A Service-Learning Project Based on a Research Supportive Curriculum Format in the General Chemistry Laboratory

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Various authors report that undergraduate students lack important science (research) processing skills critical to successful careers *(1–8)*. Functioning in today's fast-paced society requires skills in critical thinking and problem solving. Oral and written communication skills are essential to effectively communicate objectives, strategies, and results. Another important skill graduates are expected to have developed is the ability to cooperate in establishing and reaching clear goals and objectives. Service learning is an important pedagogy component of chemical education *(9–14)* that can provide experiences for students to develop these needed skills. The intent of service learning is to provide students with an opportunity to form connections between lecture–laboratory knowledge and an application of that knowledge to benefit the community.

A service-learning project is described where second-semester general chemistry laboratory students use newly developed science-processing skills. The project requires creating and communicating an interactive concept-discovery session to a kindergarten through sixth grade (K–6) class incorporating research-processing skills. To successfully accomplish this task, general chemistry students must become adept at the research process while simultaneously learning fundamental general chemistry concepts. Discovery-oriented labs are used in the first and second semesters where students create their own knowledge with guidance to rediscover fundamental concepts of chemistry, not verify (as in traditional labs). Essentially, the students learn to become researchers. By including the service-learning component, students take on the role of instructors for K–6 students. Additionally, through the service-learning project, students use their newly cultivated science skills and improve their processing skills by searching, reading, and evaluating literature necessary to articulate a research question and design an experiment for a K–6 class. The general chemistry students must effectively communicate the results of a scientific investigation by assisting the K–6 students to formulate scientific explanations using the generated experimental evidence.

Developing Science-Process Skills

While general chemistry labs often focus on content, the process of science is also essential. This component is often lacking from traditional general chemistry laboratory manuals containing organized data tables and detailed procedural steps directing students when to make particular measurements, observations, and step-by-step calculations. Little of this pedagogy teaches students the process of science or tools to assess new situations and problems in the real world. Traditional labs generally verify chemical principles rather than discovering them *(15)*.

For students to learn the process of science, a research-supportive curriculum and pedagogy are crucial *(16–19)*. The common source of a research experience is from a capstone undergraduate research (independent problems) course. Research-supportive curricula to develop science processes should be applicable throughout an undergraduate's education. Important research skills include searching, reading, and evaluating literature; articulating a research question; designing an experiment; formulating scientific explanations using experimental evidence; and effectively communicating the results of a scientific investigation. These skills are also the same sought by employers and entrance committees for graduate and professional schools but are often found lacking. Because the program at this university affects all general chemistry students, it has a greater impact on the educational development of more students than the capstone research experience.

Interest is growing in developing methods to emphasize science processes in general chemistry and other areas of chemistry *(8, 20–30)*. The Process-Oriented Guided-Inquiry Learning (POGIL) consortium's approach aims to engage students in the learning process; help students master material through understanding rather than by memorizing and pattern matching; and develop essential learning skills *(31, 32)*. The strategy is based on the learning cycle documented as how we learn best *(28, 33–36)*. The learning cycle consists of three phases: exploration (data collection in the laboratory setting), conceptual invention (what was learned from the lab), and application (new experiment, answer questions, etc.). Carrying out these phases involves key stages in the science process (i.e., the learning cycle describes the scientific research process).

Learning-cycle components involve problem-based learning and cooperative learning or team learning *(1, 22, 37–43)*. In the laboratory, problem-based learning means that students are engaged in active learning during experiments. Little information is provided about how to perform experiments and students are expected to make their own decisions. Team learning involves working in groups allowing students to share knowledge and explain concepts to peers improving cognitive processing by students.

The new structure in the general chemistry lab emphasizes the investigation process. Students work in teams designing experiments to answer a research or focus question. The instructor interactively guides students to develop a class procedure. This prelab component of the laboratory period typically occurs by writing the evolving design on the chalk board as suggestions are made. During the experimental component, students perform the experiment and gather data. The last portion of the laboratory period is devoted to postlab discussions, student presentations, reflection, and possibly a new experiment. By carrying out these discovery-oriented labs, students learn the science process necessary to successfully accomplish the service-learning project in the second semester.

