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Chemistry and the Environment: Pedagogical Models and Practices

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Chemistry and the Environment: Pedagogical Models and Practices

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Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

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Preface

As evidenced by the chapters within this volume, the field of chemical pedagogy is diverse. Models employed by authors of these chapters include guided-inquiry learning, peer-mentoring, service learning opportunities, project-based exercises, flipped classrooms, and studies-abroad. While these approaches differ, the one common thread is the use of environmental topics to capture the attention of students who then use chemistry concepts to further explain those issues and concepts. However, there is no single, optimal methodology that triggers maximum learning for all students. Additionally, different institutions are equipped with varying resources and have distinct student requirements. To complicate the matter, the way students learn is changing with the advent of new communication technologies. Therefore, different strategies are necessary now and into the future. What makes this volume unique is the compilation of examples that traverse the pedagogical field in chemistry. Each chapter within this volume provides a brief background on the specific methodology used, as well as reference to published works in the field. Thus the reader interested in environmental issues and concepts can extract detailed information from these pages on how to develop context-based activities or courses using a range of different models.

This volume, *Chemistry and the Environment: Pedagogical Models and Practices*, is a product of a symposium sponsored by the Environmental Chemistry Division of the American Chemical Society held during the 249th National ACS Meeting in Denver, Colorado in March of 2015. Several of the models in this volume were presented as papers at that symposium; other models came from invited authors. The common theme for these methods is context-based pedagogy in which chemistry concepts are presented to students through the examination of environmental issues and concepts.

King *et al.* (Chapter 1) provide an introduction to context-based learning through use of Process Oriented Guided Inquiry Learning (POGIL). A description of the learning cycle is included as well as how it is used by the authors to develop the climate change, context-based POGIL activities presented here. Five different information models, typically used in POGIL activities, are outlined with specific examples to introduce the process of model choice for the development of new context-based POGIL activities.

Eves *et al.* (Chapter 2) outline the peer-mentoring program presently used in the Southern Utah University Water Laboratory where students manage and run day-to-day operations of a water quality testing laboratory. In order to circumvent problems associated with frequent turn-over, a highly-organized peer mentoring program facilitates the process of management, training and information transfer. This chapter chronicles the evolution of a context-based approach where students

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learn by on-the-job training of laboratory techniques, management, teamwork, and customer service.

Weaver and Eves (Chapter 3) describe an analytical laboratory course in which environmental chemical analysis is the main focus. In this pedagogical model, principles and techniques are introduced to students and then applied to environmentally-oriented service learning projects. Students work in groups to carry out various water quality tests of a creek near Southern Utah University. Students are required to compile the data and report their findings for dissemination to the community. The real-world application of the projects and their impacts are detailed here.

Lanigan and Roberts-Kirchhoff (Chapter 4) offer an example of how context-based projects can be adapted for various levels of chemistry instruction. This chapter illustrates the use of drinking water quality as the theme for activities and experiments that were developed for Allied Health majors, science majors, and middle school students. A novel investigative activity, two experiments, and four mini-projects are detailed, as well as several assessment methods for evaluating the effectiveness of pedagogical practices.

Kahl (Chapter 5) reports a project-based experiment where students compare a simple smartphone spectrophotometer to a traditional one. After comparing results of water quality tests, students use an engineering approach to generate different designs to improve the smartphone spectrometer.

Archey *et al.* (Chapter 6) outline a pedagogical approach which introduces general chemistry concepts through consideration of environmental issues such as carbon dioxide uptake by the Amazon jungle. Application of concepts such as stoichiometry, molarity, solubility, and graph interpretation to the "carbon footprint" discussion of global sustainability exemplifies the utility of context-based pedagogy.

Berliner (Chapter 7) describes two approaches for introducing chemical concepts through the use of flipped classrooms. The two courses described here require students to engage in discussion of contemporary environmental chemistry and toxicology issues. Both require readings over controversial issues in environmental chemistry, student presentations and guest lecturers on related topics. The significant difference in Berliner's two approaches is that one course is offered as a two-week international travel course to Thailand. This latter approach includes opportunities for cultural enrichment as well as laboratory experience measuring water quality in the communities visited by students.

Mio *et al.* (Chapter 8) present a description of an organic laboratory course that integrates concepts of green chemistry throughout the experimental and writing components of the course. Emphasis is made on training chemistry and biochemistry students as future professional scientists by requiring students to submit ACS-style manuscripts that undergo a peer-review process prior to final submission. Details of the writer and peer-reviewer rubrics are included in this chapter.

These examples of context-based instructional practices are diverse and evaluation for each requires its own methodology. Therefore, there is a great need in the chemical education community for more published examples of practices and assessment tools for chemical educators. This volume of papers provides examples for those interested in applying chemistry concepts to environmental topics to stimulate student learning.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ot001

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Katherine Lanigan is an Associate Professor of Chemistry and Biochemistry at the University of Detroit Mercy. Lanigan's research includes analysis of trace metal accumulation both in plants and invertebrate and adsorption studies of metal-complexed EDTA on metal oxide thin films by ATR-FTIR. Lanigan received a B.S. degree in Chemistry from the University of Dayton in 1990 and a Ph.D. degree in chemistry from the University of Iowa in 1996. She joined the University of Detroit Mercy in 1999.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ot001

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Chapter 1

Choosing Appropriate Models – Incorporating Climate Change into General Chemistry

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A set of in-class activities were developed that use climate change concepts to help students learn general chemistry content. The activities are based on POGIL (Process Oriented Guided Inquiry Learning) pedagogy, in which students work in groups to develop conceptual understanding of the topics presented in the activity. A challenge faced in the development of these activities was how to effectively incorporate the climate change context. The result was a set of activities that incorporate climate change in a variety of ways. This chapter will present different model types used in these activities, along with discussion of the corresponding benefits of each particular model type. It is hoped that the reader will gain some insight into model development, and that the examples presented will make it easier for others to incorporate context-based examples into their own curricular materials.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

Introduction

Climate change is a topic familiar to most college students. It is also a topic that will likely remain an important issue in the public for the foreseeable future. Based on the importance of this issue, the topic of climate change is a way to increase student interest in chemistry. As part of an NSF-funded project, a set of in-class activities were developed using climate change concepts to teach general chemistry topics. The activities are based on POGIL (Process Oriented Guided Inquiry Learning) pedagogy. The activities were designed to be used in college-level general chemistry courses. While they were intended primarily for science and engineering majors, many of the activities have been used successfully in courses for non-science majors and at the high school level.

Context-Based Learning

The benefits of context-based learning have been documented in recent studies, e.g., (*1*, *2*). Classroom testing of modules that use real-world contexts to teach general chemistry content corresponded to improved exam performance and attitudes towards chemistry at both a small liberal arts college and a large research university (*2*). Students who used the modules asked more questions in class (six times as many at the small college and twice as many at the research university) than students who didn't use the modules. Students in the module classrooms also scored higher on in-term exams. Attitudes about the course were higher for students who used the modules at the small college; however, at the research university, students in the module classroom had less positive attitudes about the course than students in the non-module classroom (*2*). Other studies have demonstrated that incorporation of context-based curricula can increase student interest and motivation and reduce the gender differences in attitudes, e.g., (*3*, *4*). Bennett et al. (*3*) analyzed results of seventeen studies about the effects of context-based approaches in high school classrooms. Of the nine studies about attitudes towards science, seven showed improved attitudes after the use of context-based approaches. Results from five studies demonstrated that context-based approaches resulted in positive attitudes about science for female students and reduced gender differences in attitudes (*3*). Another benefit of incorporating context-based problems is that they address the need for students to use complex thinking and improve their scientific literacy (*5*).

POGIL

Process Oriented Guided Inquiry Learning (POGIL) is an instructional approach based on current research-based understanding of how students learn (*6*). In a POGIL classroom the instructor serves as a facilitator of learning rather than the source of information, and the students work in self-managed teams using guided inquiry activities designed specifically for this setting. This environment is intentionally structured to actively engage the students in mastering disciplinary content and concepts, while at the same time developing essential learning and

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thinking skills. There are three key characteristics of the materials used in a POGIL learning environment. POGIL activities:

1. are designed for use with self-managed teams that employ the instructor as a facilitator of learning rather than as a source of information;
2. generally use a learning cycle (*7*) to guide students through a model exploration to construct understanding;
3. use discipline content to facilitate the development of important process skills, including communication, higher-level thinking and the ability to learn and to apply knowledge in new contexts.

Thus, the goal of the POGIL approach is not only to develop content mastery through student construction of understanding but also to enhance non-discipline specific skills, such as critical thinking and problem solving.

The learning cycle plays a key role in the structure of a POGIL activity and is one of the hallmarks of the curricular materials used in this approach. As described by Karplus and others (*7–9*), a learning cycle has three phases. In the first, or "Exploration" phase, students seek to make sense of the information that they obtain or that is provided to them, often by looking for a pattern or trend. A diagram, image, table, graph, or even a reading may be used as a source of data for interpretation. Students generate and test hypotheses in an attempt to explain or understand the information that they have been presented. In the second phase, "Concept Invention" or "Term Introduction," a concept is developed from the pattern and a new term can be introduced to refer to the previously identified trends or patterns. By placing the two phases in this order, new terms are introduced at a point when the student already has a mental construct in place to which a term may be attached. This contrasts with the typical textbook or lecture presentation in which terms are often introduced and defined first, followed by some examples of their use. In the final "Application" phase, the concept is applied in new situations (*10*, *11*). This phase generalizes the concept's meaning to other situations, and often requires deductive reasoning skills. This is precisely the type of analysis and reasoning that should be fostered in the context of climate change education, where the ability to reason and argue from data is essential.

In light of these ideas, there are two key aspects in the general design of a POGIL activity. First, appropriate and sufficient information must be included in the initial exploration, making it possible for students to develop the desired concepts. Second, the sequence of guided questions (called critical thinking questions) must be constructed with care, allowing students to reach appropriate conclusions while also encouraging the development of targeted process skills. Typically, the first few questions direct the student's attention to the information provided in the model, and these questions may also build on their prior knowledge. The next group of questions promotes the development of a concept through finding patterns or relationships in the model. This creates fruitful territory for scientific argumentation. The third and final set of questions may require divergent thought to find further relevance or to look for boundaries in the patterns or relationships. These questions also can be used to help students learn how to apply their new knowledge in a different context. Thus, the questions

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

build on each other in complexity and sophistication, leading student groups toward discovery of a concept while also requiring and developing an array of process skills.

There are two primary types of POGIL activities. Most POGIL activities include all three phases of the learning cycle; these are referred to as "learning cycle activities". Learning cycle activities are designed to help students learn new content. Through the learning cycle approach described above, students are introduced to new terms and concepts. The second type of activity focuses on the application phase of the learning cycle; these activities are "application activities." During application activities students are expected to have had prior introduction to the primary concept associated with the activity. Rather than teaching the concept, students gain additional exposure to the concept and practice working with the concept. Application activities use the same general design as learning cycle activities, e.g., multiple models with corresponding critical thinking questions.

Characteristics of Climate Change Model

Once learning goals were established for each activity, authors chose models to support a learning cycle or application approach for each activity. Models and their linked critical thinking questions support both the chemistry content and the climate-change related context of this project. These models varied in format, such as text, table, diagram, graph, image or figure, depending on the nature of the learning objectives for each activity.

In all activities, a general climate-related issue or feature was identified to serve as the context for the activity. However, more than one approach was necessary to incorporate the context into the activity. Multiple approaches were required for several reasons. First, some of the chemistry concepts aligned easily with common climate change issues, while others were more tangentially related. For example, topics such as dipole moment and electromagnetic spectrum are key features of the greenhouse effect. This made it very easy to use a climate change feature when writing the corresponding activities. In contrast, topics such as balancing equations and stoichiometry are so broad that they didn’t map directly to a specific climate change issue. In these cases a similarly broad climate change feature, i.e., the carbon cycle, was chosen as the theme for the activities. A second reason for the varied approaches relates to the fact that it was easier to use a climate-related issue as the model in application activities than it was in learning cycle activities. Application activities, by design, assume pre-requisite knowledge that is reinforced through the activity. It is common to use a contextualized model as a way to have students apply their fundamental understanding of the chemistry concept to a new situation. In doing so they improve their grasp of the concept. Therefore, the only challenge with the application activities was to find an appropriate climate change issue that could be used to reinforce the chemistry concept, e.g., carbon sequestration and phase diagram, respectively.

In a learning cycle activity, time must be spent developing the chemistry concept. The critical thinking questions in this type of activity must focus on the concept invention. If the critical thinking questions focus on exploring the climate

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change issue, that could prove to be distracting to the students and inhibit their ability to learn the new concept. At minimum, adding critical thinking questions focusing exclusively on a climate change issue increases the length of the activity, reducing the number of questions that can be used to develop the concept. In the learning cycle activities, the climate change context was often incorporated in the initial model through the choice of which chemicals and/or examples to use. In the Balanced Chemical Equations activity (Figure 1), equations that focused on key components of the carbon cycle were used, rather than equations that used chemicals that are often chosen for the final coefficients instead of for their connection to the context. Examples related to the carbon cycle enabled the use of the carbon cycle as a model later in the activity. This helped the students directly connect the application of the concept to the initial models used to develop the concept.

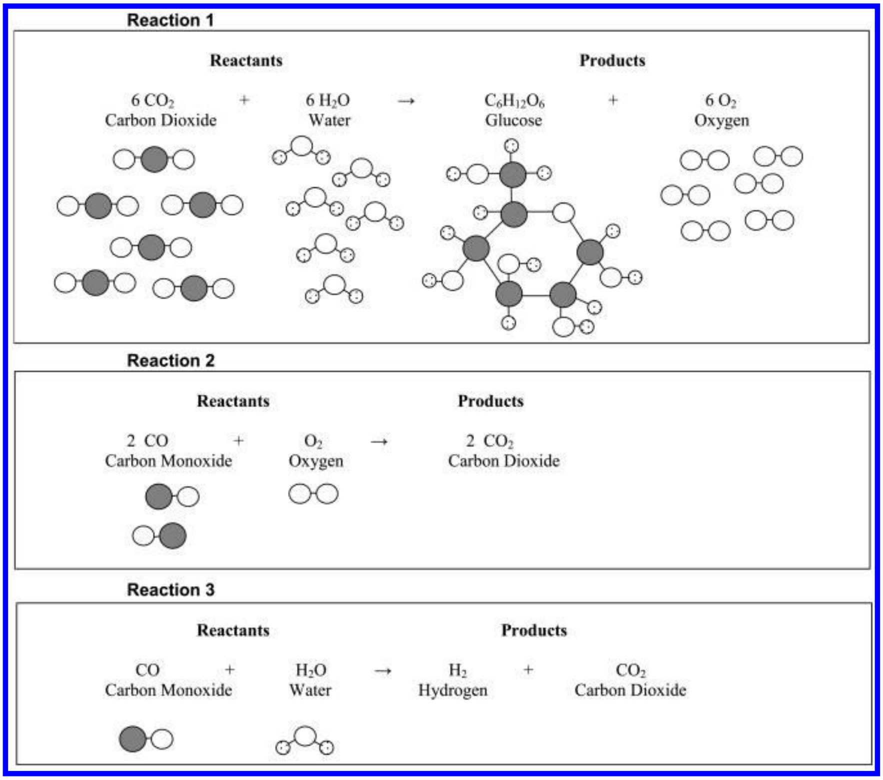

Figure 1. Model 1 from Balanced Chemical Equations: The Carbon Cycle activity. Product molecules are not included in Reactions 2 and 3 because students draw them as part of the activity.

Early in the development of the Phase Diagram: Carbon Sequestration activity, a decision was made about which type of activity should be used: learning cycle vs. application. Both activity types were possible. To create a learning cycle activity, the students would be provided with a set of data that included temperatures, pressures and states of matter. Through a series of critical

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thinking questions, states of matter could be plotted on a graph with temperature on the y-axis and pressure on the x-axis. State of matter data could include values at the phase boundaries, e.g., water: temperature = 100°C, pressure = 1 atm, and phase = liquid/gas, as well as values associated with bulk material, e.g., water: temperature = 40°C, pressure = 1 atm, and phase = liquid. Creation of the graph would help students to understand the various components of a phase diagram. The downside of this approach is that the time required to complete the phase diagram concept invention would take up most of the time allotted to the activity, leaving too little time left for the climate change component of the activity. Consequently, it was determined that the better approach would be to create this activity as an application activity. Instead of having the students create a phase diagram, Model 1 included a phase diagram of carbon dioxide. The corresponding critical thinking questions help students understand how to use and interpret the information provided in a phase diagram. For example, students are asked to identify the phase changes associated with specified changes in temperature and pressure. In another question, students are asked to identify the phase associated with the majority of a sample of carbon dioxide at a given temperature and pressure. Requiring prerequisite knowledge of phase diagrams allowed more effective incorporation of the climate change context into the activity. Rather than introducing the climate component at the end of the activity, where it might be skipped if the activity was running long, the application format enabled the incorporation of carbon sequestration throughout the activity.

Once the activity type was determined, the writing of the activity could continue. This process typically started with the identification of appropriate models. For chemistry content parts of the activity, the model type was chosen to best align with the learning objectives of the activity. Several of the activities used a list of chemical equations as the model. In each case, chemicals were chosen to align with the climate change context. This limited the range of examples that could be included in the model. However, the use of these examples did not compromise student learning. Also, the connection to the climate change aspect of the activity was more important than showing a wide range of examples of chemicals that had no particular meaning to the students. Choosing chemicals based solely on the coefficients associated with the reaction converts the activity to a mere mathematical exercise, de-emphasizing the chemical content. If students do not connect with the chemicals in the reaction, they are likely to pay attention to the coefficients and not the chemicals.

In addition to content learning objectives, each activity has two or three process skill goals. In many cases, the process skills were related to the choice of model. For example, one of the process skill goals associated with the Phase Diagram: Carbon Sequestration activity involves the ability to use a graph to determine values (information processing). In the activity, students are required to interpolate between data points to estimate a pressure at depths of 250 m and 800 m (Figure 2). In another activity, Acid-Base Equilibrium: Changes in Ocean pH, students are provided graphs of data (pH, carbon dioxide partial pressures) plotted as a function of year. The students are asked to estimate the change in these values over time. Because real data are provided in these models, there is a certain amount of scatter. Consequently, it is common for different groups to

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

get different values as their answer. The key when writing the activity is to make sure that reasonable variations in the answers do not prevent the students from correctly answering subsequent questions or from understanding the concept that is being developed or reinforced. These activities help students to gain experience working with real data sets, which many students do not do outside of lab. In these activities, graphs were obviously the model of choice. Similarly, most models in these activities were data-based (tables or graphs) due to the nature of the chemistry content and the process skills associated with the activity.

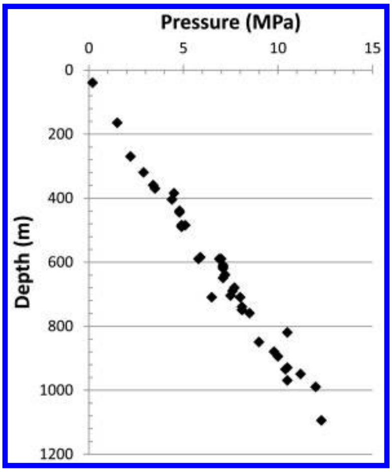

Figure 2. Model 3 from Phase Diagram: Carbon Sequestration activity. Pressures are plotted as a function of depth below the Earth's surface. Graph adapted from (12).

