An Environmentally Focused General Chemistry Laboratory W

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College-level general chemistry is a course taken by a diverse body of students, most of whom are not chemistry majors. One of the strategies for engaging this heterogeneous group is to present chemical principles in a topical context that can resonate with students' interests outside the field of chemistry. At large universities, where many sections of the same course or laboratory run concurrently, it is possible to offer sections that are tailored to particular interest groups. We have redesigned the second-semester general chemistry laboratory to include three such special sections with an environmental, materials, or biological focus. The goals of each of these laboratories are similar to those of the mainstream section: to develop skills for handling and analyzing data, to teach proper laboratory technique, and to reinforce concepts that appear in the accompanying lecture course. For the environmental section discussed in this article, the basic experiments that are performed early in the course are used to build techniques and understanding that are called upon in a final integrative project, which requires students to design their own experimental approach to a model environmental chemistry problem. This article describes the content of the environmentally focused laboratory and gives a summary of survey responses that measured the extent to which the environmental context helped to increase students' understanding of chemical principles.

Design of the Laboratory

Environmental chemistry—which includes the chemistry of the atmosphere, aquatic chemistry, soil chemistry, green chemical synthesis, and aspects of biological chemistry—can be used as the contextual base for almost all of the material that is taught at the general chemistry level. A similar contextual approach has been described for an environmental analytical chemistry laboratory *(1),* and for a general chemistry lecture–lab module on ionic equilibrium *(2).* For the environmentally focused general chemistry laboratory, we assembled a set of experiments that center around aqueous solution chemistry because of the strong emphasis of the associated lecture course on acid–base chemistry, solubility, ionic equilibrium, and electrochemistry. Within this context, we were able to include material on other topics that were covered in the lecture course, such as coordination chemistry, kinetics, and catalysis. The laboratory also introduced material on separations and aerosol chemistry, which were not covered in the lecture course.

In several cases, the experiments we used were not "new" but were adapted with small modifications from our standard laboratory manual, *Chemtrek (3),* or from literature sources, to fit the environmental theme. For example, an experiment on iron and alkalinity determination was adapted from the Berkeley module on Water Treatment *(2).* Others were based on literature experiments but were changed substantially to dovetail with other experiments or to teach specific techniques or principles. For example, we modified an experiment that teaches kinetics in the context of zero valent iron (Fe^0) remediation of contaminants in groundwater. In the original experiment *(4),* indigo carmine was used in place of an actual contaminant, and its reduction by Fe^0 was monitored by UV–visible spectroscopy. Students completed the first part of the experiment as described in the literature, and then examined the utility of iron filings in the decontamination of groundwater by using gas chromatography instead to measure the disappearance of the pesticide 2,4-dichlorophenoxy acetic acid (2,4-D). We also introduced an experiment in heterogeneous catalysis by comparing the reactivity of nickel-catalyzed and uncatalyzed Fe^0 *(5).* The gas chromatographic procedure was similar to that used in *Chemtrek* to analyze freons, but students used liquid–liquid extraction to prepare the samples for injection. The extraction and analysis techniques were quite similar to those used in the research laboratory to study the decomposition of halogenated organic contaminants by Fe^0. Apart from these modifications, borrowing of topics and methods (especially from *Chemtrek)* helped to ensure that the essential elements of the mainstream general chemistry laboratory were preserved in the environmentally focused one.

The sequence of experiments in this laboratory, the concepts they address, the techniques, and the sources from which the experiments were drawn are summarized in Table 1. Detailed procedures, hazards, and lists of equipment, chemicals and instruments associated with each experiment (apart from those drawn directly from *Chemtrek*) are available in the Supplemental Material.W

Integrative Exercise in Wastewater Treatment

The wastewater treatment laboratory presented students with the following set of learning goals by challenging them to develop their own procedure to analyze and treat a model wastewater sample:

- To identify some common sources of pollution, as well as some specific compounds that may come from each source.
- To use several methods of analysis to identify the unknown contaminants in their water samples.
- To significantly reduce the contamination of their water sample.
- To use everything from the previous experiments to reinforce what they had learned.

For the final project, students worked in pairs to identify the contaminants in the samples they were given, to estimate their concentration, to devise a strategy for removing them, and to estimate their residual concentration in the

Table 1. Experiments in the Environmentally Focused Laboratory

Experiment	Concepts	Techniques	Sources
Introduction to the Laboratory	Safety, laboratory notebook, uncertainty analysis, waste disposal, using the library		Original
Acid–Base Chemistry I Acid–Base Chemistry II	Acids, bases, polyprotic acids, indicators, buffers	Titration, pH measurements	ref *6*
Separation Chemistry: Paper, Liquid, and Ion Chromatography	Adsorption and ion exchange equilibria, separations	Paper, liquid, and ion chromatography	refs *3*, *6*
Fe^{2+} and Alkalinity Testing, and AA Determination of Mg, Ca, Na, and Fe Concentrations	Coordination chemistry, acid–base chemistry, Beer's law, atomic spectra	UV–vis spectroscopy, flame atomic absorption spectroscopy, titration	ref *2* Original
Acid Rain Deposition	Aerosol chemistry, atmospheric reactions, redox chemistry, acid-base chemistry	Cloud formation in a crystallizing dish, observations of color and turbidity changes	ref *3*
Halocarbon Removal I: Kinetics	Kinetics, heterogeneous catalysis	Liquid–liquid extraction, Gas chromatography	ref *4*, Original
Halocarbon Removal II: Analysis	Separations		Original, ref *3*
Wastewater Treatment I	Integrative exercise for reinforcement of all concepts	Previous methods and adsorption–desorption using activated carbon	Original