A unique component in the first semester is a student project where students develop a lab proposal formulating a discovery lab for use as a general chemistry lab. One lab proposal is selected by students from all laboratory sections and then implemented for the last lab of the semester.

A few case-study labs from the literature are used to provide context-rich problems in the framework of real-world situations, that is, cases present complex real-world dilemmas requiring team work and critical analysis *(44–48).* Case studies often necessitate searching, reading, and evaluating literature, an important part of a research-supportive curriculum. A case study is used in the first semester during the first week to create an environment where students feel comfortable by reducing formalities. The case study consists of a manager for a scientific consulting firm who has to hire an entry-level scientist based on five applicant portfolios. Students are asked to develop a strategy (criteria, qualities, skills, etc.) to rank candidates based on strengths and weaknesses. In the postlab discussion, student-identified skills are noted as the same process skills the laboratory course intends to develop. This case study is not new to the chemical literature and the case-study material including job application portfolios is readily available in ref *45*.

Discovery Labs

During each semester of general chemistry, laboratory sections meet weekly for three hours with 20 students per section. At the beginning of each semester, students are divided into teams of three or four students with maximum heterogeneity, for example, gender, ethnicity, and scholastic abilities *(25, 43, 49).* Students work in a traditional setting of lab benches equipped with cup sinks and gas, vacuum, power, and water outlets. Hoods are along the wall. A computer lab of personal computers is in close proximity.

For each laboratory experiment, students are provided with a single page of information composed of background material to orientate students on the importance of the topic and most importantly, a research (focus) question. Students must design experiments to answer the focus question. Listed in Boxes 1 and 2 are example information sheets and the online material has one more. At first, most students are intimidated with the idea of developing an experimental design. This anxiety is largely alleviated by the third week.

The discovery-based labs build up student confidence, developing a sense of independence in the laboratory. Much of this new-found confidence stems from the fact that the students formulate their own experimental designs and then use these designs to successfully answer research questions. Another source of confidence involves overcoming fear of making mistakes. Specifically, traditional laboratory experiments often teach students to fear mistakes that can cost time and grade points *(51).* In the new laboratory course, students realize that mistakes teach them valuable lessons and the fear of mistakes is overcome.

All labs have three fundamental phases consisting of a prelab, experimental, and postlab. While the approach is largely modeled after that described in refs *14* and *15*, the next three sections provide brief information on each respective lab phase to stress the importance of developing the science-process skills needed to effectively accomplish the second-semester service learning project. The complete list of labs in the online material shows that the usual fundamental general chemistry concepts are covered. The labs are also designed to provide a broad experience with basic laboratory skills such as glassware manipulations, measurement procedures, including pH meters, balances, and spectrophotometers, and data analysis with a spreadsheet.

Prelab

Throughout the prelab (and the rest of the lab period as well), the instructor acts as a facilitator and prompts students with guiding questions to force them to think about what they are doing to design the experiment. The intent of starting with a focus question is to put emphasis on the investigation process compelling students to create their own knowledge through a discovery pedagogy and have students actively participate in the scientific process (student-centered active learning). In this way, students rediscover concepts rather than following directions to verify.

The focal question orients students toward concepts to be developed and acts as a connector between known concepts and the ones they are expected to form. Hypotheses or predictions

Box 1. First-Semester Instruction Sheet for Discovery Lab

Determining the Percentage Composition of a Mixture

Overview: Scientists often work with samples that are mixtures. The first task is usually to separate the mixture into the different components. From this process and other data that can be measured, the percentage composition can be determined.

Question of the Day: What is the percent composition of the provided mixture?

Your Assignment: You will be given a mixture of two substances consisting of a water-soluble solid and an insoluble solid. Formulate an experimental design to determine the percent compositions of the mixture.

Waste Disposal: Your TA will instruct you on proper waste disposal. All glassware that you used must be cleaned and returned to the sideshelf.