Finding models for the chemistry content was typically easier than finding models for the climate change component. This was due, in part, to the fact that the authors were generally more familiar with the chemistry content than with the corresponding climate change concepts. The climate change models also tended to serve two different purposes. While the chemistry content models had only to align with the chemistry topic being presented, the climate change models had to introduce the climate change context and/or advance the chemistry content. Climate change models can be placed into five different categories: diagram/cartoon, graph, table, image and text. Key characteristics of each type of model are described below.

Climate Change Models: Diagram/Cartoon

This type of model incorporates content into some form of illustration. The illustration is designed to make the image more accessible to the reader than a table of values or a graph and helps the reader to connect the data to the real-world context. Several of the activities incorporate a picture of the global carbon cycle (such as Figure 3). This particular model includes cartoon images of common sources of carbon to the environment along with data that are important for the

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activity. Critical thinking questions associated with the model largely ignore the cartoon component of this model, focusing instead on the content. The cartoon component helps the student connect the image to the climate change context and hopefully creates a more interesting data presentation than simply providing a table of the data. Because this particular diagram is used in multiple activities, it helps students understand that there are connections between different topics in the course. This diagram is distinctive and easy for the students to recognize, so students who see it for a second time create an instantaneous connection to the previous activity. For example, students sometimes try to remember what questions they were asked about the diagram in the previous activity and compare those questions to the ones in the activity they are completing.

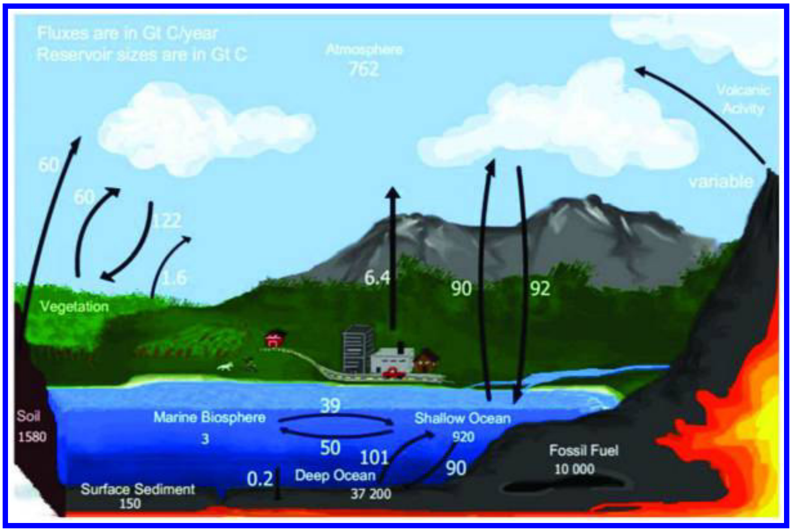

Figure 3. Global carbon cycle with carbon flux and reservoir data. Reproduced with permission from Ref. (13). 2015, the King's Centre for Visualization in Science. (see color insert)

Climate Change Models: Graphs

This type of model shows climate change-related data in a graphical form. These graphs often incorporate data that are not included in graphs used in traditional activities. In addition to common parameters, such as temperature and time, climate change data are often plotted as a function of parameters such as year or distance from a gas well. One example of a graphical model is included in the Acid-Base Equilibrium: Changes in Ocean pH activity, where pH is plotted as a function of year (Figure 4). In this activity, students gain experience working with real data, through interpolation, estimation and extrapolation. The observed trends provide a way to initiate the discussion about ocean acidification, an important climate change concept. From additional data provided in the activity, students calculate the amount of time it might take for giant scallops to be impacted by changes in ocean pH.

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On a related note, there are many publically available sources of environmental data that can be used by students to make their own graphs, if doing so is a learning objective/process skill goal of the class, e.g., (*14–16*).

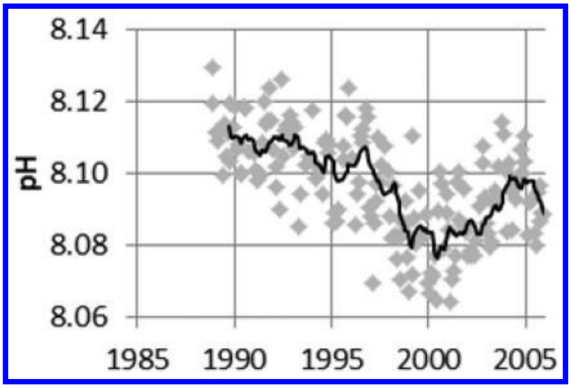

Figure 4. Model 1 from Acid-Base Equilibrium: Changes in Ocean pH activity. Graph adapted from (17).

Climate Change Models: Table

In this type of model, climate change data are listed in a table. This type of presentation can be used in a wide range of applications. The data could be used to identify trends and properties to help student to develop a concept. In the Dipole Moment: Greenhouse Gases activity, students use a set of data to relate dipole moment values of various gases to the polarity of the molecule (Table 1). This same list of gases is presented earlier in the activity, and this parallel presentation format makes it easier for students to use the initial results to draw the subsequent conclusions. In this case, the molecules that are used are common atmospheric gases. Some of the molecules act as greenhouse gases, and these gases are used later in the activity to help students identify the key features of a molecule that enables it to absorb infrared radiation and therefore act as a greenhouse gas.

The table format is a convenient mechanism to provide data that students can use to construct a graph. Graphs may be drawn by hand within the activity or completed in a spreadsheet or graphing program. Another benefit to including data in a table format takes advantage of the fact that cells within a table can be left blank for students to complete. This procedure engages students in the activity by having them generate some of the data they will need to analyze. It also helps to keep the results organized, by providing a clear location within the activity for answers to critical thinking questions. That is, by placing the answers in a table, students can easily find values they will need to answer subsequent questions in the activity.

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.
Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

Table 1. Incorporated into Critical Thinking Questions Relating to Model 1 in Dipole Moment: Greenhouse Gases Activity

Gas	*Molecular Formula*	*Dipole Moment (D)*
Nitrogen	N_2	0
Oxygen	O_2	0
Carbon Dioxide	CO_2	0
Methane	CH_4	0
CFC-12	CCl_2F_2	0.51
HCFC-22	$CHClF_2$	1.46
Water Vapor	H_2O	1.85

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

One unique aspect of the use of climate change as a context for learning chemistry is the further connection to socio-scientific issues. The potential impacts of climate change extend beyond science into all aspects of society. Therefore, each activity in this collection has a connection to social issues. Tables of data provided a convenient way to present social and economic information. This presentation format also helped students to understand that this information may be used in the same way that scientific data may be used. For example, in the Phase Diagram: Carbon Sequestration activity, students are asked to identify an appropriate location for carbon sequestration. Students are provided a table of socio-scientific data to use as the justification for their decision (Table 2). The higher unemployment rate in Maryland/Delaware could be used as a reason to place the sequestration plant in that location, since the construction and operation of the plant would create jobs. The goal is for the students to become accustomed to using data when discussing issues that are often very personal. The data were also chosen to allow for multiple correct answers. Depending on which parameter is chosen, students could make a valid argument for each location as the best location for carbon sequestration.

Table 2. Incorporated into Critical Thinking Questions Relating to Model 4 in Phase Diagram: Carbon Sequestration Activity

	Maryland/ Delaware (A)	*New Mexico (B)*	*Texas (C)*
Unemployment rates (November 2012)	6.7%	6.2%	6.2%
Average home value (2012)	$333,200	$211,900	$169,300
Farm real estate value (per acre) (2012)	$7600	$560	$1,800
Population density (inhabitants per square mile) (2011)	530	17	98
Water table depth (feet)	~20	~400	~30

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Climate Change Models: Image

In content-based models, it would be extremely unusual to have a model that consisted simply of an image. However, in context-based models, an image might be the best way to introduce the student to the climate change concept. Below are two examples of images that have been incorporated into the climate change activities. The first image shows several different carbon sequestration techniques (Figure 5). The purpose of this image is simply to introduce the students to the concept of carbon sequestration and let them know that there are multiple techniques by which carbon dioxide can be isolated from the atmosphere. This image is more effective than providing a list of the techniques because it also provides implicit information about some of the differences between the different techniques. In order to provide a similar amount of information in text form, a full paragraph would have been needed to explain the key features of each technique. Since the activity focuses on one of the techniques (deep aquifer), this level of detail is unnecessary. So, this image allows us to introduce the one technique included in the activity, while also letting the students know that there are other techniques available for the same purpose. Students who are interested in this issue could investigate the other carbon sequestration methods outside of class.

The second image provides a visual representation of the recent loss of sea ice in the Arctic Sea (Figure 6). While the same information could be presented in other ways, such as a table of sea ice area over time or a description of the loss of sea ice, this image is likely to illustrate the change more effectively. In this activity, the image is used primarily to introduce the climate change concept and create motivation to understand the chemistry concepts associated with the loss of sea ice. No critical thinking questions are asked about this image. However, at the end of the activity, data associated with the loss of sea ice (presented in graphical form) are used to directly connect the chemistry content learned during the activity back to this image.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

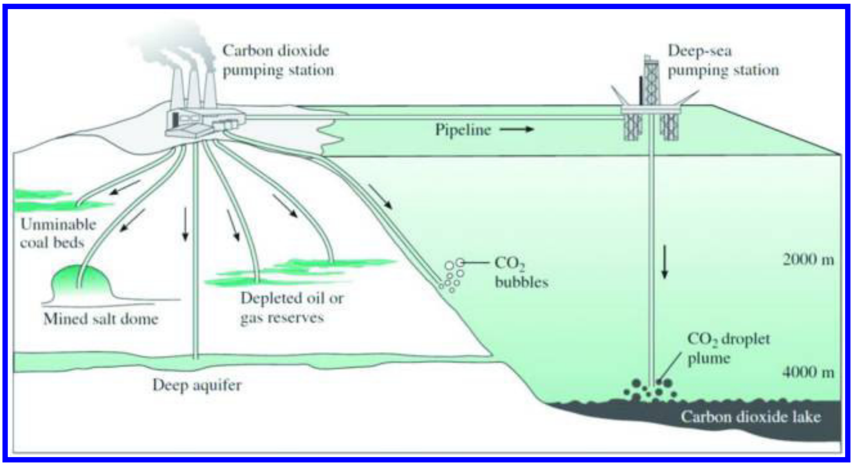

Figure 5. Model 2 in Phase Diagrams: Carbon Sequestration activity. Reproduced with permission from Ref. (18). 2012, W.H. Freeman and Company. (see color insert)

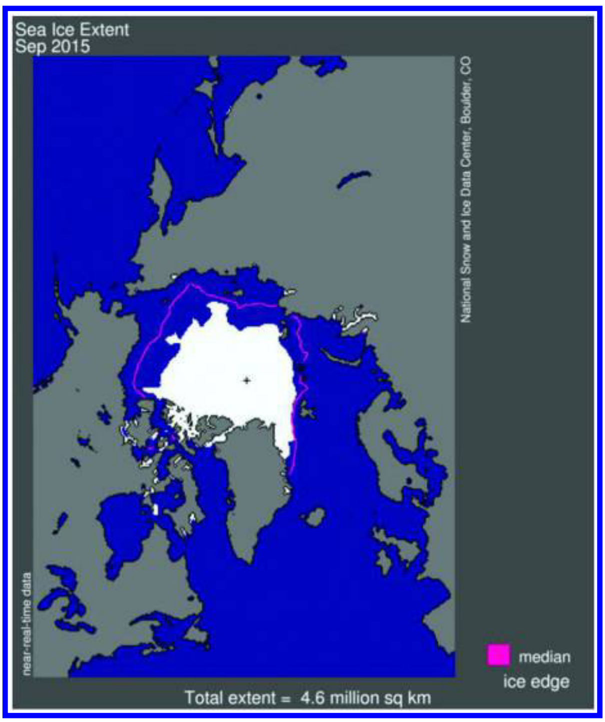

Figure 6. Model 2 in Specific Heat, Heat Transfer and Climate Change Modeling activity. Arctic sea ice coverage in 2015 compared to median extent from 1981 to 2000. (Source: National Snow and Ice Data Center; data from (19)). (see color insert)

Climate Change Models: Text

While it may seem that text would be a poor choice to introduce the climate change context, there are times that it is actually the best method. In the Dipole Moment: Greenhouse Gases activity, the term “greenhouse gases” is introduced and defined in a paragraph. If this activity had been written to develop the concept of greenhouse gases, which might be appropriate for an environmental science class, a more elaborate model would be more appropriate. However, in this activity, greenhouse gases are merely the context through which dipole moment and infrared absorption are presented. Spending class time developing the concept of greenhouse gases would have reduced the amount of time spent on the chemistry content.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch001

Climate Change Models: Controversial Aspects of Climate Change Issue

One of the concerns addressed when activity writing began was the possible adverse reaction of students who did not believe in climate change. Would the activities put these students in a negative frame of mind, thereby decreasing the effectiveness of the activities? With this concern in mind, the decision was made to avoid presenting either side of the climate change debate. The activities focus on the science of the issues related to climate change without promoting any agenda. For example, in the Intermolecular Forces: Hydraulic Fracturing activity, fracking is used as a way to contextualize a discussion about intermolecular forces. The activity does not discuss the advantages or disadvantages of this process. In the Dipole Moment: Greenhouse Gases activity, the concept of global warming is briefly introduced. However, the impact of human activity on global warming is not presented. Greenhouse gases are described as having natural and anthropogenic sources, but this is connected to potential regulation of the gases, not to global warming. There have been no complaints from students about the climate change component of the activities, possibly because personal viewpoints were not included.

An argument could be made that it is important for students to engage in the debate about climate change. However, since these activities were designed to be used in general chemistry courses, faculty teaching general chemistry may not want to spend class time on such topics. For any faculty who are interested in addressing the climate change debate, these activities could serve as a good starting point for additional discussion.

Conclusions

While POGIL activities have been demonstrated to help improve student learning, they typically use content-based models, rather than context-based models. As part of an NSF-funded project, a set of in-class activities were written that use climate change context to teach general chemistry content. The goal was to create activities that would engage students through the use of climate change models. The challenge was how to best incorporate the context. It was discovered that benefits are associated with diagrams, graphs, tables, images, and text. When deciding which type of model to use, it was important to think about how each chosen model supported the learning objectives for an activity. For example, using a graph to display the climate change data enables students to develop their ability to interpret graphs, which is a skill that will benefit students beyond the general chemistry course.

With respect to controversial aspects of the climate change debate in classroom activities, the decision was made to restrict the activity models to climate change data. In some activities, the controversial issues are not included at all. In other activities, the controversial components are defined, but neither side of the issue is presented. The controversial aspects of climate change were avoided to ensure that students focused on the activity content and were not distracted by personal feelings about climate change issues. Furthermore, having students use data to support answers surrounding a potentially controversial topic serves as an effective classroom example of how scientists interpret data. It is anticipated that the use of contextualized information to learn scientific content will help the development of scientifically literate students.

Preliminary results of classroom testing of these activities show that they have been generally well received. It appears that the use of climate change as a context-based model in this activities has increased student interest in the content. Additional testing is necessary, however, to determine if these activities improve student learning of the chemistry content.

Acknowledgments

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Chapter 2

Southern Utah University Internship: A Working Model of Peer Mentorship

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In 1974, an environmental water-testing laboratory was established by the Department of Physical Science at Southern Utah University. Since its inception, the Water Lab has involved students in every facet of its operation while maintaining state certification/National Environmental Laboratory Accretidation Program (NELAP) certification. However, relying on student workers means that the Water Lab suffers constant turnover, which makes both training and maintaining state certification difficult. The SUU Water Lab solves this problem by relying on peer mentorship. In this chapter, we present the challenges of constant turnover and discuss how we maintain state certification with student workers, as well as the overall benefits of the peer mentoring process to students.

Introduction

Southern Utah University first established its environmental water-testing laboratory in 1974. The lab serves a key function in the southern Utah region: the lab is available to the public for water analysis; it also facilitates basic student training in sample collection and interpreting test results. Since its inception, the Water Lab has involved students in every facet of its operation while maintaining state certification/ National Environmental Laboratory Accretidation Program (NELAP) certification. Water Lab employment constitutes a paid internship for students. Over 100 student internships have resulted from this program.

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

Due to the nature of relying on student workers means that the Water Lab suffers constant turnover. This turnover has made both training and maintaining state certification difficult. The means by which the SUU Water Lab relys on to solve this problmen is peer mentorship. Students serve as lab analysts, perform quality control/quality assurance duties, and handle the day-to-day clerical duties of the laboratory. Also, each student trains their replacement in these duties, which not only solidifies conceptual learning, but allows new interns to learn in a supportive peer environment. Other benefits of the Water Lab include the acquisition of soft skills, such as communicating instructions and interpreting test results. Interpreting the test results usually means explaining the state and/or EPA standards to the client and how the analysis relates to that standard. This is an important part of the experience as student interns interact with community members who rely on the Water Lab.

Overall, participation in the Water Lab helps students learn about what it takes to be a successful chemist in a real working environment. In this chapter, we present the challenges of constant turnover and discuss how we maintain state certification with student workers, as well as the overall benefits of the process to students.

Historical Background

In 1948, the Federal Water Pollution Control Act was ratified, but was not universally enforced until the Act was significantly reorganized and expanded in 1972, and became known as the "Clean Water Act" (CWA). The CWA is the primary federal law in the United States governing water pollution (*1*). The objective of this Federal Water Pollution Control Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by preventing point and nonpoint pollution sources, providing assistance to publicly owned water treatment facilities for the improvement of wastewater treatment, and maintaining the integrity of wetlands. Thus the CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. However, the CWA did not directly address groundwater, and so in 1974, the "Safe Drinking Water Act" (SDWA) was passed by Congress to protect public health by regulating the nation's public drinking water supply. The law has been amended both in 1986 and 1996 and requires numerous actions including source water protection, operator certification and compliance monitoring to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells (*2*).

The SDWA of 1974 authorizes the United States Environmental Protection Agency (US EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. With guidance from the US EPA, all states and water systems must then work together to make sure that these standards are met (*3*). The SDWA equally applies to every public water system in rural Utah, even small water systems like Scofield, Utah, with a population of 24. A major difficulty for many of these rural areas is the distance to the nearest analytical laboratory (as much as

400 miles) and sample tests with short holding times cannot be mailed and arrive at the lab within the prescribed time frames. For example, pH, residual chlorine, and alkalinity must be analyzed within 24 hours. Microbiological analysis must be performed within 30 hours. In 1974, it took more than 24 hours for mail to travel from Cedar City, Utah, to Salt Lake City, Utah.