treated samples. Water samples were spiked with substances that were likely components of wastewater in our local Spring Creek watershed, and each sample contained a set of contaminants that required at least two steps to remove. Only one of these could be something that was removable by simple filtration. Soluble contaminants were limited to salts of various metal cations, an organic dye, and low pH levels: contaminants that they had already encountered in the course, or that could be successfully analyzed by one of the techniques they had used.

In their reports, students were asked to write about possible sources of their contaminants and to compare and contrast the techniques they used in the laboratory setting to those that could be used at the scale and within the economic constraints of practical wastewater treatment. If there were contaminants that they could not remove from their samples, they were asked to explain *why* they were unsuccessful, and to find out how that particular contaminant is removed in large-scale wastewater treatment plants. These activities were intended to help reinforce the connection between the materials students had learned throughout the course and practical issues of wastewater treatment.

Survey Results

This class was run as a pilot in the spring of 2003 with 15 students. An attitudinal survey was conducted at the end of the course to gauge students' perceptions of the value of an environmentally focused laboratory section. The results are compiled in Table 2.

From the instructor's perspective, it was exciting to note that all students responded that they understood how chemistry was relevant in their lives (question 3); the topics covered had broad enough appeal to engage all students in learning chemistry. Students also took a greater interest in making sure they completed and understood the experiments well, as indicated by the longer time they spent in lab when they were doing the same experiment as the regular sections (0.5–1.0 h more) and by the extensive research they conducted for the introductions to the two required formal lab reports.

As with any introductory laboratory course, there was a necessary period of introduction to instrumentation and to basic chemical concepts. The bulk of the course consisted of experiments designed to build students' analytical skills and to introduce them to current chemical solutions to environmental problems; these experiments helped the students develop the necessary background skills to complete the wastewater treatment experiment. During this time, background information, quiz questions, and postlab write-ups highlighted the environmental applications of the chemistry, though this could have been more extensive (question 4). The curriculum is designed to include a field trip halfway through the course to an acid-mine drainage remediation site or wastewater treatment plant; such a trip would have demonstrated the relevance of the analyses conducted in the earlier, more structured experiments (question 4). Clearly, the students preferred the open-ended, capstone wastewater treatment experiment (question 2). Though the experiment was not designed to be quantitative, a few groups devised methods to make it quantitative with the available resources. Many were surprised by and proud of their newfound abilities as water chemistry sleuths. Overall, the overwhelmingly positive responses confirmed our initial reasoning that some students would benefit from a context-based course.

Table 2. Summary of Student Assessment

Questions	Responses (*n* = 15)
1. What topics did you enjoy investigating in this course?	The "waste water lab" was mentioned most frequently (4 students). One student called it "a joy". The second most frequent response was "all of them" (3 students).
2. Which experiment was your favorite and why?	The overwhelming favorite was the "waste water lab" (11 students). Some of the reasons given: it involved "real life", it was "open-ended", it involved "thinking" and "group work", it was "less cookbook", it was "self directed".
3. Did setting the chemistry in the context of environmental issues help to increase your understanding of the chemical principles? Why or why not?	All 15 students responded, "yes". The dominant reason had to do with relevance, for example, "I understood why we care…", "[I]… see how everything we learn in the labs actually means something in reality", "it actually provided relevance, unlike most other chemistry classes I've had", and "learning about something that actually matters is always more interesting".
4. What would you change?	Most comments recommended pushing further in the direction that we are already going, for example, there were suggestions to include more open-ended labs, to shorten or remove the structured labs, to include more information on environmental relevance, and, if possible, a field trip. Two students indicated that they would not change anything.
5. Would you recommend this course (with changes) to future students?	Fourteen of fifteen students responded positively. One student left the question blank. The students clearly felt that this type of class would be of interest to typical students. "I think it is a good class for everyone." "I would recommend it to students in any science or engineering discipline, because the course is partially about problem solving, which is important for everyone."

Conclusions

The environmentally focused general chemistry laboratory provides a format for teaching the basic concepts of our mainstream laboratory course within an environmental context. The real-world relevance was, according to all students surveyed, a positive factor in stimulating them to master the material. The capstone integrated exercise emerged as the overwhelming favorite part of this laboratory. This experiment gave students an opportunity to do a self-directed project, using the tools they had already mastered, to solve a problem that they considered relevant to environmental issues.

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[W]Supplemental Material

The laboratory manual is available in this issue of *JCE Online.*

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