Box 2. Second-Semester Instruction Sheet for Discovery Lab

Developing a Reduction-Potential Table

Overview: There is no way to measure voltage for a half-reaction; however, voltage can be measured for a redox reaction. Since the redox reaction can be divided into two half-reactions, it is possible to determine a standard reduction voltage (potential) and a standard oxidation potential for a given redox reaction. This relationship is

$$E^\circ_{\text{cell}} = E^\circ_{\text{red}} + E^\circ_{\text{oxd}}$$

where E°_{cell} denotes the standard voltage for the overall reaction, E°_{red} symbolizes the standard reduction potential, and E°_{oxd} signifies the standard oxidation potential. Thus, if the cell potential is measured and either the reduction or oxidation potential is known, the other can be determined.

Question of the Day: Using a silver electrode (standard potential of 0.80 V relative to the standard hydrogen reference electrode), how can standard reduction potentials of other metals be determined and hence tabulated?

Your Assignment: You will be provided with half-cells of silver, lead, cadmium, zinc, and copper with salt bridges. Each half-cell consists of the metal and a nitrate salt solution of the metal, e.g., Ag metal and $AgNO_3$ for the Ag half-cell. Given that the standard reduction potential of silver is 0.80 V, design experiments that use a multimeter (volt meter) and the half-cells to determine the standard reduction potentials of the other metals. Form a reduction potential table with results tabulated from largest to smallest. Compare your measured values to those tabulated in Table 6 on page 96 of ref *50*.

Prelab Assignment: Sketch a diagram of an electrochemical cell. Label all key components.

Box 3. Example Lab Focus Questions

What is the mathematical relationship between Celsius and Fahrenheit? (1)
What are good apparatuses for measuring approximate volumes and accurate and precise volumes? (1)
What is the formula of the copper(II) hydrate? (1)
What is the molarity of a saturated solution for the provided substances? (1)
What are the heats of solution for the provided substances? (1)
What is the relationship between temperature and time to carry out the following reaction? (2)
For what types of salts and acids can a pH meter be used to estimate the K_{sp} and K_a, respectively? How can this be accomplished? (2)
Using a silver electrode, how can standard reduction potentials of other metals be determined and hence tabulated? (2)
What is the relationship between color, wavelength, absorbance, and concentration? (2)

Note: Values in parentheses indicate first (1) or second (2) semester.

are prompted from the lab section and an experiment is designed. Sometimes the start-point is a prelab assignment where team presentations are made before going into the focus question and development of the experimental design. The prelab assignment usually consists of questions or problems to initiate the prelab phase with discussions of transferring concepts to assist in forming testable hypotheses. Numerous variations are possible with this flexible discovery-based format. Depending on the class prelab discussion direction and student creativity, some teams may use different procedures. After the first semester, students are comfortable with the idea of designing experiments. Thus, second-semester labs are generally designed in teams with oral presentations of designs.

Boxes 1 and 2 show example instruction sheets provided to students. The typical assignment from a lab-instruction sheet is "Formulate an experimental design to ..." . Listed in Box 3 are other focus questions for the two semesters. At the beginning of the first semester, questions are simple and primarily meant to assist students in realizing that even answering a simple question scientifically requires several levels of deliberation and decisions. As the first semester progresses, the degree of complexity increases as the students begin to learn more chemistry from lecture and are becoming comfortable and confident with processing skills they are learning from previous labs.

Experimental

During the experimental phase, students carry out designed experiments and collect data to sustain or challenge the hypothesis. At some point in the experimental portion, data analysis occurs including calculations, plotting, observing data trends, and so forth. Throughout the experiment, the cooperative nature of teams is emphasized for scientific discoveries by relying on division of labor and team discussions of experimental results in preparation for class discussion in the postlab.