Because of these difficulties, in 1972, a group of concerned citizens established a voluntary association of five rural Utah governments to help local elected officials in these small rural communities cope with the regional challenges like those imposed by the CWA and later the SDWA. This group was called the "Five County Association of Governments." The five Utah counties involved were Beaver, Iron, Washington, Garfield and Kane Counties. In response to the closing of the Cedar City, Utah, branch of the Utah State Health Lab in 1974, the Five County Association of Governments met with Dr. Joseph L. Comp of then Southern Utah State College (SUSC, now called Southern Utah University (SUU)) regarding the establishment of a laboratory capable of testing water for adherence to the CWA and SDWA. The Five County Association of Governments was able to sequester $10,000 to help start this project. Dr. Comp agreed, and two chemistry students, Scott Jolley and Darrell Callison, volunteered to be part of this start-up effort. The $10,000 was spent on one piece of equipment, a Jarrell Ash 151 flame atomic absorption (AA) spectrophotometer (*4*). No other budget or support was available except a room in the basement of the science building at SUSC. Jolley and Callison worked without compensation for the opportunity to apply their chemical knowledge. Both students wanted to get into graduate school and wanted research experience. There were no research programs available at SUSC so analyzing water was the best means of gaining practical experience. This project became known as the SUSC Water Lab (*5*).

The SUSC Water Laboratory 1975-1982: Students were self-taught.

The early goal of the SUSC Water Lab was to develop all the methods necessary to certify a community's drinking water, and once developed acquire certification from the appropriate government body. The analytical methods for water analysis require pure water as solvent for solution preparation. SUSC did not have any source of purified water, distilled or deionized (DI), so the students set up all the lab benches with 200 mL Erlenmeyer flasks with boiling chips, distillation columns, and receiving flasks for making the distilled water. This was done around the clock in a fume hood in a chemistry laboratory. Fortunately the early analytical demand from customers occurred during the summer, so the entire lab was available for distillation setups, since no classes or labs were in progress. Potassium permanganate ($KMnO_4$) was added to tap water to oxidize all the organics because they would distill over and the water distillate was collected. Jolley and Callison took turns checking the distillations setups, collecting the distilled water and refilling the flasks. This distillation was a 24/7 effort, until sufficient water was obtained to generate the standard curves for the different analyses (*5*).

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Many of the techniques were self-taught, with support and cooperation from local wastewater treatment plant technitians. Of particular interest for the treatment plant staff were the measurement of the biochemical oxygen demand (BOD) and the E. coli bacteria count of the influent and effluent from each plant. The atomic absorption (AA) spectrophotometer also facilitated some trace metal analyses. Ion selective electrodes (ISE) were just becoming available and a few were purchased. Sulfate ion concentration was determined by adding barium to a fixed volume and reading it on a spectrophotometer (UV-Vis.) By 1976, the SUSC Water Lab had received funds to purchase a commercial still and some 5 gallon Pyrex receiving bottles for storage. Even with the storage capability, the still had to run almost constantly in order to provide the analysis grade water. Modern-day desktop computing was unavailable at the time, so to input the data, punch cards were used and programs had to be written in order to track the billing and payment needs of the customers and laboratory (*5*, *6*).

At the time, the dean of the School of Science was results-oriented and did not extend the Water Lab or the students any special favors or funding until Utah state laboratory certification could be achieved. By 1976, the SUSC Water Lab obtained certification to test community drinking water. When the founding students Jolley and Callison graduated in 1977 with their B.S. in chemistry, Dr. Comp bought them steak dinners. That was the only "pay" they received for working in the Water Lab. Callison writes, "But I have no doubt that if I had not gained the experience I did in the Water Lab, I would not have earned an M.S. in chemistry. I have since worked 35 years in the semiconductor industry. My chemistry background allows me to understand all the processes that take place even though I have never had a process job." Jolley went to the University of Utah, pursuing a Ph.D. in chemistry (*5*).

In 1977, the lab purchased a state-of-the-art controller to use with the ion selective electrodes, and a student named Kent Richman took over the day-to-day tasks of supervising/running the water lab. Scheduling was difficult with the demands of the local communities and coursework. Titrations, AA, gravimetric, and specific ion electrode tests (fluoride, ammonium, etc.) made up the bulk of the analyses. While the laboratory made money for the tests it ran, it was not enough to pay for equipment, supplies, and labor. The lab was able to stay in business by demonstrating to the college and the dean that it could provide a very valuable internship and teaching tool for chemistry students. From this point forward, the Water Lab internships became a significant opportunity for students in chemistry laboratory course curriculum (*6*).

During this time, the student chemists had quarterly visits from a Board of Health auditor who was helpful in developing the necessary quality assurance manuals and general laboratory quality. The founding students ventured out into the community, trying to get contracts for larger water development projects and finding undergraduate research opportunities, such as the study of nitrogen content in hay (*6*). The early years of the Water Lab were thus characterized by insufficient funding and extensive dedication from student volunteers.

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The SUSC Water Laboratory 1983-1989: Peer mentorship initiated but not formalized.

As in the founding years, during this period of the Water Lab's existence, all day-to-day workings of the laboratory were performed by students. Employees tended to be the best SUSC science students – they naturally seemed to rise to the top and find their way to the Water Lab because the Water Lab offered the best opportunity to enhance a student's chemical education at SUSC through a peer mentored internship. This trend continues today.

The primary foci of student workers Joe Hoagland and Ty Redd were to create student-friendly Quality Assurance (QA), Quality Control (QC), and Standard Operating Procedure (SOP) manuals. Their goal was to streamline the training and workload for students in order to generate funds for equipment maintenance and purchase. These students taught each other basic protocols and learned important multi-tasking skills in order to be as effective as possible. This was the first time the Water Lab had self-generated funds for its operation. When Hoagland and Redd graduated in 1987, a former SUSC student, now professor, Dr. Kent Richman took over the laboratory operation until Dr. Ty Redd returned in 1990 as a faculty member and laboratory director.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

The SUU Water Laboratory 1990-2000: Peer mentorship formalized.

Dr. Joe Comp retied from SUSC in 1989, Dr. Richman left SUSC in 1990 and Ty Redd took over management of the Water Lab. He quickly recruited several top freshman and sophomore chemistry students who demonstrated a diverse and desired set of personalities, such as attention to detail, reliability, initiative, and collegiality. These students were trained in the QA/QC practices of an environmental water laboratory. Dr. Redd formalized a model of peer mentorship by training a sophomore student to serve as the laboratory QA officer. This QA officer trained each new student worker, who was subsequently certified by the State Health Department on specific analyses. During this time period, good laboratory practices were fostered and maintained. The laboratory developed into a quality operation that provided consistent results, customer service, and retained Utah state certification. This certification required the lab to analyze a sample, obtained from the EPA, and get values within a certain threashold.

The SUU Water Laboratory 2000-Present: Peer mentorship flourishes.

The training of students has evolved substantially since the beginning of the Water Lab. Initially the training consisted of students reading the Standard Methods for the Analysis of Water and Wastewater and US EPA methods in order to perform the analysis and manage the laboratory. This was supplemented by limited faculty guidance, a full-time student technical director, and yearly training by the State of Utah laboratory agency, the Bureau of Laboratory Improvement

(BLI). In 2004, Kim Weaver, a former Water Lab student worker (1986-1988), returned to SUU (SUSC became SUU in 1991) as an analytical chemistry faculty member and was hired as technical director of the Water Lab.

Dr. Weaver led the laboratory to national certification under a National Environmental Laboratory Accreditation Program (NELAP) in 2001, relying heavily on peer mentoring to train students to meet certain standards. This program requires strict adherence to all promulgated EPA regulations, procedures, and standards, and demands traceability of the total laboratory system from beginning to end. The procedures used to train students evolved in order to meet National Environmental Laboratory (NELAP) standards, which are based upon the International Organization for Standardization (ISO) while still maintaining the unique internship experience of the Water Lab.

The NELAP standards require that more faculty/managerial instruction occur, but even with this increase in faculty oversight, peer mentoring still plays an important role within the Water Lab. The primary mode of training falls on the more experienced analysts. New students begin by observing the analyst performing their tests and gaining an understanding of the basic structure of the analysis. After the initial observation, the new student works in tandem with the peer mentor until they are competent enough to be the lead analyst. Once a student demonstates their competence they certify in their chosen analysis.

Duties of the Student Analysts

As it has been since its inception, the Water Lab is almost entirely student run. With the exception of managerial and quality assurance officer duties, the students conduct all other duties. In addition to sample analysis, students also perform basic assurance duties such as verifying their quality control checks are laboratory control limits. They also work the front desk of the laboratory which is where laboratory samples are submitted from the general public. Front desk duties, include such things as receiving samples from customers, preserving samples and maintaining documented custody of those samples, measuring the physical properties (pH, temperature, turbidity) of all received samples (see Appendix 1.) They also verify calibration of analytical balances, pH meters, and verify the temperature of sample receipt and storage refrigerators, analysis ovens, etc. Student analysts prepare reports of sample analyses, verify those reports, mail the reports and then help prepare invoices. No student works more than four hours at the front desk at a time, even during the summer, and during the school year, students work shifts as short as one hour.

Because so many students work the front desk during a day it was necessary to develop a system so that all students working the front desk are interchangeable in order to allow tasks, such as verification and preparation of reports, to be performed by several different students. The interchangeability requires more effort in the training of student workers. For an outline of the general work flow in the lab, see Figure 1.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

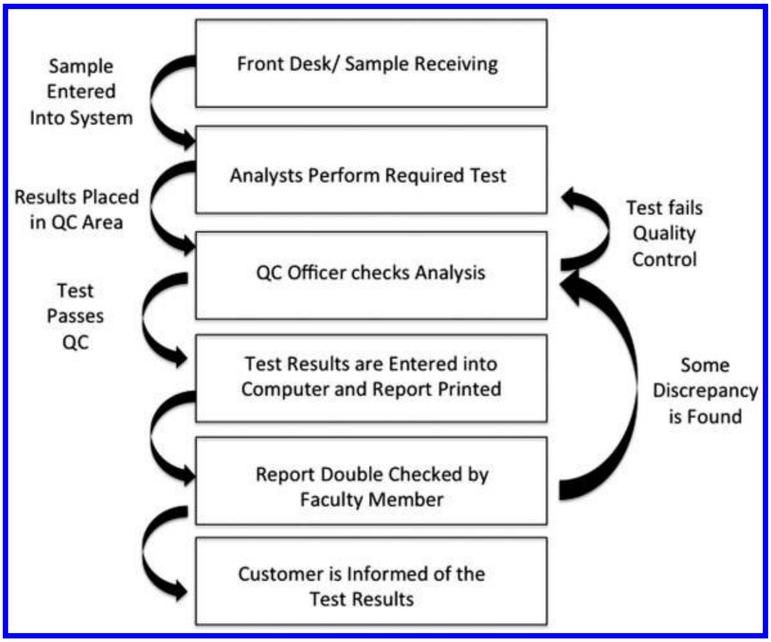

Figure 1. The work flow of the Water Lab. Once a sample is received, it moves through the analysis with checks and balances to ensure that the sample is processed correctly.

Although ostensibly just a clerical position, in fact, the front desk experience augments the practical chemistry experience the students gain from performing the chemical analyses. Students working the front desk receive important context for their analysis. As students record source information for their samples, the samples become more than just bottles of water. The analysis of these samples will be used to make important decisions, such as whether the water is safe to drink.

Training Student Analysts

Because this is a NELAP approved laboratory, students must follow good laboratory practices as outlined in the NELAP standards. Hence, proper training is critical to the success of the water lab. When properly trained, the student work is defendable and trustworthy. Ultimately, good training benefits not only the lab, but the students themselves: the skills student learn are transferable to many different areas when they graduate and seek employment. Training is critical to the Water Lab's success. While much of the training is done by the students themselves, where the more experienced students train the less experienced students, a formalized training process is critical to prevent deviation from NELAP standards. The success of laboratory depends on three things: 1) students reading and following the Quality Assurance (QA) manual and all Standard Operating Procedures (SOP) and policies; 2) Proper training and oversight by faculty; 3) Proper peer mentorship; The formalized training program that the students follow is outlined below.

The training of students begins with a 45-hour unpaid internship for credit. This is a time were the student determines whether or not he/she is wants to work in the Water Lab and Lab leadership determines whether or not the student has the aptitude to work in the laboratory. During the 45-hour internship, students read the QA manual, learn how to receive samples, maintain a notebook of everything they learn and certify for one analysis such as simple pH or turbidity test or in other cases, the analysts certify for trace metal analysis using an ICPMS. At the completion of the 45-hour internship, the student is expected to write a summary of what they learned and if the summary shows sufficient proficiency to the Lab leadership, the student is hired as an analyst.

The formalized training continues with the students learning duties on other "checklists." Because all students must work the front desk, the Lab leadership provides a checklist of what must be learned to work on the front desk. This checklist both insures that the students perform the duties necessary to properly run the laboratory and allows them to know what needs to be done with minimum supervision. Students meet certain qualifications as they progress in their ability to work at the front desk. The front desk qualifications are divided into six levels. (Appendix 1) The first level entails the most basic details such as answering phone calls and receiving samples. An analyst at the second level perform such duties as measuring the receiving temperature and pH of incoming samples and determining bacteria test results from lab records then reporting these results when the customer calls. When an analyst is at level three, the analyst can do such things as verify chemical test results and process bacteria and chemical test results. At level four, the analysts are certified to test for bacteria in water and measure the official pH of a water sample. At level five, the analyst can measure turbidity and residual chlorine and perform other QC duties. The level six analyst can electronically enter results for bacteria in order to directly submit these results for public water systems to the Drinking Water Division of the State of Utah.

All analysts are expected to reach level three for front desk qualifications. They complete ethics training and agree in writing to follow the ethics guidelines. These guidelines include being as correct as possible when reporting results and making sure to analze samples within their specified holding times. The guidelines also warn against being involved in any deceptive or dishonest practice as well as using expired standards or reagents. They demonstrate the ability to prepare reagents, calibrate standards, observe QC standard and performance testing samples (PT) as outlined in SOP and QA manuals and document their preparation in the appropriate log book. Peer training is vital to reach qualification level three. New analysts begin working in the lab watching an experience analyst work the front desk. Every item on the check list involves an experienced analyst showing how the task is done. While there are policies and procedures for each item, nothing puts the inexperienced analyst at ease more than seeing how the task should be performed. Experience has taught the students that it is easier to prevent a mistake rather than fix the mistake after the fact. So often times the students will verify that the front desk has been handled properly, In fact, such

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

tasks as sample receiving have a verification component such that the next analyst works at the front desk verifies the work of the previous analyst.

The final key to insuring adherence to NELAP standards entails a weekly Water Lab staff meeting. While figuring out student schedules can be difficult, a time is found that works with the majority of the students and then those unable to attend find an alternative time to meet with the faculty member to discuss the contents of the meeting. In this meeting, the progress of sample analysis and reporting is reviewed. Students play a vital role in leading these informative training meetings. During these weekly meetings, student workers are reminded of past training items, sections of the QA manual are reviewed, policy and procedures are explained, and new quality issues are discussed. This is an informal meeting where students share their concerns and expertise with each other.

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Certification of Student Analysts

In order to be certified to perform an analysis for a certain analyte, students have to be properly trained and then demonstrate capability as outlined in the NELAP standards. Training in the Water Lab to perform a test begins with the student reading the SOP pertaining to the analysis in question. After the analyst reads the SOP, a certified analyst trains the aspiring analyst in how to perform the test and answers any pertinent questions dealing with the analysis. At this point peer mentorship becomes critical. The SOP required by the NELAP standards are divided into 24 sections and many of these sections do not directly lead to a step-by-step outline of the procedure. Thus, the experienced analyst is critical so that the new analyst understands what needs to be done. Once the new analyst feels that he/she is ready and the training analyst is confident in the trainee's understanding and ability, the analyst and mentor approach the faculty QA officer about certifying for the test. As a final measure, each analyst must demonstrate capability by analyzing a sample of concentration not known to the analyst correctly four times. The analysts also measure the detection limit if possible for their method. After successfully completing demonstration of capability, (DOC) the analysts are ready to analyze samples for the purpose of certification. For a student to be certified on a particular analytical procedure, he/she must pass an audit by the BLI. These evaluators interview and inspect each student's performance in all areas of the laboratory operation. They also inspect each student's performance on quarterly performance (PT or blind) audit samples, where the student analysts must report accurate results on a sample of unknown concentrations of analytes.

While all analysts have the ability to learn and certify in all of the methods, generally, the analysts specialize in one or more of the following areas: 1) analysis of nitrates and nitrites (*7*); 2) trace metal analysis by ICP-MS (*8*); 3) anions analysis by Ion chromatography (*9*); 3) Total Suspended Solids (TSS) (*10*) and Total Dissolved Solids (TDS) (*11*); 4) Biological Oxygen Demand (BOD) (*12*); and, 5) determination of mineral cations by flame atomic absorption) (*13*). Other tests such as potentiometric measurement of fluoride (*14*) and ammonia (*15*), alkalinity (*16*) and cyanide (*17*) are non-systematically assigned to analysts.

All analysts are eventually expected to certify for pH, turbidity and residual chlorine. Nitrates and nitrite analysis of water samples are measured by USEPA Method 353.3. In this test, nitrates are reduced by a cadmium column to nitrites. The reduced nitrites react with a sulfanilamide/N-(10naphthyl)-ethylenediamine reagent to form an azo-dye in which the absorbance of the dye is proportional to the nitrite concentration. Nitrites are determined in the same manner without the reduction of the cadmium column. This is a high volume test which demands the solo attention of one analyst. The measurement of ions by ICP is a highly technical test which demands faculty supervision and extensive training such that only one student operates this instrument on campus at a time. Typically the analyst that performs TSS and TDS analysis also determines the specific conductivity of samples. The determination of BOD is a unique test that is part science and part art and each test takes 5 days to conduct, therefore, only one analyst performs this test. Likewise, operating a flame atomic absorption spectrometer is a unique skill.

Importance of Peer Mentorship

Although peer mentorship allows the Water Lab to thrive, its benefits reach beyond those of community members needing water samples tested. The real beneficiaries of peer mentorship are the students. Working in the Water Lab gives students hands on experience, applying theoretical concepts to real-life situation. Because peer mentorship requires that students teach one another, not only do they come to a fuller understanding of the concepts and techniques in question, they also emerge more confident of their understanding.

Peer mentorship also allows analysts to learn important techniques within the lab. This was recently highlighted in the turnover of our ICP analyst. Our ICP-MS is an expensive instrument to operate due to the cost of parts and argon used to operate the instrument. Warm up of the instrument takes almost an hour and typical analysis takes several hours. Procedures must be followed exactly or the results are excessively costly. For the last two years, we had a dedicated student analyst running the ICP for both the lab and departmental student research projects. Before this student left, he spent over three months training the new analyst. Initially, the new analyst only watched, then the experience analyst would set up analysis batches for the new analyst to run. Finally, the new analyst could set up the batches and perform the complete analyses. While not all peer mentorship situations are as demanding, students learn valuable procedures and technologies from each of them. A generalization of how much peer mentorship is involved in various stages of the process can be seen in Figure 2.

Student mentorship also occurs during the multiple verification events in the laboratory. For example, when all chemical analysis for a sample are completed, students must prepare and verify a chemical report. During the verification, another student confirms that the information on the analysis bench sheet agrees with the report. When discrepancies occur, the analysts talk with each other to identify what mistakes were made. In addition, when samples are received at the front desk, the subsequent front desk worker checks to insure that all paper work was completed and the samples were properly preserved.

Figure 2. A generalization of the relative amount of peer interaction during the mentorship process at the SUU Water Lab. This graphic hopes to show that peer mentorship can last as long as the students are working together.

