writing reports that include notations of both precision and accuracy; and relating chemical analyses to everyday common experiences.

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Literature Cited


Appendix. List of Experiments

Cluster A: Carbon is Number One

Experiment:
A1. Formation of Silicate and Polyvinyl Alcohol Polymers
A2. Measurement of the Heat of Reaction of a Hydrocarbon
A3. Gas Chromatographic Separation of a Mixture
A4. Step-growth (Condensation) Polymerization
A5. Chain-growth (Addition) Polymerization

Cluster B: Swimming Pool Experiment

Experiment:
B1. Determination of the pH of Pool Water
B2. Determination of the Alkalinity of Pool Water
B3. Determination of Chloride Ion Concentration in Pool Water
B4. Determination of Free and Total Chlorine in Pool Water
B5. Determination of the Total Hardness of Pool Water
B6. Analysis of Swimming Pool Data Using a Spreadsheet: Calculation of Saturation Index and $[Ca^{2+}][CO_3^{2-}]$ Ion Product

Cluster C: Show Your Metal

Experiment:
C1. Multiple Oxidation States of Manganese
C2. Stoichiometry of a Redox Reaction
C3. Determination of the Empirical Formula of a Transition Metal Oxide
C4. Iron Determination by Titration with Permanganate
C5. The Driving Force of Redox Reactions: Reduction Potentials and Electrochemical Cells
C6. Concentration Cell
C7. Constructing a Commercial Battery
C8. Experiments with Pennies

Cluster D: The Mystery Module

Experiment:
D1. Color Additives in Foods: Thin Layer Chromatography
D2. The Eight Test Tube Challenge
D3. Acid–Base Titration: Classical Analytical Method
D4. Acid–Base Titration: Potentiometric Titration
D5. The Oxidizing Strength of Household Bleach
D6. Analysis of Copper in Brass
D7. Analysis of Fluoride Ion in Drinking Water

Cluster E: Think Like a Chemist

Experiment:
E1. Kinetic Study of an Oxidation–Reduction Reaction: A Clock Reaction
E2. Determination of the Equilibrium Constant of FeSCN$	ext{B}^+$
E3. NO$_2$/N$_2$O$_4$ Equilibrium: Variation with Temperature
E4. Synthesis of a Coordination Complex of Iron: $K_3[Fe(C_2O_4)_3]·3H_2O$

Cluster Mac: Computers in Chemistry

Experiment:
Mac1. Signing on to the Canisius College Macintosh Network
Mac2. Using Excel and Summary of Basic Spreadsheet Operations
Mac3. Temperature Conversion and Percent Composition using Excel

Note: Several experiments will make use of Cricket Graph and Excel for analysis of the data and presentation of the results.