Postlab

In the postlab, data are often pooled and if applicable, team graphics are posted. Posted data are first interpreted in the teams, followed by oral team evaluations, and concluded with a class discussion. If the results do not support the hypothesis, then a new hypothesis needs to be formed. New experiments or issues can be proposed and if time allows, experiments can proceed. In the postlab, the instructor can solicit applications of the new concept or assign problems using the developed concept. Essentially, reflection on what has been learned and how to use the new knowledge occurs during postlab.

Lab Proposal Project

During the first semester, students have been designing experiments to answer focus questions. For the first-semester lab project, students are now required to design all aspects of a discovery-lab experiment to teach a chemical concept as if they were the instructor. Many students come up with their own experiment and some are obtained from journals and Web searching. Changing a variable in a previously performed lab is acceptable. This portion of the course provides the opportunity to gain experience and understand what is involved in formulating a lab. The project also assists students to identify processes for effective teaching and what will be useful in the next semester service-learning project.

Six weeks are allocated for team development and presentation of this lab proposal. The first four weeks provides ample time for teams to search the literature (if necessary), discuss all required components, and fully develop the proposal. In the fourth week, lab proposals are collected and distributed to other teams whose task is to critique proposals. Critiques are returned allowing teams to revise proposals to better meet evaluation criteria. In the fifth week, final versions are due and teams orally present proposals. Respective laboratory sections vote on the best proposal and winning proposals are posted to the lecture Web page and the complete class votes. Students vote based on how well the lab proposal addresses required material. The final winning proposal is used by the students and instructors in the last week of class.

Required proposal components consist of a focus question instruction sheet that can be used as a student handout and a teaching guide. Students use instruction sheets from previously performed labs to guide them. The teaching guide requires specific sections on relevant concepts, inquiry-oriented guiding questions, common student misconceptions, potential procedural and calculation errors, materials and equipment list with a budget, actual procedural steps, safety precautions, hazardous waste disposal, and references. Even though the lab is not actually tested, students gain the benefits of problem-based and team learning. Students in a team work together to agree on what to and not to include in the lab proposal while each student is responsible for different aspects of the proposal. The syllabus in online material further describes the project components.

Service-Learning Project

The second-semester project requires students to use their newly developed science-process skills by developing and carrying out a discovery activity for a K–6 class. Six weeks are allocated for team development and presentation of this service-learning project. Specifically, students design, develop, and complete an interactive concept-discovery activity titled with a research question that teaches a chemical concept(s) to a K–6 class. Students are instructed that the project is not a chemistry demonstration to impress the K–6 class but must actively engage the students to participate as a class. Each element of the discovery session requires guiding questions from the team and answers from the K–6 students before the next part can be discussed or carried out. The idea is for a team to guide the K–6 students into forming the experiments the team has brought to answer the research question. The chemical concept(s) being taught must be connected to how chemistry affects their everyday lives at home, in the classroom, on the playground, on vacation, and so forth.

From completing the first semester and after much of the second semester has passed, students have designed a multitude of experiments with oral presentations of results and a formal report (lab proposal) on a team-developed discovery lab. Thus, students are knowledgeable in the discovery-based lab format and have gained confidence to devise their own inquiry-oriented approach for the service-learning project where the K–6 students are now the student-centered active learners. This project requires the chemistry students to articulate a research question as well as formulate and effectively communicate scientific explanations to the appropriate age group.

A list of teachers in the area willing to work with the project is provided and the teams make all contacts and arrangements. Teachers are previously informed of what to expect from the students and are requested to fill out an evaluation sheet after the students have completed the activity. The online material has this information.

With four weeks allocated, students have ample time to test procedures and think through how it works or why it did not work and corrective action. The project also requires a written report and a poster left with the K–6 class. Team oral reports are given in the last week of the semester and overview written reports and their service-learning experience. Required material for the written report consists of an overview; relevant concepts and connections to real world; materials and equipment list (with budget); safety precautions and hazardous waste disposal; script with questions to guide K–6 students to develop experiments; and references. Before a team can start its project, an abstract and list of materials must be approved by the instructor (see the syllabus in the online material).