Outcomes of the Water Lab Experience

The benefits of an analytical laboratory internship are easy to imagine. The opportunity to see actual chemical principles being applied in a real world situation enables students to connect the knowledge they have acquired in the classroom with the practical application. Furthermore, students then have a stock set of experiences to base their future coursework upon, so that when abstract concepts, like titration theory, are being discussed, they can see the real world application. In addition to connecting theory to practice, the students also get a better feel for how their education will be applied in the work force. They will see that good note taking, following standard operating procedures and documentation will lead to better analysis and more accurate results. They can also use that experience to gauge if they want to pursue a career in the private sector or if they would like to investigate other options. A glimpse into a working lab helps to inform students to what they can expect if they pursue analytical chemistry.

Over the 40-year history of the Water Lab, more than eighty students have benefitted from being a student analyst. These students have learned the ins and outs of an analytical lab and have seen what it takes to be successful in a real life setting. In order to get a better picture of just what the students have learned from their time at the Water Lab, both current and former employees were surveyed about their recollection of their time working as an analyst. Ten questions were asked dealing with the benefits students perceived from their time at the SUU Water Lab (Appendix 2)

A total of thirty responses were obtained for these questionnaires and all thirty of the responses were positive based on the tone and type of comments

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found in the survey. Due to the repetitive nature of some of the answers of the questionnaire, a summary of the results is included to give a sense of the responses. Twenty seven of the respondants felt that working in the Water Lab set them apart from their peers. Also noteworthy, twenty two pursued and completed some post-graduate education. Twenty two wished they could have learned more while working at the Water Lab. Of these twenty two respondents, nine reported wishing they learned more about instrumentation; four wanted more information on microbiology testing; two wanted more experience with management and the final seven did not specify what it was they wished they had learned.

From these surveys, the most commonly responded benefits of the Water Lab experience deal with specific tasks that are part of the daily routine. Many students listed the ability to perform dilutions, conduct quality control, keep clear records, work comfortably within a lab setting and use equipment as major benefits of internship. These same students replied that being able to generate a calibration curve and apply it to an analysis gave them a better appreciation of their coursework and of the care that should be given an analysis. Another common benefit cited was that the hands on nature of the Water Lab helped them to feel more confident than their peers both in their undergraduate and post-undergraduate careers.

Other stated benefits of the Water Lab included developing successful traits, including the ability to work independently, appreciate customer service, and implement creative problem solving. These can be classified as soft skills, but they are important nonetheless. The close working relationship between the analysts often creates camaraderie and dependence on one another. For example, once a student is through with their training, they have a responsibility for their test. In the early days, once a student was certified in their test, more often than not, they were the only one who could perform that analysis. This instills a sense of responsibility and independence. With the time constraints on the samples, there were many times that a student would have to perform an analysis at odd hours, in some extreme cases in the middle of the night. But because the students have taken ownership of the analysis, they would also accept the responsibility and very rarely complain about the unusual situation.

In addition to the information gained from the surveys of past and present employees of the Water Lab, some less obvious benefits have resulted from this experience. Customer service is a large part of the students experience because they have the responsibility of interfacing with the public. The students learn quickly that most of the customers want clarification and explanation of what the test results mean and how that will affect their lives. It is from these interactions that the student analysts can better appreciate their influence on the community. Students also learn to communicate complex information clearly and efficiently.

Creative problem solving was especially important in the early days of the lab. Since resources were scarce, many times a student would have to look for ways to solve a problem with the resources on hand. This allowed for out-of-the box thinking to flourish and helped the students try and find solutions to their own problems. In particular, when students were persistent in trying to understand problems they encountered, they often discovered answers that were contrary to the initial expectations of customers and/or analysts.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

For example, during the first EPA certification for the Water Lab in 1974, the lab failed to accurately determine the sulfate ion concentration in the unknown sample provided. The analyst was concerned because he was confident that he had performed the analysis to the best of his ability. The official who had supplied the sample from the EPA explained that he had diluted the 10 mL sample with Ozarka brand water purchased from a Safeway. When a separate bottle of Ozarka water was analyzed for sulfate it turned out that the product had a higher sulfate concentration than the EPA sample (*5*).

Another example of the dogged nature and creative thinking of student analysts comes from a Nevada man living near an old mine. The man reported some health issues and suspected that the water he was drinking had some residual cyanide from the mining operations. Upon analysis, the cyanide level of water was below the detectable range. Not satisfied with this result, the analyst ran further tests and found that the BOD was very high. The client received the analysis but what the client did with the information is unknown as there was no further communication (*5*).

A similar instance of creative thinking and industriousness concerned a Cedar City family living 100+ yards north of the landfill, who brought in a water sample for testing. A large amount of gravel had been placed between the family's well and the landfill in order to filter out any contaminants. The testing revealed high levels of BOD. Without any further information, the students suspected that maybe they were just too close to the landfill. When the students went out to the property to take another sample, it was revealed that the well was on the fence line of a corral and open to manure falling into the well. This fecal matter accounted for the high BOD result, so the mystery was solved; it wasn't the proximity to the landfill but the location of the well next to the corral that caused it to be unpotable. The students weren't required to search for answers outside the Lab, but their commitment to their work drove them to identify the root cause of the high BOD (*5*).

In terms of hands on application of analytical chemistry at Southern Utah University, the Water Lab internship serves as the best opportunity to use analytical equipment. From the early days to the present, the Water Lab has served as the repository for the majority of the analytical instrumentation available for chemistry students at SUU. Until recently (2012), more than half of the chemical instrumentation was housed in the Water Lab. Because of this, any students desiring to use analytical instrumentation have found the Water Lab as a great resource. With the added benefits of peer mentorship, the faculty feel more comfortable letting the students use the limited equipment because there is more oversight than would be possible in an open lab situation.

The analytical laboratory experience students gain in the Water Lab has led many of them to job shadowing opportunities, future mentoring relationships, graduate school fellowships, and even employment. Because student workers are essential for the existence of the Water Lab, the experience gained from their time as analysts provides a unique analytical resource for undergraduate research. Students have used this laboratory to conduct undergraduate research projects ranging from analyzing calcium in urine, arsenic bioremediation, novel methods for removing perchlorates in water, molybdenum in soils, anions and cations

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

in surface water and even ammonia in waste water lagoons. Additionally, the resources of the laboratory have been used to enrich many chemistry and biology classes.

Conclusion

When the Water Lab first began in 1974, few of the students or faculty involved could have foreseen its growth. What began as an effort to help community members has become a productive opportunity for students to apply their chemical knowledge in a working laboratory and to mentor one another. The Water Lab is an excellent example of how a student-run internship program can use peer mentorship to efficiently and competently run a nationally certified laboratory. Peer mentorship helps solve the problem of high student turnover (as is common in most internship programs), as students are primarily responsible for their own training, with some faculty oversight. The demanding peer mentorship that emerges from the internship program fosters intellectual independence and creativity, improves analytical skills, develops soft skills like customer service, reliability, and communication—all while providing an environment of personal growth.

While summarizing the sum of the experience gained from this program, it is important to share some of the important lessons that have been learned from this process. It is important to have a back-up in place in case something happens to one of your analysts. Up until 2000, to have only one analyst trained on the more complicated or time sensitive analyses (e.g. AA and microbiological respectively) was not unusual. It put undue strain on the students because they often had to stay in town on the weekends in order to perform the tests. To releave this stress, it is now common practice to have everyone trained in the more time sensitive tests, so that anyone might take care of that analysis. Also, it is important to have periodic refreshers of techniques. The public demand for some tests is very low and there is a possibility that a student may only perform the analysis two or three times a year. To prevent the students from forgetting the process, it helps to have a refresher. This has been facilitated by the weekly meetings so that the lower frequency tests can periodically be discussed to keep it in their minds. This also helps to correct any bad habits that may develop overtime. If any mistakes are made, the quality control helps to remind the students that what they are doing is important and that a poorly done test will have to be reanalyzed until it meets the quality control standard. This helps to reinforce the importance of the work perfomed by the students.

When the Water Lab mentorship program operates at its peak, it becomes more than just a training ground for students. One student wrote, "I believe the Water Lab helped me gain a sense of ownership and belonging that embedded confidence in to me and was key to my success and graduation." She also mentioned that is helped to find a place where she belonged and could be surrounded by like-minded people. The Water Lab was not simply a laboratory; for some of these bright scientists, it served as a home away from home.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch002

Appendix 1: Front Desk Qualification Criteria

Front Desk Qualifications

Level 1: To be qualified at this level, one knows how to:

Answer phone calls
Use the answering machine
Wrap bacteria bottles
Receive samples

Level 2: To be qualified at this level, one knows how to:

Measure receiving temperature of samples
Measure receiving pH of samples
Enter chain of custody information into Lablite
Enter receiving temperature and pH into Lablite
Preserve samples
Read bacteria results from the bacteria log book
Notify analyst of tests they need to do
Measure temperatures of all fridges and ovens

Level 3: To be qualified at this level, one knows how to:

Enter and verify chemical results
Know what bottles are necessary for anaysis
Prepare Chemtech samples for shipment
Receive Chemtech results and input into Lablite
Operate still
Scan bacteria results and process bacteria results except for entering into state reporting
Process chemical reports

Level 4: To be qualified at this leve, one know how to:

Analyze a bacteria sample (including having completed a DOC)
Enter bacteria results after reading a sample batch
Analyze a sample for pH (including having completed a DOC)
Autoclave samples

Level 5: To be qualified at this level, one knows how to:

Analyze a sample for turbidity (including having completed a DOC)
Analyze a sample for residual chlorine (including having completed a DOC)
Calibrate bacteria bottles for volume

Test bacteria bottles for residual chlorine
Download Idexx (bacterialogical analysis materials provider) certificates

Level 6: To be qualified at this level, one knows how to:

Enter bacteria results for state reporting

Appendix 2: Survey Questionnaire

- How long did you work at the SUU Water Lab?
- What do you value most from your Water Lab experience?
- What did you learn from your experience in the Water Lab that was new to you and/or unique?
- How did your experience in the Water Lab help you in your undergraduate education?
- How did your experience in the Water Lab help you in your post undergrad education?
- Has your experience in the Water Lab helped you in your career?
- Did your Water Lab experience set you apart from your colleagues?
- Is there anything about your time at the SUU Water Lab that you would want other people to know about?
- What did you learn in the Water Lab that you didn't learn anywhere else?
- Is there anything do you wish you had learned or done in the Water Lab?

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Chapter 3

Environmental Chemistry and Analytical Chemistry: A Synergistic Relationship in the Teaching Laboratory

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A common problem among chemistry undergraduate students is their tendency to perform qualitative analyses without understanding the importance of their measurements. We believe environmental chemistry provides an optimal context for students to evaluate the importance of their measurements. At Southern Utah University, every student who graduates in chemistry is required to enroll in an analysis lab where environmental chemistry plays an integral part in the curriculum. This laboratory class is a two credit class that meets twice a week for a semester. This is an intensive class which includes training in classical wet methods as well as GC, HPLC, NMR, spectrofluorimetry, UV-Vis and IR Spectroscopy. Using environmental chemistry in this course allows students to compare their measurements of environmental samples to their peers in class, prior years' analyses and in some cases other environmental situations. Some facets of the course include classical wet methods (e.g., titrations to determine the concentration of chloride in surface water), anion chromatography (also to determine anions in the same surface water) and gravimetric analysis. A service-learning component is also included where the students analyze organic chemistry products for the lower division students. As a capstone for the course, students are required to complete a group project that asks them to evaluate an environmental question and incorporate all possible analytical techniques to complete

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ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

this project. The capstone process helps to drive home the importance of good technique and proper analysis. The success of this class is demonstrated by the analytical training allowing the students to perform environmentally significant work.

Introduction

One of the challenges of teaching analytical chemistry is making the experience meaningful for the students, who often get fixated on details and fail to see the overarching concepts and real-world application. For the past 15 years, Southern Utah University (SUU) has elected to use environmental chemistry as a bridge between what students need to know and real-world applications. This has proven to be an effective way to provide real world problems to our chemistry students and at the same time expose the students to environmental chemistry. Environmental chemistry lends itself well to the study of analytical chemistry because the principle skills taught in analytical chemistry class are needed to solve environmental issues. During this time, the resources and facilities at the campus have grown, and as such, so has the instrumentation available for laboratory classes. Even with steady growth, environmental chemistry has remained a focus of the class, thus demonstrating the usefulness in using environmental chemistry as a theme in teaching analytical chemistry, no matter the resources of a curriculum. This paper illustrates how the authors have used environmental chemistry to engage analytical chemistry students.

Development of SUU's Analysis Lab: CHEM 4240

Fifteen years ago, Analysis Lab (CHEM 4240) was the sole analytical laboratory course for chemistry majors, thus, considerable pressure was put on the course to effectively train students in analytical principles and techniques. CHEM 4240 met twice a week for three hours each time, during which time the students learned both wet chemistry techniques and instrumental methods. Due to scheduling logistics, students generally enrolled in the class in the spring right before they graduated. Originally, the only working equipment available was an Ocean Optics diode array spectrometer that sat on a board of a PC computer. While the department had little equipment for general student laboratories, it was able to draw from the resources of the university's commercial environmental laboratory, the Water Lab, which was established in 1974 to provide internship experiences for SUU students and meet the analytical needs of rural southern Utah. As only a limited number of students were able to work in the Water Lab, many students were not getting the same analytical training. Given the resources of the Water Lab, and the background of the instructor (who supervised the Water Lab), it seemed a natural fit to focus on environmental monitoring in the laboratory setting in order to extend this analytical expertise of the Water Lab to better train all chemistry students.

All though Analysis Lab students were allowed to conduct experiments in the Water, students were not given unrestricted access to the Water Lab in order to

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maintain quality control. At this time, the Water Lab possessed a graphite furnace/flame atomic absorption (AA) spectrometer, an ion chromatograph, multiple ion specific electrodes and a turbidimeter. In addition, a myriad of wet chemistry techniques were routinely used, including titrimetric and colorimetric techniques. Rather than bring the students to the Water Lab, the experiments were brought to the Analysis Lab, and when students needed to use the ion chromatograph or AA, sample and standard preparation was performed in the laboratory classroom and the instrumental measurements were made in the Water Lab. Students were then carefully monitored when present in the Water Lab so as not to affect the quality of the work performed in the Water Lab.

As the university administration support for the chemistry curriculum improved, the department was able to acquire more equipment in order to gain ACS program approval. Initially, an Agilent 8350 UV-Vis diode array spectrometer was acquired. This was followed by a Varian 200 MHZ NMR, a PTI Spectrofluorometer, a Perkin Elmer Spectrum 100 FTIR spectrometer and a Waters HPLC. At the same time, several used Agilent 5890 Gas Chromatographs were acquired with FID and TCD detection capabilities. Then due to a new building construction, an Agilent 7820/5975 GCMS, Agilent 7700 ICP MS and a Bruker x-ray diffractometer were acquired. Finally, two years ago, the Varian 200 MHz NMR was replaced by a Bruker 400 MHz Spectrometer.

With the acquisition of the equipment, it became clear that due to the smaller size of the physical science department, students at SUU would have the opportunity to use almost all of the equipment. The Analysis Lab seemed the appropriate venue to teach all students to use the equipment, and experiments were designed to accomplish this. For example, at the beginning of the spring semester, all Analysis Lab students were taught how to use the NMR Spectrometer through a series of experiments. Then they were given a service learning opportunity where, outside of class, they took turns collecting NMR ^{1}H spectra in all products produced by the organic chemistry students. As such, the training the students received at the beginning of the semester was reinforced during the semester as they provided needed support for the organic chemistry students.

The incorporation of instrumental training into the class was used to reinforce the previous theme of environmental chemistry. With departmental growth, a Quantitative Analysis Lab class was created as a prerequisite to the Analysis Lab and students are consequently better prepared when they take Analysis Lab. The Analysis Lab is still taught twice a week. The first part of the semester, the students are given very prescriptive experiments where they are told what to do. This segment of the semester has a strong environmental chemistry theme, beginning with the Coal Creek experiments which will be discussed later. In fact, many of the experiments are adapted from the Water Lab's Standard Operating Procedures (SOP). During the next part of the semester, students are then trained on all of the instrumentation. While much of this instrumentation isn't as readily applicable to environmental chemistry, experiments still incorporate this theme during this segment of the class. For example, ion chromatography is used to measure anions, and colorimetry is used to measure iron in water. The final segment of the semester is a group project. In this group project, students are given a problem to solve using analytical chemistry. About 70% of the projects are environmentally related. The

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students are given an instrument to use and are given free rein to conduct the project while using proper quality controls to verify the validity of their data.

SUU chemistry students have a limited background in environmental chemistry, because the rigorous and structured nature of the chemistry curriculum prevents many of them from taking specialized courses. Most students graduating from SUU in chemistry either go to medical or dental school or go on to study in graduate programs in chemistry. While an environmental chemistry class is taught, very few of the future doctors, dentists, pharmacists, Ph.D. candidates and high school teachers enroll in the class due to lack of interest and time. Hence, the CHEM 4240 Lab became an important exposure to environmental chemistry for most students.

In addition to learning general concepts of environmental chemistry and analytical chemistry techniques, the Analysis Lab also emphasizes communication. Students are required to complete a formal report for each laboratory experiment and one final report for their group project. In each report, students are expected to make sense of the data in the conclusion section of the report. The environmental theme proves to be provides a frame work for the students to apply their chemistry skills. With only a little background in environmental chemistry, the students have minimal expectations of what the results will be from their testing. As such, when asked to evaluate their results in the conclusion section of the report, they are forced to rely upon their data in order to make conclusions. They must judge the quality of their data by their quality controls and compare their results to other groups and results from other water bodies. Each report requires the student to find a literature reference corresponding to their experiment. Then when differences occur, the students must ask themselves why the values are different: is it due to bad analysts or is something physically occurring in the stream they are monitoring?

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

Coal Creek and the Students

Every year that the course has been taught, the entry point into the environmental theme involves water analysis of Coal Creek, a creek running through Cedar City, UT, less than half a mile from SUU's campus. Draining 80.9 square miles, the average flow rate is 34 ft^3/s (*1*). The principal source for coal creek is the Ashdown Gorge/Cedar Breaks Drainage basin (Figures 1 and 2). Located approximately 12 miles east of Cedar City, the drainage basin principally begins with Cedar Breaks National Park which principally consists of an amphitheater of beautiful red cliffs that descend from an elevation of up to 10662 feet to canyon below at 8100 feet. Up to 30 feet of snowfall occurs yearly. The melting snow creates a perennial stream fed by springs at the bottom of the amphitheater that flow from the breaks through the Ashdown Gorge wilderness area, converging to form Ashdown Creek. Ashdown Creek then exits the wilderness area, passing through a narrow limestone canyon and converging with Crows Creek to form Coal Creek. As this point, state Highway U-14 follows Coal Creek for about 8 miles, until both emerge from Cedar Canyon and pass through Cedar City. Coal Creek then passes through much of Cedar City before

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being diverted for agricultural irrigation and Lake Quitchipa or Rush Lake, where the water either enters the aquifer or evaporates. Given the pristine source of Coal Creek and lack of much human interaction prior to Cedar City, environmental monitoring can easily be used to test the effect of non-point source pollution from Cedar City upon Coal Creek.

Figure 1. Cedar Breaks National Park as seen from the South Side. Photo Courtesy of Jason Kaiser, Southern Utah University.

In the first weeks of the course, students are divided into groups (usually of four) to monitor the creek. Each group is assigned a coal creek sampling location (Figure 3). The first sampling location (A) is located 0.7 miles upstream of the city. The second site (B) is located of adjacent to a city park where the creek first enters Cedar City. The third sampling location (C) is only 0.5 miles downstream in a residential area adjacent to a ball field with many parking lots. The fourth sampling location (D) is located where Main Street, the principle thoroughfare in the city, crosses the creek. The fifth sampling point (E) is located after the creek has pass through most of the city. When necessary, an additional sampling location can be assigned at Lake Quitchipa, several miles downstream and another sampling location can be assigned several miles up the canyon. Each group collects water at the same location for any experiment that requires environmental sampling. Admittedly, very little change is expected for some of the sites, but as the students don't know this, they are left to come to the appropriate conclusion by themselves. Each group collects water at their assigned location, and then they analyze their water sample and an unknown sample. The unknown sample is a standard which is used to verify the competency of their analysis. Additionally, a portion of their

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

grade in the class is dependent upon how accurately they analyze their unknown sample. Students must post the value of the creek sample on a shared file so that all of the students may compare their results to each other. This allows for some unique comparisons which will be discussed later.

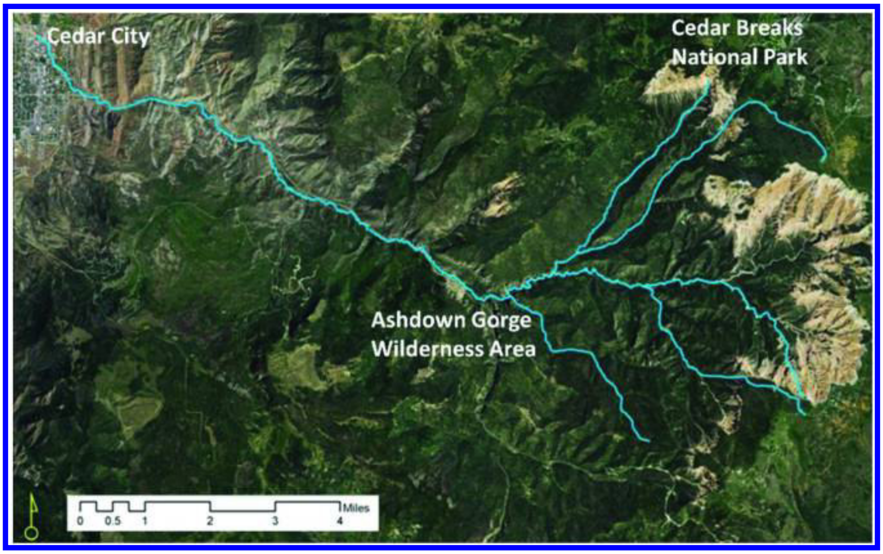

Figure 2. Map of Coal Creek and its Major Tributaries. Courtesy Dave Maxwell, Southern Utah Unversity (2).

Figure 3. Map of Cedar City Utah and the Coal Creek sampling locations for Analysis Lab. Courtesy Dave Maxwell, Southern Utah Unversity (3).

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

Environmental Experience in the Current Curricula of 4240

The summary of experiments taught within the semester are outlined in Table 1. As discussed earlier, weeks 2 through 5 involve wet chemistry analytical methods testing for environmental parameters in surface water, including the samples gathered from Coal Creek. The first two environmental monitoring experiments involve titrations: chlorides by argentometry and alkalinity by titration with sulfuric acid modeled after Standard Methods (SM) 4500 Cl- B and 2320 B (*4*). While many of these students have performed such titrations since freshman chemistry or earlier, experience in this laboratory has demonstrated that they have not reached the skill level to accurately determine chlorides and alkalinity for environmental monitoring. These two experiments incorporate this general technique. The next experiment involves gravimetric determines of sulfates by SM 4500 SO_4^{2-} D (*4*). While gravimetric determinations infrequently occur in analytical laboratories today, this experiment is an effective way to use a once important technique yet maintain the environmental chemistry theme. In addition these determinations are highly accurate, which allows students to compare the accuracy of volumetric techniques with gravimetric techniques. The fourth environmental chemistry experiment involves the second of three experiments in which sulfates are determined SM 4500 SO_4^{2-} E (*4*). In this experiment, sulfates are determined by turbidity, in which barium chloride is added and the resulting turbidity is measured. This experiment works well to enforce the analytical concept of plotting response (turbidity, something students have never seen before) with concentration to generate a calibration curve. In the laboratory class, total dissolved solids of water and organic carbon in soil are determined. Here students learn to evaluate the overall quality of water and learn a preparatory technique to evaluate soil samples.

Analytical techniques are also applied during the instrumental section of the class. The first several experiments enforce the concepts of UV-Vis spectroscopy, then in the next experiment, iron is determined by colorimetry in method SM 3500-Fe D (*4*). In this technique, HACH Ferrover® packets are added to a water sample and an orange-red color results if dissolved iron is present. The students first determine the wavelength of maximum absorbance and plot absorbance at this wavelength versus concentration. Students are surprised to learn that this technique is not adequate to measure the very low levels of iron in water from a creek in "Iron County." Once they come to this realization, they are asked to determine the detection limit of this technique as they report the concentration of the creek as less than this detection limit. They also firsthand determine the linear range of this method and realize that they are also limited to how high they can measure. The students also learn ion chromatography where they apply anion exchange to determine the concentrations of fluoride, chloride, nitrite, nitrate, orthophosphate and sulfate ions at one time (*5*). Not only do the students learn how to determine multiple analytes present in water samples at once, but they also get to compare the results for chlorides and sulfates with those from previous classes.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

Table 1. Summary of Experiments Used in CHEM 4240

Week	*Experiment Number and Title*	*Environmental Component?*
1	Introduction: QA/QC in the laboratory NMR Training, and Check-in	No
	#1 Qualitative NMR	No
2	#2 Quantitative NMR	No
	#3 Determination of Chloride by Silver Nitrate Titration	Yes
3	#4 Determination of Alkalinity by Titration	Yes
	#5 Gravimetric Determination of Sulfate	Yes
4	# 6 Turbidimetric Determination of Sulfate	Yes
	#7 Determination of Total Dissolved Solids # 8 Determination of Organic Carbon	Yes
5	# 9,10 UV Spectroscopy	No
	#11 Colorimetric Determination of Iron in water	Yes
6	#12 Spectrofluorometry	No
	#13 IR Spectroscopy	No
7	#14 Colorimetric Determination of pH	No
	#18, 21 Introduction to HPLC and Ion Chromatography	No
8 &9	#19 Ion Chromatography Method Development	Yes
	#20 Analytical Ion Chromatography	Yes
	#22 HPLC Method Development	No
	#23 Quantitative HPLC	No
10-12	Group Project	Yes
13	Group Project/Present Group Project	Yes
14	Gas Chromatography	No
	#24 Determination of Water Hardness by Flame Atomic Absorption	Yes
15	Practicum	No

After learning both the wet chemistry and the instrumental methods, students are given 3-4 weeks to conduct an open-ended experiment. Students are asked to solve a problem, chosen from a list of projects presented to students. Each project involves a particular instrument that the student will use. As a group, the students decide which project they want to do and decide how they are going to proceed. Most projects involve developing a method to measure the analyte in question, including the determination of a detection limit and linear range. Environmental projects in the past have included the determination of chlorophyll in local

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

streams, including Coal Creek, by spectrofluorometry; measuring anions in Coal Creek by ion chromatography; measuring cations by flame atomic absorption; evaluating Lake Quitchipa for aquifer regeneration; measuring lead in soil at a shooting range by Graphite furnace AA; determination of pesticides in water by GCMS; and finally, measuring mercury in water by ICP-MS. Some of these experiments have proven to be more successful than others. These successful projects lend themselves to follow-up experiments the next year. Students are asked to submit their report in electronic form and these reports are available to all students that take the class in subsequent years. Students are encouraged to review these prior projects during and after the completion of their work. This gives the students a better perspective of the importance and quality of their work.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

Analytical Success

Understandably, student work isn't always accurate as they learn these new techniques, as demonstrated by inaccurate results submitted for the student's unknown sample. This introduces another factor for the students to evaluate when they compare their results with each other. Students are asked to share their results with each other, but they generally do not know how well the other students have analyzed their unknown samples. Thus, when a sample or samples disagree with each other, the students have to decide whether or not something is also occurring at or near a particular sample collection site, or their colleagues have made a mistake. Figure 4 is an excellent example. Four of the five groups measured values from 211 to 250 ppm $CaCO_3$ for total alkalinity. The final group measured a value of 108. In the student's reports, they had to determine if this was a result of a unique phenomenon. Because Site A was upstream and Site B was downstream, students came to the conclusion that the data from students in Group B were due to an incorrect analysis.

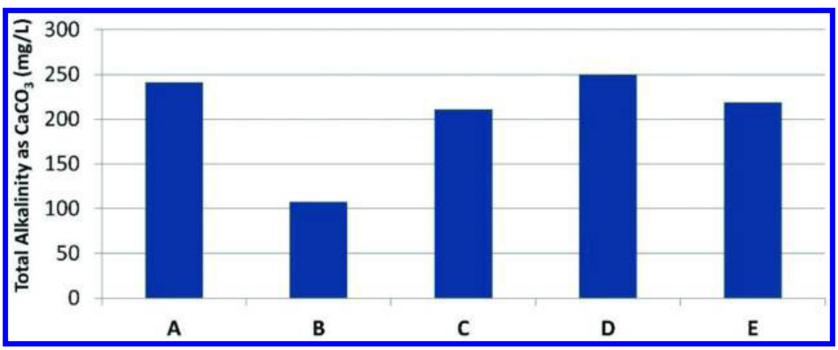

Figure 4. Total alkalinity measured once at each of the five sampling sites in 2015 (single measurements).

On a separate occasion, the students were assigned to measure sulfate by turbidity. As can be seen in Figure 5, with the exception of site E, all values ranged between 120 and 144 ppm sulfate. The student analysts for site E measured a value of 61.7 ppm. Understandably, these students were a little concerned by the

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fact that their value was so much lower than the other values. After consulting the instructor, the students were informed that the majority of creek water had been diverted to an irrigation ditch and now there was a greater influence of the snow melt from the city on Coal Creek. The high sulfate values from the creek were due to the mountain runoff passing over sulfate rich rocks. The city runoff only passes over asphalt and thus contains much less sulfates. Thus lower than normal sulfate concentrations are an excellent indicator of urban runoff.

The consequence of students' limited experience with the different techniques are highly variable results that make it difficult to recognize trends and distinguish events as seen in Figures 4 and 5. The relative standard deviations of 6.4 and 8.8% (excluding the outliers) are typical for the students' work. While it would be preferable that the students' work was better, the students gain a real world appreciation of the variability in analytical measurements. These students are trying very hard and yet variability in their results exists. This understanding will help the students regardless of their chosen professional field.

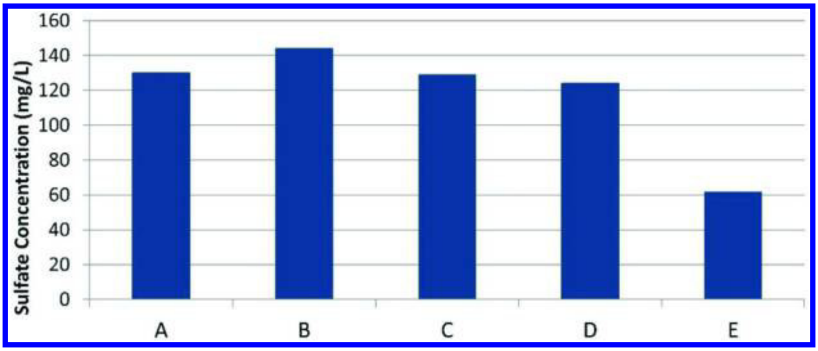

Figure 5. Sulfate measurements once at each of the five sampling sites in 2015 by turbidimetric method (single measurements).

The students also have the opportunity to evaluate their results for the same parameter using different techniques. For example, as discussed earlier, the students measure sulfates in water gravimetrically, turbidimetrically and by ion chromatography. They also measure chlorides by titration with silver nitrate. This allows the students to ask themselves if the mineral concentrations change over time or if there is a particular bias in the different techniques they are using. An example of this is seen in Figure 6. Here the concentration of sulfate was first measured by precipitation to be 168 ppm. Then, two days later, the sulfate concentration was determined to be 130 ppm. Finally, six weeks later, the same group determined the concentration to be 78 ppm by ion chromatography. The difference between the first and second measurements could be explained by a bias of the gravimetric measurement where the students didn't thinks to filter the creek water before precipitation. The students also didn't think to account for the natural turbidity in the creek water on the second measurement, but the effect was less. Here we see a lesson for the students that when making measurements, they need to account for interferences. If they had accounted for the interferences, they could have determined if concentrations were changing over time.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

During the preparation of this manuscript, it has become apparent to us that we can enhance the laboratory experience by keeping the earlier collected samples to be measured by subsequent techniques. While there may be some difficulty with holding times, this will allow the students to measure samples collected on different days to evaluate if there is a change in concentration with time.

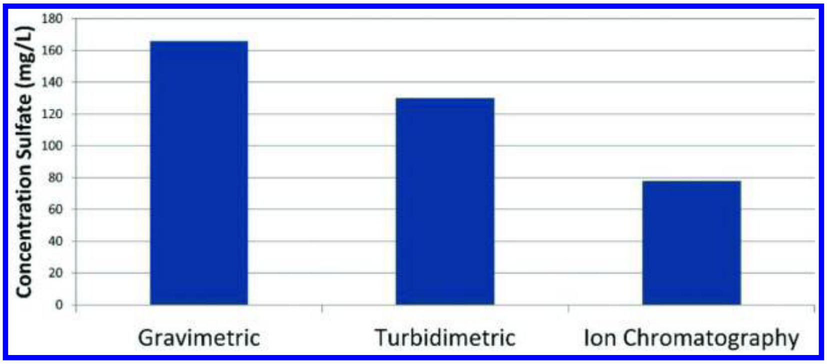

Figure 6. Measured sulfate concentration vs. measurement technique in Analysis Lab 2015. (Single measurement each method at Sample Site A).

Students also gain experience with calibration curves in the course. A common theme of all the early experiments is determining the calibration curve for every experiment. When determining iron concentrations in water, students were surprised not only because the iron determination showed a concentration below the detection limit, but also the calculated values were calculated to be less than zero. Here the students ask: "How can I have a value less than zero?" This was an excellent chance to reinforce the concept of establishing the zero intercept with a calibration curve.

Group Project Successes

We have seen that the analytical proficiency of the students progresses during the semester. While the accuracy and precision of the students at the beginning of the semester is lacking, the students learn the analytical principles and become comfortable with operating the instrumentation, to the point that the work of the project is comparable to many first year research projects. Some of the group projects have met with notable success.

For instance, in 2014, the local water conservancy district wanted to pump the water from Lake Quitchipa to a new percolation bed to allow the water to enter the local aquifer. Three students were assigned to this project. They collected water samples at different locations in the lake at different times. They measured total dissolved solids of the samples they collected. They also measured the anions and other analytes in the lake. They determined the TDS concentrations at the inlet (Coal Creek) to be approximately 400 mg/L and over, 6000 mg/L in the lake. They came to the conclusion the water was too salty due to the many years of evaporation. With this information, the conservancy district abandoned the project.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

Another successful group project involves measuring chlorophyll concentrations. One of the unique attributes of the creek is the very low biodiversity of the creek. No fish are found in this creek and very few invertebrates are found either. Students have been assigned to evaluate why this is so by measuring concentrations of chlorophyll in the creek. The goal is to use the chlorophyll concentrations as an indicator for primary producers in the creek. They are instructed to follow EPA Method 445.0 (*6*) where they filter water samples and extract the chlorophyll captured in the filter with 90% acetone. The students determine the chlorophyll by spectrofluometry without being allowed to use preset filters and had to determine the best wavelength of excitation and emission. They are not allowed to use literature values to select these wavelengths, but rather have to measure fluorescence versus different excitation and emission wavelengths. They prepare a calibration curve and measure the detection limit of their method. Not surprisingly, the students have determined very low concentrations of chlorophyll in the samples from the creek and much higher values in samples from other streams and creeks.

In 2015, a student group was able to develop a method to measure mercury in fish. One of the members of the group, an avid fisherman, collected the fish samples for the group. Another student was the dedication analyst for ICP MS for the department. The students developed a method to digest the fish with nitric acid using the Mod Block™ . The students found significant amounts of mercury in the fish which correlated with state advisory of fish consumption from the reservoirs from which they were collected.

The most successful project has involved the characterization of ion content from dissolving minerals in Coal Creek. The usefulness of characterizing mineral anion content was demonstrated in Figure 5 where ions from mineral deposits such as sulfates can serve to identify water which is not directly from Coal Creek. As such, it is important to understand how the concentrations vary. This is very important during the spring when there is a pronounced diurnal variation in Coal Creek's flow rate due to the melting snowpack. Because the students were allowed to collect samples whenever they wanted, the possibility of the variability being due to stream flow variations always remains. Thus it is a good opportunity to allow the students to determine how mineral anion concentrations change during the course of the day and the spring. In 2012, an interesting phenomenon was discovered. During the fall of 2011, a major landslide occurred just downstream of where Crows Creek converges with Ashdown Creek. This landslide temporally dammed up Coal Creek and blocked all vehicular traffic on State Highway U14. Road construction to repair the highway didn't begin until the spring of 2012. The students wanted to determine if the construction was affecting the water quality of Coal Creek. Their sampling plan included sampling twice a day as the construction progressed, once at low flow and once at high flow. They could not sample above the landslide because of the road blockage so they sampled below the land slide at the first available site that didn't interfere with construction. This site was next to the only tributary below the slide. So they sampled the tributary and then another several miles down the canyon. While the study didn't show any effect from the landslide, as evidenced by no change in concentrations before or after the beginning of repair of the highway, they discovered that the

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

sulfate concentration increased significantly from the first sampling spot to the third sampling spot while the tributary had a lower concentration (Figure 7). This was very surprising because the sulfate concentration of the tributary was less than the original location so the tributary was not the source. No other tributaries were known to exist over this relatively short section of the creek. The question remained to determine how the concentration of sulfates was nearly doubling in only a few miles.

The next spring (2013) another group was assigned to determine concentration along the creek to identify where the concentration of sulfates were increasing. Each week, they collected five samples over the stretch of the creek in question. They incorrectly calibrated the ion chromatograph such that concentrations of all samples were roughly ten times their actual values. Despite this error, their data demonstrated that not only the sulfates were dramatically increasing over this stretch of the creek, but that the concentration of chlorides was also increasing. The students were not that precise in selecting their locations, but the data demonstrated an apparent linear increase versus distance for the concentrations of both these analytes without any drastic increases with in concentration at any sample sites. As such, the students once again only showed a considerable increases in ion concentrations without identifiying any sources.