Some project focus questions are (i) Why is salt used when making ice cream?, (ii) Is there iron in your cereal and how can you get it out?, (iii) Why do rocks float?, (iv) Why do sunsets and sunrises have color?, and (v) What are the phases of matter? As a typical example, the online material contains a presentation given by students summarizing their project addressing the last question. Briefly, the team first introduced properties of matter to a second-grade class to develop the ability of the students to distinguish between different phases of matter with the ultimate goal of challenging the class to identify an undefined phase of matter as either a solid or a liquid. The connection to the real world is that different phases of matter are all around us in everything we do. Thus, the chemistry students hoped to develop the second graders' analytical skills to make their own inferences with anything they encounter. Using an interactive poster, the chemistry students involved and guided the class to answer the questions: Do you know what the different phases of matter are? and Do you know what determines a solid, liquid, or gas? To address the second question, the chemistry students focused on how molecules are oriented in each phase of matter using models. The class then made slime and was asked: Is it a solid or a liquid? A hypothesis was formulated and experiments were designed by the second-grade class and carried out followed by discussion and reflection on what was learned. In addition to the poster, the second-grade students were given a word game on the activity and some slimy candy. This student project contains all the science-process components emphasized by the lab course.

On average, there are 40 service-learning projects carried out by approximately 160 students and about 100 K–6 teachers typically indicate a desire to participate. Thus, it is not difficult for teams to find a willing teacher. In the two years of these projects, there were two mishaps in the first year and none in the second. The mishaps stemmed from miscommunication in scheduled visits and the process is now better clarified to the students and K–6 teachers. The online material contains the information in the syllabus and the teacher expectation document.

Instructor Training

Most lab sections are taught by teaching assistants (TA) and thus, some training is essential owing to the importance of the TAs teaching students the process skills needed for the service-learning project. Prior to each semester, a two-day workshop is held. The workshop begins with each TA introducing another TA describing what that TA thinks their role is as an instructor for the lab. The discovery approach is explained and their role as a facilitator is emphasized. Most of the workshop consists of mock laboratory sessions where TAs work in a team to formulate a couple of prelabs. Each TA then undertakes running a prelab session with the rest of the workshop participants acting as the students. Mock prelab sessions with a TA assigned as the instructor are also held at weekly TA meetings for that week's lab. The TA in charge for the meeting must provide a lab overview explaining goals, list key points needing to be developed by students in the experimental design, explain how their prelab will be run, and their plan for reflection on what was learned.

To assist TAs in forming guiding questions and initiating discussions in the postlab, teaching notes are provided. Some instructor questions for the lab listed in Box 2 are shown in Box 4. The complete set of teaching notes is available in the online material for this lab. The notes contain information regarding how to carry out the experiment including background information on the importance and relevancy of the lab, questions for further thought to generate student responses and discussions, common misconceptions, sample procedures, procedural and calculation errors, safety precautions, and hazardous waste disposal. Several procedures are usually provided of which, any one or more may be used during the lab. Depending on the level and creativity of the class, variations can result. In some cases, follow-up experiments are also provided. The material list is available to the TAs to allow maximum flexibility for guiding students to design the experiment. However, students sometimes limit themselves in designs when they see what chemicals and equipment are available in the laboratory that week. Procedures

Box 4. Example Teaching-Note Questions for Lab in Box 2

1. What is an electrochemical cell?
2. What is a redox reaction?
3. What is a standard reduction potential?
4. What is a standard oxidation potential?
5. For Table 6 on page 26 of ref *50*, what is the reference electrode?
6. What is the purpose of a reference electrode in measuring the cell potential of an electrochemical cell containing the reference electrode?
7. Do batteries have a reference electrode?
8. There are 5 half-cells, how many electrochemical cells can be measured?
9. What data are to be collected and how should they be organized?
10. How do the experimental reduction potentials compare with the tabulated values? Why is there a difference?
11. What is the reference point for atomic masses?
12. What is the reference point for electronegativity?
13. Why are all reduction potentials in Table 6 relative to the hydrogen electrode?
14. If the hydrogen reference electrode was used with the standard silver electrode to form an electrochemical cell, what would the cell voltage be?
15. What have we learned today?
16. How is what we learned today relevant or applicable?
17. Based on what you have learned today, how would you answer the question … ?
18. Using what you learned today, work problem …

that are legitimate, but not possible due to lack of equipment or time constraints are also noted.