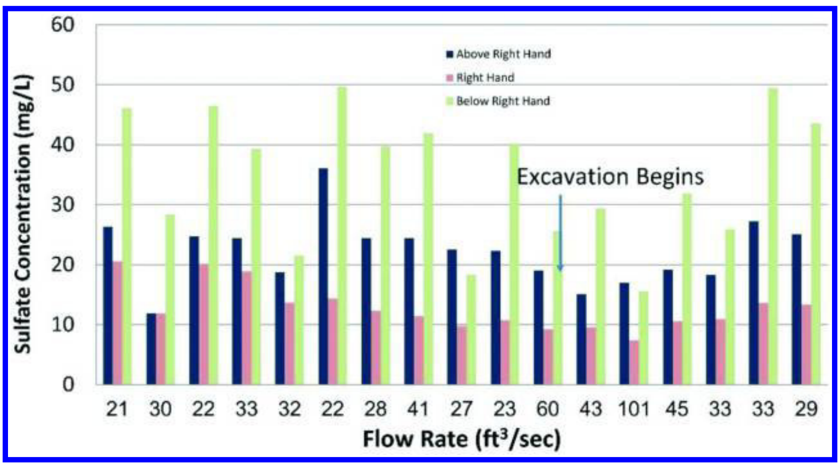

Figure 7. Spring 2012 sulfate concentrations for Coal Creek just above its Tributary (Right Hand) , in Right Hand Creek and 4 miles below Right Hand Creek. Concentrations are plotted in the order they are collected, the flow rates of the day of collection are shown to reference stream flow.

In spring 2014 (Figure 8) the group assigned to characterize the mineral ion concentrations of the creek not only measured the concentration of anions by ion chromatography, but they also measured the concentration of mineral cations by flame atomic absorption spectroscopy. This group determined that the concentrations of chlorides increased from 10 to 15 mg/L and the concentration of sulfates increase from 40 to roughly 100 mg/L.

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch003

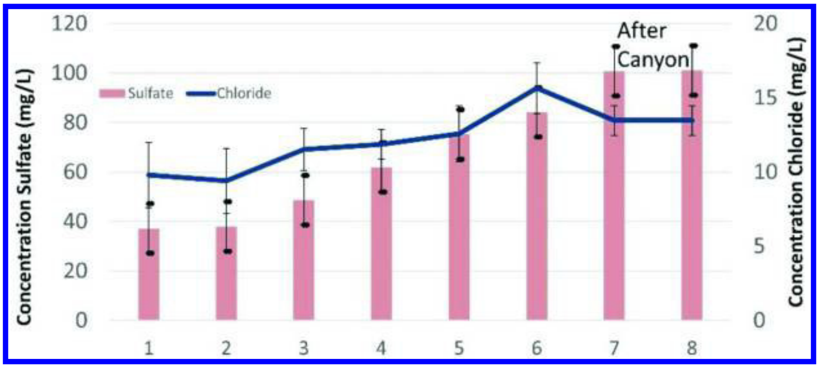

Figure 8. Spring 2014 Coal Creek sampling locations average results for chloride and sulfate. Sample locations 7 and 8 were collected after the creek had exited the canyon.

Finally, in summer 2014, two students were assigned to this project. Both of these students asked to take the class over the summer to free up their schedules for the spring of 2015 when they wished to graduate. They were very meticulous. This was demonstrated in the scores they received for analyzing their unknown samples where they scored higher than any other students have in the history of the class. With this level of precision, it seemed natural to assign them this project. They chose sample locations using mile markers so that their sampling locations would be correlated to distance down the creek. They collected at the same time every day in order to minimize variability. They collected samples on Monday, Wednesday and Friday for three weeks. They chose the sampling location most upstream on the creek, (mile marker 7) to be location 0 and the site locations were numbered such that mile marker six was site number 1 and mile marker 5 was site 2 etc. The students didn't use the mile markers for the lower site locations 5.5, 6.5 and 7.5 because they corresponded to historical site locations and the students wanted to maintain some consistency with previous years. These sample sites were determined halfway between highway mile markers by car odometer and thus were give their identities as 5.5, 6.5 and 7.5. While a small gradual linear increase in concentration with distance traveled was observed up until sample location 4 (Figure 9), the students discovered an abrupt increase in both sulfates and chlorides between sample locations 4 and 5.5. A similar increase in concentration was also observed for sodium. The correlation was not as strong for potassium, calcium and magnesium.

The students quickly observed this phenomenon during the course of the analysis, and the students decided to collect additional samples between mile marker 3 and sample site 5.5. Using the odometer of a car as reference, samples were collected every 0.3 miles. The students discovered that the concentration of sulfates increased from 60 to 80 mg/L between sampling locations 4 and 4.3. The sulfate concentration also increased from 80 to 100 mg/L between sampling locations 5.2 and 5.5. A less dramatic jump was observed for the chloride concentration as well for the same sampling locations (Figure 10). Next, the students walked along this section of creek and discovered two small springs,

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emptying into the creek, one located between sample locations 4 and 4.4 and the other between sample locations 5.2 and 5.5. Water samples were collected at each spring. Not surprisingly the mineral concentrations were determined to be very high with the concentration of sulfates to be over 600 ppm. Water samples were also collected upstream and downstream of each spring to verify that the springs were responsible for the increase in mineral concentration. At this point, the students were done with their project; however the students then contacted a geology professor to help them identify the geology behind the springs. The students have now published their work in an undergraduate research journal (*7*).

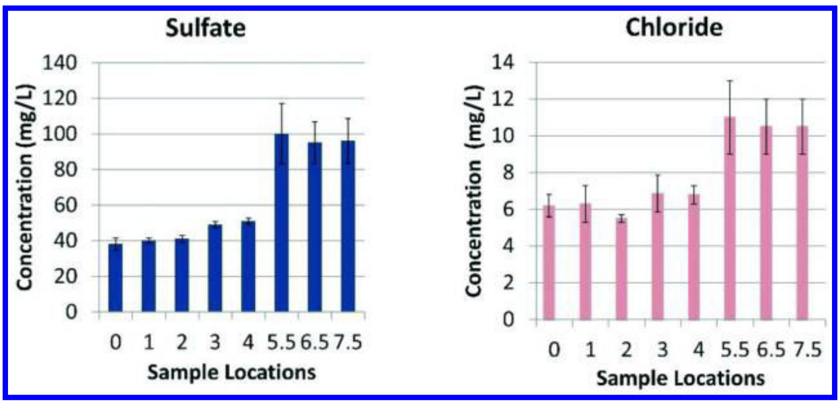

Figure 9. Sulfate and Chloride concentrations per sample location 0 to 7.5 for samples collected in the summer of 2014 (single measurements). Adapted with permission from reference (7). Copyright (2014) DigitalCommons@CSB/SJU

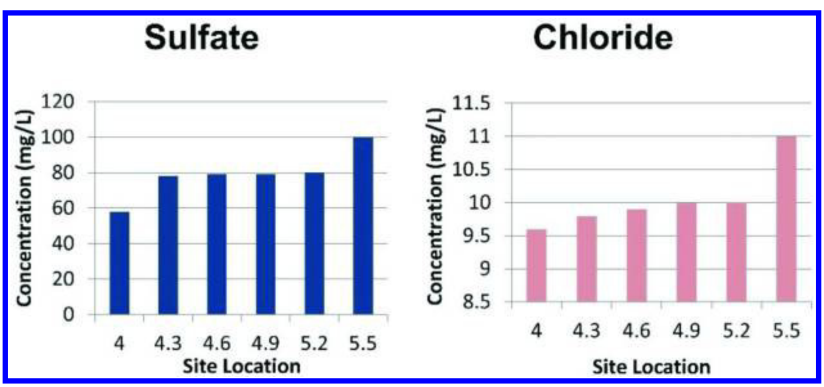

Figure 10. Sulfate and Chloride concentrations per sample location 4 to 5.5 for samples collected in the summer of 2014. Adapted with permission from reference (7). Copyright (2014) DigitalCommons@CSB/SJU.

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Conclusion

The environmental emphasis has proven to be an effective platform to provide meaningful analytical problems for students to apply the principles taught in analytical chemistry. As no control group exists to test the effectiveness of this program, we are relegated to anecdotal evidence. Despite the large number of students in the analysis lab who are not particularly interested in environmental issues little push-back has been observed from the students. The students work hard a generally see the value of their training. No requests for a more medicinally applied analytical program have been made. The environmental theme also allows many opportunities for the students to learn analytical techniques and instrumental methods which can be applied to many fields. Thus the students are able to see many real world applications to what they learned in the classroom. Finally, the skills and techniques learned in this manner allow the students the ability to make meaningful measurements that have environmental applications.

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Chapter 4

Investigating Drinking Water Quality: Theme-Based Activities for a Range of Instructional Levels

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Drinking water quality is the theme for several related projects presented here. College level activities for Allied Health majors and science majors as well as those adapted for junior high school students are described. The projects involve researching U.S. Environmental Protection Agency guidelines and water quality reports published by municipalities in addition to examining drinking water hardness both by titration and atomic absorption spectrometry. Assessment of the pedagogical impact of these was determined from students' written commentary, content and attitude surveys, exams, personal interviews, and classroom observations. The projects resulted in an increased awareness of and enthusiasm for environmental issues as well as knowledge of environmental topics and analytical methods by students at various levels of chemistry instruction.

Introduction

Students respond with great interest when the topic of drinking water quality is introduced; it is no wonder that there is a myriad of water products sold these days with special marketing attention to teenagers and college students. There is plain bottled water, spring water, mountain spring water, European spring water, and even glacial water from Iceland (*1*). Lately, the market now sells "pure" water with "beneficial" additives like caffeine and vitamins. It seems that good quality drinking water is highly marketable. Part of the reason may

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be that the importance of quality drinking water is easily understood and the recognition of poor quality water is easily seen, tasted or smelled. Of course, we as scientists know better. Good looking, tasting, and smelling water can be deceptively unhealthy and bottled water is often no more "pure" than tap water. The advantage of water quality as an educational theme is that with some chemistry knowledge and research skills students can discover for themselves what water "purity" really means, the differences between bottled and tap water, distilled and deionized water, effects of water softening, and federal policies that protect U.S. citizens from harmful contaminants in drinking water. With this in mind, the following research projects and experiments were developed as project-based learning, i.e., they were activities that took advantage of students' interest in a topic of relevance, namely water quality, in order to assist them in their learning of chemical principles and development of investigative skills.

One component of the water project described here was initially developed as a research project for Allied Health majors. For this project, students obtained water quality reports from their hometown, researched the report and the U.S. Environmental Protection Agency (EPA) website for answers to questions posed, and wrote papers summarizing their results. This project was adapted into a similar one for use by science majors who take general chemistry laboratory. In the general chemistry version, students' research included water hardness values and water quality assessment for hometowns compared to U.S. cities. With the addition of two experiments for analysis of water hardness, the general chemistry water quality project took on multiple dimensions. The final transformation of the project was into four activities carried out by eighth grade students in a pre-college chemistry program on campus. In essence, this paper gives an example of how a theme-based project can be manipulated for use by students at various levels of chemistry instruction.

Water quality is a common subject for undergraduate analysis, therefore many papers describing experiments which test for water quality can be found in the chemical education literature (*2–21*). Two quantitative analysis methods for the measure of water hardness, atomic absorption spectrophotometry (AAS) and volumetric analysis by ethylenediaminetetraacetic acid (EDTA) were adapted from these articles. Recreating this project for eighth grade students was done by altering experiments to make them qualitative in nature and by using AAS data previously collected by general chemistry students. The data was compiled and presented in a format useful for basic mathematical analysis and evaluation of water hardness. O'Hara et al. described a similar application of this idea to GC/MS experiments (*22*). In that case, components of the experiment were separated into mini-experiments appropriate for different grade levels. For example, sixth graders carried out measurements for pH and conductivity as well as spreadsheet management of drinking water samples, high school students carried out solid-phase extraction of samples, and the GC/MS analysis was done by college students. In the projects described here and the one described by O'Hara, students seemed to respond with greater interest to activities that gave personal relevance to chemistry principles through multifaceted projects.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Project Descriptions

Chemistry for Allied Health Majors

A research project was designed for freshmen taking Principles of Inorganic Chemistry, the first semester of a two-semester chemistry sequence for Allied Health majors. In this two-semester series, several projects have been developed to highlight the relationship between course material and societal and environmental issues. For this project titled "Water, Water, Water," the students were required to request the water quality report from their municipality or obtain one online and then answer a series of questions concerning science policy and drinking water quality including the U.S. Safe Drinking Water Act (SDWA), the government agencies responsible for overseeing the safety of municipal drinking water or bottled water, and recent history in regards to allowable levels of arsenic. In addition to these topics, students compiled data for a select list of contaminants including measuring units reported, measured levels, maximum containment level (MCL) values, maximum containment level goal (MCLG) values, and contaminant sources. Students were required to speak with someone that shares the same drinking water (e.g. a family member) and report on this interaction. Finally, the students determined how to have their water tested and wrote a paragraph commenting on the safety of their water supply. The questions used for the project are presented in Table 1. Table 2 shows proposed student outcomes from the activities. A list of suggested websites for their research was provided on the external links site of the course webpage. This list included the U.S EPA site on Ground Water and Drinking Water and the National Resource Defense Council (NRDC) site focusing on water (*23*, *24*). A grading rubric was provided with the initial handout given to the students. The rubric included a column for the student to score his/her effort on the project and a section for the instructor to score the project. The students turned in their projects and the rubrics with the student-scored column completed.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Table 1. Questions for the Allied Health Chemistry Project

1. What U.S. government agency oversees the safety of municipal drinking water? 2. What is the primary water source type for your drinking water? 3. What is the "Safe Drinking Water Act"? 4. For each of the following: arsenic, total trihalomethanes, turbidity, and lead, answer these questions: Define the measuring unit used for each. What is the allowable level of each? What are some of the adverse effects of high levels of these contaminants? How do these get into the water supply? What is the level in your water supply? Even if one of these is not found in your drinking water, you must answer all but the last question for each contaminant. 5. Describe what has occurred over the past several years regarding the level of arsenic that is allowed in US water supplies. What is required beginning in January of 2006? Why is it an issue to require lower levels of arsenic in our water supply? In your description identify and comment on the stakeholders involved and comment on the health issues vs. economics. (Stakeholders are all the different groups or people affected). 6. What US government agency is primarily responsible for the safety of bottled water? 7. List and discuss two differences in standards or testing regimens for tap water and bottled water. 8. Go to the NRDC site and look at the 1999 report on bottled water "Bottled Water: Pure Drink or Pure Hype". Summarize in one paragraph the findings of the NRDC concerning bottled water. 9. Go to the NRDC website and look at the report Grading Drinking Water in U.S. cities (2003). What grades did the Detroit Water Supply get? How can Detroit improve its rating in regard to source water protection? 10. How would you answer the question: Which is safer, bottled water or water from your tap? 11. Discuss what you have found with someone (not in this class) who shares the same water supply. Include any comments or questions they had about the information you discussed. 12. How would someone have their water tested for contaminants? Give specifics including the company name, mailing address, sample preparation instructions, and cost for analysis. 13. What are secondary standards in regards to water quality? 14. Write a paragraph in which you comment on the safety of your water supply.

Table 2. Skill Areas and Content Objectives from Water Quality Activities for Allied Health Chemistry Project

Project	*Skill areas*	*Specific content*
Water quality report research project	Research Compiling data Reporting data Comparing data Reference citation	Safe Drinking Water Act Government and public policies Measuring units Interpreting water quality data Listing sources of reference

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Chemistry for Science Majors – A Research Project

The project detailed above was adapted for students taking General Chemistry II Laboratory and titled "Your City's Water Quality". Students in this course were assigned to investigate the water quality in their home town and another city within the U.S. Suggested sources for information were the EPA website and cities' water quality reports which could be obtained online or directly from the municipality offices. The assigned handout contained a list of questions similar to those for the allied health course concerning the U.S. SDWA and Detroit's water quality grade reported by the NRDC. The questions used are presented in Table 3. Students were required to cite the references for each of their answers. In addition to these questions, students had to compile data for a select list of contaminants including units reported, measured levels, MCL values, MCLG values, and contaminant sources. Students were asked to report on lead, arsenic, total trihalomethanes, turbidity, and total hardness. For cases in which one or more of these values was not reported, students were directed to indicate "N.L." for 'not listed'. This table was filled out for both the student's home town and a city of their choice within the U.S. The 'pick city' was submitted to the instructor for approval to ensure that all students had a unique report. For the final component of the project, students specified which of the two cities had better water quality based on the cities' reports.

Table 3. Questions for General Chemistry II Laboratory Research Project

1. What U.S. government agency oversees the safety of municipal drinking water?
2. What is the "Safe Drinking Water Act"?
3. What are adverse effects of lead in drinking water?
4. What are adverse effects of arsenic in drinking water?
5. What change was required beginning in January of 2006 with respect to arsenic in drinking water?
6. Go to the NRDC website provided and look at the report Grading Drinking Water in U.S. cities (2003). What grades did the Detroit Water Supply get?
7. How can Detroit improve its rating in regard to source water protection?
8. Where could one get information on getting their drinking water tested?
9. Define the measuring units used for the contaminants found in water quality reports.

Chemistry for Science Majors – Experiments

Two experiments were designed for freshmen taking General Chemistry II Laboratory, both analyzed for the hardness of drinking water samples. Procedures were adopted from previously published work and *Standard Methods for the Examination of Water and Wastewater (25–27). The first method of analysis for water hardness utilized EDTA as titrant and Eriochrome Black T as metal ion indicator. Similar protocols and applications of the EDTA method have been published previously (14–21, 25).* The second method utilized flame atomic absorption spectrophotometry (FAAS) and was also adopted from the *Standard*

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ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

Methods and previous articles (*16*, *25*, *27*). A Perkin Elmer AAnalyst 400 FAAS with auto-sampler was used. The auto-sampler expedited the measurement of the standard solutions and samples that were used by about 30 students in each of the three class periods. Each pair of students calculated their own average water hardness from both the titration and FAAS data and then compared the two methods to each other and then to the accepted value for water hardness. Statistical comparison using student's t-tests could have been done, but was not in this case. Table 4 shows proposed student outcomes from the research project and two experiments.

Table 4. Skill Areas and Content Objectives from Water Quality Activities for General Chemistry II Laboratory

Experiment/project	*Skill areas*	*Specific content*
Water quality report research project	Research Compiling data Reporting data Reference citation	Safe Drinking Water Act Government and public policies Measuring units Interpreting water quality data Listing sources of reference
Water hardness analysis by EDTA titration	Laboratory techniques Mathematics Basic statistics Results assessment Inorganic chemistry	Weighing Titration Solution preparation Notebook keeping Metal-ligand complexation Metal ion indicators Volumetric analysis calculations Mean and standard deviation Student's t-test Hardness of water Water softening by ion-exchange
Water hardness analysis by FAAS	Laboratory techniques Mathematics Basic statistics Results assessment Inorganic chemistry	Solution preparation Notebook keeping Metal-ligand complexation Beer-Lambert Law and application Mean and standard deviation Student's t-test Hardness of water Atomic absorption spectrophotometry

Chemistry for DAPCEP

The research projects and laboratory experiments described above for Principles of Inorganic Chemistry and General Chemistry II Laboratory were adapted for use in a pre-college program called DAPCEP (Detroit Area Pre-college Engineering Program) (*28*). This program provides science, technology, engineering, and mathematics opportunities to minority students

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.
Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

through various courses offered by local universities. The "World of Chemistry" course within the DAPCEP program is offered by the Department of Chemistry and Biochemistry at the University of Detroit Mercy. This course, held every spring for six Saturdays, provides laboratory experiences for approximately 50 Detroit area eighth graders, 99% of which are minorities. The "Tap Water Analysis" project which encompasses four activities was designed to develop skills in the areas of graph and table interpretation, statistical analysis, results assessment, experimentation, observations/record keeping, team work, and communication.

The four activities were created using data collected from the AAS experiment "Flame AAS Analysis of Hardness of Water" and the research project "Your City's Water Quality." For the first activity, the handout contains a graph of experimental AAS data obtained from students in General Chemistry II Laboratory (Figure 1). The y-axis is the number of students that obtained each concentration value, while the x-axis is the concentration of $CaCO_3$ equivalents found in the sample of tap water. Students were instructed to calculate the overall average value after being provided with an example calculation and then compare it to the value obtained by the most number of students. Lastly, they were asked questions concerning the reliability of the results, such as "Would a value collected by five students be more reliable than from one?"

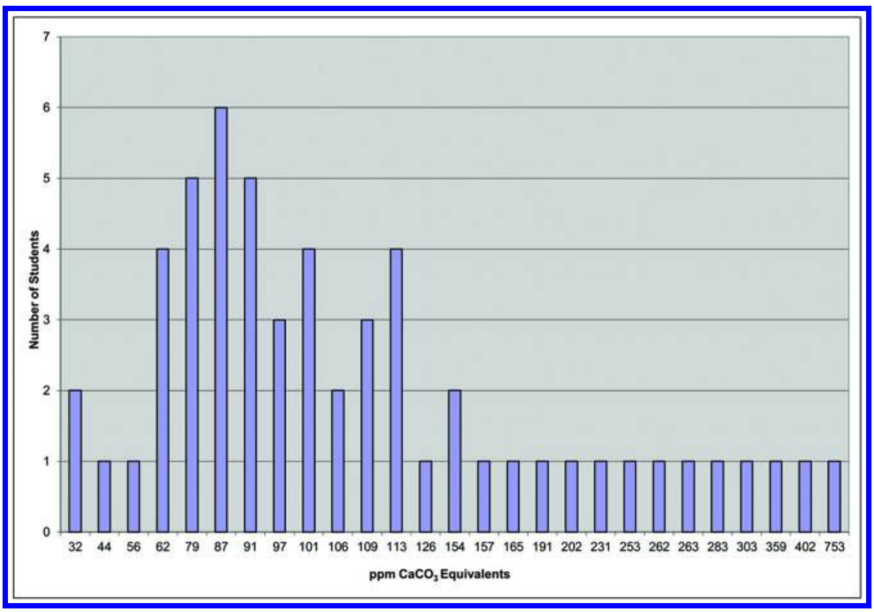

Figure 1. Hardness of tap water from UDM chemistry building in February 2007 measured as calcium carbonate equivalents. The concentrations shown are averaged values of data points within 2 ppm.

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

The data was presented a second time without single-value data points greater than 126 ppm. Students were asked to identify the difference between the two graphs, recalculate the average for the new data set, and reanalyze the reliability of the data. Lastly, students were asked to assign a degree of water hardness to the tap water sample. The objective of this exercise was to develop the students' math, data interpretation, and reasoning skills. In the second activity, students were asked to read information from the U.S. EPA website about the SDWA, adverse effects of arsenic and lead, how to get drinking water tested, water conservation, and potential contaminants in drinking water. In addition, they were asked to define MCL, MCLG, and measuring units for contaminant levels in drinking water. The final component of this activity is to read water quality reports from the city of Detroit and another destination city and compare reported values for various contaminants as well as the hardness value. From the general chemistry course, more than 90 cities' water quality reports were submitted. The most complete and easiest to read were selected and reused in the DAPCEP program. This activity required skills necessary to interpret the reading assignment, collection of data from the readings and analysis of the data. For the third activity, students carried out an experiment which measured hardness of several water samples. This experiment involved the use of EDTA and a metal ion indicator to test for the presence or absence of calcium in water samples. The college level quantitative experiment was adapted to be much shorter and qualitative. Rather than asking eighth grade students to quantitatively measure the hardness of the tap, distilled, and deionized water samples, they were simply asked to identify the presence or absence of calcium in the samples. The fourth activity instructed groups to act out a newscast reporting on the water quality of their city in front of the rest of the class. Students were to self-assign positions (anchorperson, field reporter, assistant, and producer) and to make a broadcast informative yet interesting to their peers. Skill areas and content detail are provided in Table 5.

Table 5. Skill Area and Content Objectives from Water Quality Lab for DAPCEP

Activity/experiment	*Skill area*	*Specific content*
Data analysis of a water quality study	Mathematics Graph interpretation Basic statistics Results assessment	Calculation of mean value Collecting data from graph Comparison of mean Hardness of water Reliability of data
Water quality report research project	Comprehension Table interpretation Data interpretation	Collecting data from EPA website Collecting data from a citys water quality report Measuring units Definitions MCL, MCLG Comparison of data for two cities

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Table 5. (Continued). Skill Area and Content Objectives from Water Quality Lab for DAPCEP

Activity/experiment	*Skill area*	*Specific content*
Testing for water hardness	Experimentation Observations Recording data Data analysis	Water hardness Comparison of calcium content of tap, distilled, and deionized water
Breaking news – water quality of our city	Team work Communication Creativity	Assigning jobs Acting out a newscast Dissemination of the results

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Dissemination of the ResultsAssessment

Chemistry for Allied Health Majors

Forty-one students in the fall term of 2005-06 and 18 students in the fall term of 2006-07 completed the water project in the allied health chemistry course. One objective of this project in this course for non-science majors is to increase the awareness between course material and environmental and societal issues. These reports were analyzed for common themes in the information given in response to two sections of the report. The instructions in these sections were to "Discuss what you have found with someone (not in this class) who shares the same water supply. Include any comments or questions they had about the information you discussed." and "Write a paragraph in which you comment on the safety of your water supply." Table 6 gives a compilation of some of the common themes that were found in the discussions the students had with someone who shares their water supply or in their final paragraph commenting on water safety. In several cases, specific contaminants, often arsenic or lead, were mentioned. In the paragraph commenting on water safety, at least 63% of the students cited the water quality reports or specific data from water quality reports in their comments. The topic of tap water versus bottled water was a common theme for the discussions with others. Several students cited the importance of source water protection in their comments or discussions with others. Finally, several students or the people they interviewed reported some knowledge gained, shock or surprise at some information. The following are some of those comments (uncorrected):

> "Beforehand, I never really cared about water quality. For the most part I drank water if it looked clean. I never really thought about biological contaminants before this."

> "As for my community, I will stay informed regarding water supply/ treatment of the water. This study has really opened my eyes…"

> "I discussed this issue with my mother and she was somewhat surprised by this information."

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

"I am glad I did this project because it opened my eyes to something I would have probably never looked at before. I have already discussed my water quality report and this report to 3 interested people."

"The project and my research has definitely arose awareness in my mind as to what I am drinking and who should be following the contaminants that are contained in the water."

"I also find it very important to take notice where you get your water supply from and recommend looking at the water quality report for that city."

"I have just recently started drinking tap water again because I have learned that Detroit has some of the cleanest water."

"After all the research I have done throughout this project, I have found that some of the things that I held as truths in my head actually are not true. I have always thought our tap water is quite contaminated, and actually not good for us to be drinking. My findings are quite contrary."

Table 6. Common Comments Found in Two Sections of the Student Reports

Topic	*2005-06 (n=41)*		*2006-07 (n=18)*	
	Discussion with others	*Comments on safety of water*	*Discussion with others*	*Comments on safety of water*
Mentions specific contaminants, units, or source of contaminants	10	6	4	4
Comments on safety with reference to data or evidence	4	26	9	13
Comments on safety of tap versus bottled water	21	12	9	5
Comments on protection of water source or pollution of water source	3	6	2	4
Acknowledges surprise, shock, or knowledge gained	8	12	2	1

For the "Water, Water, Water" project, the students were required to submit a scoring rubric in which they had completed the first column labeled "Student Score". The project was worth a total of 40 points and the rubric clearly described the point values for each activity. The students (39 in 2005-06 and 16 in 2006-07) completed a scoring rubric and turned this in with their projects. The instructor then completed the second column of the scoring rubric. The students performed well on this project as evidenced by the average of the scores determined by the instructor, 37.4 (± 3) for both groups of students. At least 43% of the overall scores given by the instructor were equal to or greater than the scores the students gave themselves. There were two areas that many of the students were deficient. Approximately 50% of the students did not adequately respond to question #5 about the changes in the allowable levels of arsenic in drinking water. In addition, approximately 25% of the students did not provide an acceptable citation format for websites they had consulted.

Chemistry for Science Majors

In order to assess the gains in understanding of the chemistry principles presented during the flame atomic absorption experiment, General Chemistry II Laboratory students were offered a voluntary pre-lab survey (A) and post-lab survey (B) given before and after the pre-lab lecture and subsequent completion of the atomic absorption spectrometry experiment. These surveys were handed out during the weekly recitation periods before and after the experiment. In addition an attitude survey (C) was offered to students to fill out online outside of class. For all three surveys, a consent form was provided in order to inform students of the voluntary and anonymous nature of the surveys. A brief explanation of the purpose of the surveys was included.

Results of the content surveys (A and B) show that the majority of students had basic knowledge of environmental topics such as common contaminants, water hardness, methods of analysis, the role of the EPA, and careers for environmental scientists (Table 7). It should be noted that prior to this experiment, students had carried out the EDTA titration experiment described in the methods section of this paper. In addition, a speaker from a local watershed project came to campus prior to the atomic absorption experiment to present volunteer opportunities for students (*29*). Therefore, students had some prior knowledge concerning water quality analysis with respect to water hardness, metals involved, volumetric methods, and local water quality issues. For analysis of the results the average percent correct and standard deviation from seven different questions answered by students who took the surveys were calculated. For questions concerning common contaminants, the benefits of environmental analysis, hard water elements, common tests for water quality, and eco-sphere involved, the percent of students that answered these correctly was 83% (± 2) on Survey A and 92% (± 2) on Survey B. This indicated that a large number of students who took the survey had a good understanding before the atomic absorption experiment and an even larger number after the experiment. For questions concerning principles of atomic spectrophotometry such as excitation, spectra, Beer-Lambert Law, detection limits, analytes, type of radiation, and purpose of the flame in FAAS, the percent of students that answered these correctly was 39% (± 25) on Survey A and 71% (± 32) on Survey B. A dramatic improvement in understanding of most of the content was evident and likely a result of the pre-lab lecture, experimental handout and questions, and experience with the FAAS analysis method.

Students as a whole obtained equal or lower scores for four questions. While 57% of students knew the name of the federal agency overseeing water quality in

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

the U.S., there was no increase in this percent as a result of the FAAS experiment. Two questions were identified as misconceptions. A significant percentage (35% Survey A, 41% Survey B) of students misunderstood calcium and magnesium to be heavy metal contaminants. Students incorrectly assumed that since they had tested for calcium as a measure of water quality and since it was a metal, that it must be a heavy metal. The other misconception occurred when students confused the purpose of the flame and radiation in FAAS. The last question of concern (careers) was disregarded as a poorly-written question based on the answers given by many students. Overall the results of content Surveys A and B show an increase in correct answers from 58% (± 27) to 76 % (± 25), suggesting that students gained knowledge of basic environmental principles and methods.

An online evaluation tool called Student Assessment of Learning Gains (SALG) was used to prepare an attitude survey for General Chemistry II Laboratory students (*30*). This free online tool, developed by Elaine Seymour and Sue Lottridge, is housed in the Wisconsin Center for Education Research at the University of Wisconsin-Madison. The website provides templates for a wide range of disciplines, student access, and compiled results for instructors. A copy of the survey used here is included in the supplemental material.

Students were asked to fill out the survey outside of class. Twenty students out of 76 enrolled took the survey. It should be noted that the survey was completed after the two experiments described above were completed but before the water quality research project was carried out. Three categories of questions concerned helpfulness of class activities, gains in understanding of content, and gains in appreciation or confidence in abilities with the latter two being of primary interest when evaluating the effectiveness of activities presented here. The category with the highest average rating was gains in understanding content. This category's question asked, "As a result of your work in this class, how well do you think that you now understand each of the following items?" The items included basic principles of spectrophotometry, flame atomic absorption spectrophotometry, analysis of metal concentrations by FAAS, calculations, objectives of environmental analysis, and harm of heavy metals. Each of these items received an average rating of 3.65 to 4.00 on a scale ranging from 0-n/a, 1-not at all, 2-a little, 3-somewhat, 4-a lot, 5-a great deal. According to this data 90% of students thought that the course helped with this content "somewhat," "a lot" or "a great deal," in agreement with the findings of Survey A and Survey B. As discussed above, the evidence for improvement in understanding of basic principles of atomic spectrophotometry as a result of students participating in the FAAS activity was quite dramatic (39 to 71%).

The appreciation/confidence question asked, "To what extent did you make gains in any of the following as a result of what you did in this class?" The items related to students' impression of their gain in enthusiasm for environmental issues, appreciation of methods for environmental studies, and confidence in their abilities to carry out the experiments. The average scores ranged from 2.90 to 3.85 on the same scale as above. Interestingly, the lowest score was given to "gain in enthusiasm for environmental issues/science." However, when asked to rate their interest in environmental science before and after the FAAS laboratory, the average increased from 2.65 (before) to 3.55 (after). The lower overall average

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

for appreciation/confidence (3.52) as compared to gains in understanding content (3.78) may be due to the fact at the time of the attitude survey students had some quantitative measure (midterm exam grade) of their understanding of content. For students taking chemistry, rating their own enthusiasm, appreciation, and confidence is a less common experience and potentially more difficult than rating their own understanding of content given the traditional assessment of students in chemistry courses.

Table 7. Results of Pre-Lab and Post-Lab Surveys A and B Taken by General Chemistry II Laboratory Students during Term II 2006-07

Topic	*Survey A pre-lab test % correct (n=51)[a]*	*Survey B post-lab test % correct (n=56)[a]*
A. Environmental basics		
common contaminant in water and soil	84	93
benefit of environmental analysis	86	95
element that contributes to the hardness of water	82	91
common test for characterizing water quality	82	91
eco-sphere studied by environmental chemistry	82	89
government agency that is responsible for monitoring environmental quality in the United States	57	57
type of career that environmental chemists might have	73	70
heavy metal contaminant in the environment	65	59
B. Atomic spectrophotometry basics		
cause of excitation of chemical species	55	41
atomic versus molecular spectra	0	6
relationship between concentration and absorbance	67	79
most accurate method for low concentrations of metals	41	73
detection limits for FAAS	67	98
types of chemical species quantified by FAAS	45	96
type of radiation is utilized in FAAS	26	86
purpose of flame in FAAS	12	91

[a] The number of students enrolled in the course was 76.

Evidence for increased awareness of environmental issues by General Chemistry II Laboratory students as a result of the water quality research project was clearly found in results from midterm and final exam scores (Table 8). The

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

number of students who were able to correctly define "anthropogenic" and "MCL" (maximum contaminant level) on the midterm was 71 and 83%, respectively. These high scores were likely a result of the fact that both of these terms were used during the experimental laboratories prior to the midterm exam. Between the midterm and final exam, these terms were used by students to complete the water quality research project. As a result, 97% of students correctly identified these terms on the final exam. Ninety four percent of students knew the relative magnitude of MCL versus MCLG during the final exam. Seventy two percent could correctly identify the change for arsenic content in drinking water that was required for states beginning in January of 2006. Forty nine percent knew the units for turbidity. Each of these topics was a component of the water quality research project. The high percentage of correct answers suggests that the activity was valuable in students' learning of these topics.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch004

Table 8. Results of Midterm and Final Exam Scores Taken by General Chemistry II Laboratory Students during Term II 2006-07

Topic	*Midterm exam % correct (n=70)[a]*	*Final Exam % correct (n=72)[a]*
anthropogenic	71	97
define MCL	83	97
water hardness ions	81	n/a
heavy metals	64	n/a
federal agency that oversees water quality and acronym	n/a	90
relative magnitude of MCL and MCLG	n/a	94
arsenic MCL for January 2006	n/a	72
turbidity units	n/a	49

[a] The number of students enrolled in the course was 76. n/a, not available.

Chemistry for DAPCEP

The objectives of the four DAPCEP activities were to facilitate the achievement of problem solving skills such as data analysis, experimentation, and research as well as awareness of environmental issues related to water quality by junior high school students. The project was a success for the most part. During all of the activities, students were observed working together in their self-assembled groups of three or four. Two instructors and seven teaching assistants monitored the groups' progress, answered questions and posed additional ones. It was observed that the students were engaged in the hands-on activities 1, 3, and 4 (Table 5). For the first activity students were observed writing out calculations, double checking numbers with each other, sharing the results from the calculators, and discussing data. Students were able to carry out average values calculations, answer all exploratory-type questions, and most of the concept-development questions. Similar team-work was observed during the third activity (EDTA test) as students carefully performed the procedure. For the fourth activity (newscast), group-work was still apparent however the atmosphere was much more jovial. The first objective of this activity was to show relevance of water quality reports to citizens, while the second objective was for students to be creative. One could hear students laughing and suggesting humorous ideas for how to perform the newscast skit. During these skits no factual information was communicated. In fact, the groups made up dramatic water quality warnings for their local drinking water sources to make the newscasts more shocking. Topics ranged from radioactive contaminants found in local drinking water reservoirs to dangerously high levels of calcium in bottled water. While not factually correct, students obviously gained some awareness of water quality issues from the activities. Groups had no time for rehearsal, so much of the lines were improvised. As an expected result, skits were met with laughter and cheering. While most students were comfortable with this activity, several groups were reluctant. In the end, only those who volunteered actually performed their skits.

The second activity (water quality reports) was not as successful as the other three. Students found it to be dry and had a difficult time staying on task. Several factors contributed to this. The first was the lack of explanation of terminology and directions on how to read the reports at the beginning. Second, the water quality reports and the EPA handouts contained too much extraneous information that overwhelmed students. Finally, too many contaminant values were assigned. Correction of these three points would likely results in a more palatable project with the same potential outcomes.

Conclusion

Skill and content objectives for the three instructional levels of chemistry, allied health majors, science majors, and junior high school students were determined to be met based on assessment by written work, content and attitude surveys, exams, personal interviews, and classroom observations. For the allied health majors' course, emphasis of the research project was placed on awareness of environmental and societal issues. Effectiveness of that project was determined based on common comments found in student reports and the overall scores. For science majors, emphasis on content objectives focused assessment on surveys and exams that evaluated knowledge at various points during the course. Lastly, classroom observations were used to determine whether objectives were met in the DAPCEP project. In these three chemistry courses, awareness and enthusiasm for environmental studies increased as a result of the described activities. Based on content surveys and exams, students in the science majors' chemistry course scored higher on most questions after the laboratory activities indicating that they gained knowledge of environmental topics and methods as a result of the course.