Evaluation

Because the discovery-lab component of each semester is patterned after that described in refs *14* and *15*, this aspect has not been formally assessed with tools such as student assessment of learning gains (SALG) *(52)*. However, the teaching methodologies implemented are well-documented *(43, 53–55)* and have been used elsewhere with improved assessment results *(8, 25, 29, 31, 56, 57)*. End-of-semester solicited student comments were favorable with comments such as "All the labs are well worthy and understandable."; "The lab experience was the pinnacle of undergraduate education."; and "The lab experience which possessed this my last semester was utterly effervescent and refreshing." In general, students enjoyed the discovery-lab approach and found projects to be interesting and the service-learning component to be rewarding. Projects from both semesters were of good quality.

The focus of the pedagogy described here was to teach the chemistry students the science process to successfully complete the second-semester service-learning project. Thus, a useful assessment is the feed-back from the K–6 teacher evaluation form. (A copy is available in the online material.) In the first year, 100% were returned and 99% in the second year. The overall K–6 teacher reaction was enthusiastic. In the first year there were some comments reflecting problems with age appropriateness of the activity. This aspect was further emphasized to the general chemistry student in the second year and fewer negative comments were received.

All K–6 teachers expressed a desire to continue participation the next year. To the evaluation question "Was the activity interactive and discovery or explorative in design?", answers were unanimously yes. Typical comments were "The students were involved and engaged."; "This activity was very interactive and had the students moving and exploring. I think the student came up with wonderful-great ways to teach."; and "They were able to engage the students through questioning, demonstrating, and explaining. They allowed/asked students to make predictions, and then reflect on the actual results." Common responses to the question "Was the chemical concept relevant to the students' everyday lives?" consisted of "They were able to clearly relate the chemical concept to the students' everyday lives through examples and conclusions. They continuously checked for understanding and reworded or showed them in a different way until understanding was obtained." and "Yes, your students did a good job of using items that my second graders were familiar and comfortable with." Numerical scores to the teacher ratings of the activity ranged from 9 to 10, on a 10-point scale, while the overall process satisfaction rating was unanimously 10.

Conclusion

Two approaches to incorporating science processes into laboratory courses are (i) to use an inquiry-based method where chemical principles are rediscovered and (ii) to integrate a real-world application to stimulate student interest and learn the importance of chemistry. These approaches can be guided or open ended. This article describes a method to incorporate the first approach into general chemistry. Students are guided to develop experiments to answer incrementally more difficult focus questions through the semesters. The first semester concludes with students designing a discovery lab for use in general chemistry. In the second semester, students put their developed skills to designing a K–6 guided-inquiry activity. By using this holistic approach to teach the science process, students should be better prepared for the real world, that is, students are presented with an opportunity to understand what science is, not just a hands-on experience. Student teams actively participate in the scientific process creating their own knowledge through a discovery-based pedagogy. From this approach, students should be better tooled to think scientifically with improved reasoning ability to make their own decisions and solve problems together by sharing knowledge. Confidence also increases and experience is provided in written and oral communication of scientific concepts. Essentially, any traditional lab can be converted into a discovery-lab format by removing information students need to generate for themselves *(9)* and most importantly, eliminating the experimental procedure.

While the approach described here was developed for a two-semester general chemistry course, it can be adjusted to fit a one-semester general chemistry course. The first-semester lab proposal project would need to be removed and the number of discovery labs reduced. The level of maturity in the service-learning projects may not be as great as with the two-semester approach, but the K–6 students would still be able to learn the science process.

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Supplement

Syllabi, laboratory schedules, example student lab instructions with instructor teaching notes, a selected service learning report, K–6 teacher expectations, grading protocol, and evaluation tools