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Chapter 5

Smartphone Spectrometers: The Intersection of Environmental Chemistry and Engineering

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Project-based learning is an engaging way to allow undergraduate students to explore environmental chemistry by providing them with an open-ended problem to solve rather than the traditional format of prescribed laboratory exercises. This technique also allows for partnerships with other disciplines like engineering. In this exercise, chemistry and engineering students worked together using paper spectrometers originally designed by PublicLab. The students compared the performance of the paper spectrometer with existing instruments using prepared water samples and brainstormed how they might improve the design. Students also discussed how the portability of an instrument might affect field measurements and how "citizen science" can be used to get data. Students appreciated the interdisciplinary collaboration and felt that the activity enhanced their understanding of spectrometry beyond that of a traditional laboratory.

Introduction

The changing nature of education necessitates novel approaches for teaching the next generation. Scientists must often cross interdisciplinary boundaries to develop solutions to environmental problems, and researchers must share knowledge across pedagogical borders (*1*, *2*). Water resources, and clean water in particular, lend themselves to a non-traditional course approach, as the issue is current and evolving (*3*). Non-traditional students must also be engaged by course delivery, and one way in which to reach this audience is to provide links to real

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world problems outside the classroom. These users benefit from interacting with their peers in ways which the traditional classroom can lack, as those students often feel that their opinions go unheard in the class "group-think. "The term non-traditional student refers to adult learners, or those who may have been away from the classroom for an extended length of time. Tilbury and Wortman have identified several skills that should be evident in sustainable chemistry environment, in particular systemic thinking and critical reasoning which we hoped to strengthen with this activity (*4*). In particular, these students often find themselves in the sciences and engineering as they hope to expand their career options.

Methods

In this exercise, students from both general chemistry and engineering were scaffolded into the design challenge of evaluating tools for gaining community data about clean water with a series of lectures about water quality and analytical chemistry tools. This is the first time students have used a spectrophotometer so they were provided the schematic that appears in Figure 1.

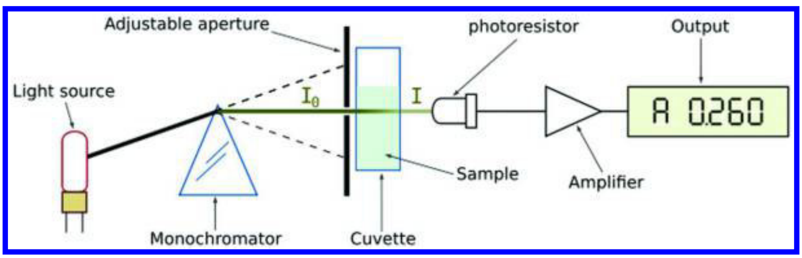

Figure 1. Schematic of a single beam spectrophotometer.

Students were primarily freshman and sophomore level with some adult learners. Students from general chemistry and engineering were participants in this project. Students worked separately for initial measurements of the water samples using the traditional spectrometer and then together as a combined class for the paper spectrometer. In-class discussions were held as a combined class as well. Students were required to attend regular class meetings as well as participate in the laboratory portion of both courses. Throughout the semester, students reflected upon their learning, and were occasionally surveyed regarding the courses. Unique cross-disciplinary topics included the chemistry of climate change, worldwide water usage, and hydraulic fracturing. The architecture of this environment has been to scaffold the student with a foundation of knowledge so that they not only understand the material, but interact actively with it by providing real world questions based in chemistry or engineering for students to explore. The scenario discussed herein is how to obtain crowd-sourced water quality data that can be used for communities to make decisions about their water resources. Students from chemistry and engineering courses worked cooperatively for this exercise.

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Our students are digital natives, so it was chosen by instructors to compare a smartphone paper spectrophotometer from PublicLab that allows one to gather data using a smartphone app with a traditional spectrophotometer. This spectrophotometer is comprised of a folded piece of heavy paper with a diffraction grating made from a piece of a DVD. The paper is folded to fit around the lens of a smartphone with the diffraction grating inside. The Public Laboratory for Open Technology and Science, known as PublicLab, is a non-profit organization that develops open source tools for environmental exploration investigation. PublicLab can be found on the web at publiclab.org. The traditional spectrometer was a recent model made by PASCO that is also lightweight, but with more bulk and that is run by computer application. These instruments are shown in Figures 2 and 3.

Figure 2. PublicLab smartphone spectrophotometer.

Figure 3. Traditional spectrophotometer.

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Students then used these tools to evaluate prepared water samples. The prepared water sample consisted of tap water that had varying levels of ammonia present. Using HACH pillows, students reacted each water sample and then used the spectrophotometers to estimate the ammonia concentration. HACH pillows use ammonia cyanurate as a reagent to give a colorimetric estimate of the ammonia content. This bright color gradient gave students sufficient information for their spectrophotometers to estimate a measurement of the ammonia concentration as well as to evaluate the tools given. During this challenge, students were required to answer the following questions:

> Do smartphone spectrophotometers give good data compared to a traditional spectrophotometer?
>
> Are smartphone spectrophotometers easy to use?
>
> Could the design of the smartphone spectrophotometer be improved? In what way?
>
> What are potential community uses for the smartphone spectrophotometer?

Students answered these questions both orally and in the written form of a laboratory reflection. It was found that the smartphone spectrometers performed as well as the traditional spectrometers within a reasonable margin of error (10-15%). In the field, the smartphone devices were more portable and easier to use than the traditional spectrometers. Students critically evaluated the two instruments with regards to performance, ease of use and portability in their laboratory reflections. They were also required to redesign the smartphone spectrophotometer and present their design to the class.

Discussion

The redesign activity resulted a series of student schematics, along with an extension activity discussing community or crowdsourced data in class. Students proposed many differences between the paper and traditional spectrometer. It was frequently noted that the traditional spectrometer is bulky and impractical for transport, while the smartphone spectrometer is small and portable.

Students requested additional class time to talk about the topic, and were each granted 5 minutes to clarify and defend their designs in class. There was also additional discussion regarding citizen science, as students tried to think of ways that the smartphone tool could be used in the community. One student example of possible citizen science use was to give out paper spectrometers to residents affected by floodwaters as a way to measure water quality and changes over time. Others suggested that smartphone spectrometers could be used to create a database for areas affected by mine drainage. Students responded positively to the inclusion of the design challenge as a way to enhance interaction with course materials,

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all (n=50) citing either agree or strongly agree in answer to the question "Did the real world activities enhance your learning in this course?" One student noted that the interdisciplinary nature of the project "…helped me to see science from another's' perspective. It was great to work with my peers!" In response to the query "Did the redesign portion of the course help you feel more comfortable with the material?" all students except for one who responded neutrally (neither agree nor disagree) cited either agree or strongly agree as a response. Students also noted in the comments portion of the survey that presenting their ideas to the class helped them to better understand the material. One student put it thusly "Often in class I feel that I'm not quite sure I'm getting the entire concept. By presenting to the class I was able to refine my ideas and really grasp the material."

Conclusions

This novel course activity has resulted in an engaged student experience that provides in-depth topic exploration and familiarity with the material. Students benefited from the interaction with real world problems as well as the presentation of material by their peers to provide enhanced understanding. Students responded overwhelmingly positively to this activity, and it is planned to continue to include this type of engagement with material as a regular feature of the course.

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Chapter 6

Using Models of Growth in the Amazon To Bring an Environmental Chemistry Topic into the General Chemistry Class

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Significant archaeological evidence exists that in 1491, much of the Amazon basin was more aptly described as managed parkland than as jungle. This evidence also indicates that there were more people living in urban environments in Amazonia than there were people living in urban environments in Europe. The decimation of the native peoples which occurred after European contact resulted in the growth of the enormous jungle that most people now think of as "the Amazon," and is a significant factor in mitigating the current planetary climate change. Simple, model-based problems involving stoichiometry, molarity, and solution chemistry that have been used in freshmen-level general chemistry classes to raise awareness of this enormous environmental change are presented.

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Introduction

Large numbers of students are required to take a general chemistry class, often for two semesters, as part of the first year of study in most science and engineering majors. Similarly, many of these same students must take fundamental mathematics courses such as pre-calculus and calculus. Faculty often struggle to find engaging problems and contexts into which to put the concepts that must be taught in these classes (*1*, *2*). There is significant appeal to using the growth of the Amazon jungle from the time of contact between indigenous peoples and Europeans as a background from which to present and discuss chemical or mathematical concepts because it connects with numerous facets of environmental chemistry, climate change, and history.

There appears to be a widespread popular misconception that prior to the year 1492, the Amazon was a pristine, untouched rainforest with few people dwelling in the area. Significant evidence exists to the contrary (*3–6*), and has even been published in the popular press (*7*). An understanding of the peoples, the civilizations, and the environment of that time can teach us more about our modern world. Connections to the ideas that are introduced in general chemistry and mathematics classes are actually rather straightforward.

We will begin by describing the archeological evidence for the actual state of the Amazon River Basin in 1491. Then we will present four examples of problems used in general chemistry or pre-calculus courses – covering stoichiometry, molarity, graph plotting and interpretation, solubility – that tie together the Amazon jungle and general chemistry concepts. We will conclude with a discussion of the importance and effectiveness of using such problems.

Archaeological Evidence

One of the first reports of the large population density along the Amazon River is that of Father Gaspar De Carvajal, the priest who accompanied the first Spanish expedition from Peru to the mouth of the river in 1535 (*3*). Perhaps obviously, a reference like this must be read with an understanding of the author and the time in which it was written, as De Carvajal was not a scientist, and did not necessarily record what he saw in the same manner as an expeditionary recorder would today. Nevertheless, such a report can be a valuable piece of background information when trying to engage students in current problems, and help them see how a current situation fits into a greater historical context.

Much more recently, the scholarship of Heckenberger in regards to the pre-Columbian habitats of the Xingu region of the Amazon (*4*), as well as that of Meggers (*5*), Roosevelt (*6*), and Young-Sanchez and Schaan (*6*) give highly detailed pictures of settlements and the peoples of various sections of the Amazon. Corollary to such research, one comes to a realization that prior to European contact, the large number of people living in the Amazon basin must have been accompanied by extensive, selective cutting of vegetation so that fruits and crops could be managed and harvested. Only after what might be called an inadvertent disease-based genocide of these peoples, the jungle that exists today grew and expanded to the extent it reached just prior to current, large-scale cutting. The chemistry involved in such growth can serve as the basis of several different discussions in the general chemistry class.

Amazon – General Chemistry Connections, Examples, and Discussion

The following four examples serve well to make relevant connections between an understanding of how the Amazon has grown into the rain forest it is today and general chemistry concepts.

Example 1: Stoichiometry

The growth of trees involves the uptake of CO_2 according to the equation:

$$6\,CO_{2(g)} + 6H_2O_{(g)} \rightarrow C_6H_{12}O_{6(s)} + 6\,O_{2(g)}$$

The reaction is certainly a simplification, and it can certainly be taught in classes without involving the idea of the growth of the Amazon rain forest to the state it is at today. The growth of the jungle, and the need for the greenhouse gas carbon dioxide during that growth, provides an excellent context for a stoichiometric equation that is not a simple series of one-to-one ratios, and it raises student awareness of an important current issue. Problems of this type also tie into the mathematics curriculum because they require solving systems of linear equations.

While problems, class examples, and test questions usually involve some relatively small amount of starting materials – for example, converting 100 grams of CO_2 to some amount of $C_6H_{12}O_6$ – a problem can just as easily start with 1 ton of CO_2 and determine how much plant material is formed. As well, a problem can begin with 1 ton of $C_6H_{12}O_6$ and ask how much carbon dioxide is taken up in the growth of a one-ton tree.

Another way to utilize this reaction and connect it with growth of vegetation in the Amazon basin is to examine the uptake of carbon dioxide in various units of area, such as an acre, a hectare, or a square mile. An established, single number for such uptake – meaning an amount of CO_2 taken up for any of these unit areas – can be found, but is often different depending upon the source cited. For example, the values of 300-400 metric tons of carbon dioxide per hectare, or roughly 120-160 tons per acre have been determined (*8*). Nevertheless, such numbers can serve as the starting point for basic problems dealing with stoichiometry, and thus can reinforce both the chemical concept, as well as increase awareness of the issue of the Amazon rain forest. Furthermore, the differing published estimates on the amount of CO_2 uptake per unit area provide an excellent opportunity to discuss sources of uncertainty in measurements and the process of making simplifying assumptions in order to create a functioning model system.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch006

Example 2: Molarity

The Amazon river itself can serve as an example for CO_2 uptake in water, and thus for the molarity of a solution made from a gaseous solute in a liquid solvent.

Much like Example 1, above, most problems that students perform in class involving molarity tend to be on a relatively small scale. In this example, an estimated volume for the entire Amazon river needs to be found and used – and although there are numerous numbers posted at popular websites, estimates vary, and the river itself varies with the seasons.

But while there are different estimates for the volume of the Amazon river and its tributaries, the value for the amount of CO_2 that can be absorbed in water at 25°C is known to be 0.034 mol/L (or 1.496 g/L). Using this, students can be presented with problems such as:

- How much CO_2 is sequestered in the water of the Amazon River basin if the rivers are uniformly holding 1% of the amount of CO_2 that can be absorbed in water?
- Assuming the waters of the Amazon River basin are carrying 10 tons of CO_2, what will the molarity of the waters be (using a volume that you have chosen from a source)?

Once again, the answers will be much different numbers than students may be accustomed to when working problems that deal with 1 L – 5 L containers, but the concept of molarity is taught and awareness of the chemistry of the Amazon River basin is again raised.

Example 3: Data Plotting and Recorded Atmospheric Levels of CO_2

An understanding of the graphical representation of CO_2 in the atmosphere is used in pre-calculus and in general chemistry classes. Data for atmospheric CO_2 concentration has been recorded since 1975, and the annual average temperature for the continental United States for even longer (*9*). These data can be graphed, as shown in Figure 1.

Students can be presented with problems such as:

- What are the meaning and units for the slope of this line?
- What are the meaning and units for the *y*-intercept for this line?
- Is finding the *y*-intercept here interpolation, reasonable extrapolation, or reckless extrapolation?

These problems provide a mathematical example of how the slope or *y*-intercept of a line can represent a physical phenomenon, in this case the rise in global temperature as CO_2 concentration rises (°C per ppm). This opportunity can be used to talk about how the units for the slope are the units of the *y*-variable per the units of the *x*-variable because of the nature of the formula for slope, as well as how the slope of a line can indicate a trend. It also is a chance to remind students of the dangers of extrapolating far outside of the data set.

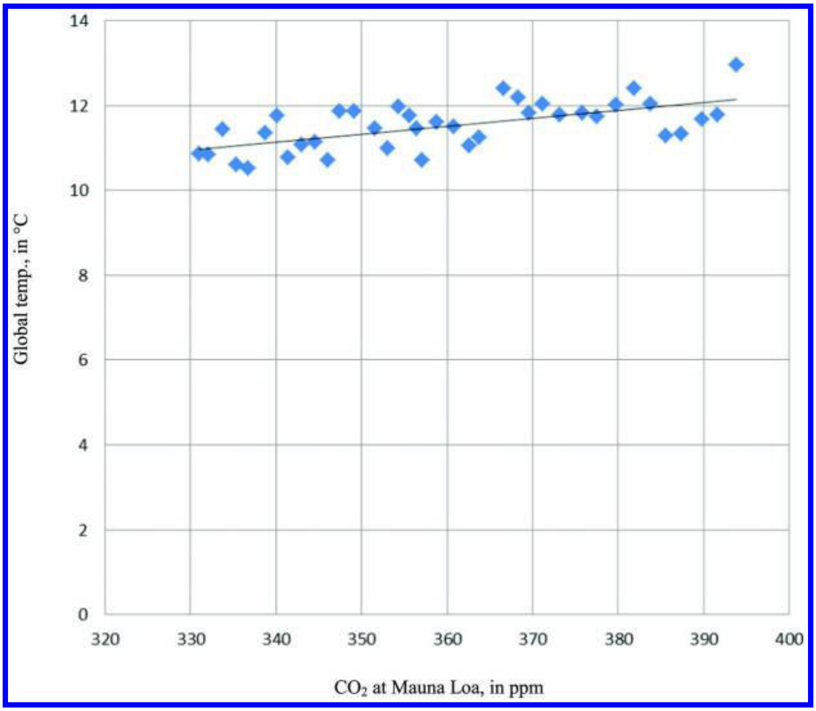

Figure 1. Global temperature (in °C) versus carbon dioxide concentration (in ppm).

The increase of atmospheric carbon dioxide on a global scale and its uptake by vegetation in the Amazon Basin and the waters of the Amazon River itself do not necessarily have a direct correlation, but the awareness of one can be used in class to again raise awareness of the other.

Example 4: Solubility, K_{sp}, and the Amazon

Various ions are suspended in all natural waters, including in the Amazon River and its tributaries. Indeed, mining operations for various metals exist today at or near the waters of these rivers – and in some cases have for centuries. Thus, the river can be used as a model for solubility product constant problems, since the K_{sp} values of numerous compounds are tabulated. It is straightforward to link the K_{sp} of a particular ion (such as tin, silver, or gold) to the actual amount that can be contained in a volume of water, often a liter, then extrapolate this to the amount of the ion that can be held by the entire water system of the Amazon basin. Questions can be asked as follows:

- Knowing the volume of the river and the K_{sp} of $SnCl_2$, how much tin can the river hold if saturated with $SnCl_2$?

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- Assuming a 0.01 M concentration in the river of Cl^-, how much Sn^{2+} can the river hold, again assuming it is saturated in this ion?

As with the previous examples, final numbers are extremely large when compared to those from what can be called standard examples, and the different estimates for the volume of the water in the river system will result in widely different answers. But, pedagogically this is a sound way both to teach the concept of K_{sp} and to introduce to students how ions and water interact, in this case in the Amazon River basin. From a mathematical perspective, this work with large numbers helps to develop number sense and an appreciation for the utility of approximations.

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Conclusions

Despite significant amounts of published evidence, many people still believe the Amazon River Basin was a pristine wilderness in the year 1491. Because of this, and because of the realization that deforestation of significant parts of the Amazon basin appears to be changing the climate of the planet, it has been worthwhile to utilize the Amazon as context for several general chemistry concepts, problems, and exercises.

Students appreciate problems such as these, even though they are more difficult, because they "extend our in-class learning with an applicable real world example" (*10*).

The models presented here are simple, but simple models do indeed give approximations of how much CO_2 has been sequestered as rain forest grew from the year 1492 to roughly the year 1600 CE.

Models incorporating stoichiometry can be used to estimate amounts of CO_2 absorbed by a growing Amazon rain forest. Solution concentration can be discussed in terms of carbon dioxide in the river itself. The K_{sp} modeling can be used to estimate ions that can be contained and suspended in the river basin.

Since this phenomenon – the inadvertent decimation of native peoples' populations in the Amazon basin and subsequent re-growth of the rain forest to roughly what exists at the present – probably represents the largest CO_2 uptake, environmental change, and subsequent climate change in the direction of cooling ever produced by mankind, albeit unintentionally, it serves as an excellent means of connecting basic chemical concepts to a real-world problem.

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Chapter 7

Teaching Environmental Toxicology by Cooperative Learning Methods

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Environmental chemistry and toxicology was the topic of two different, yet similar style courses: one an organized, one-term on-campus course and the other a two-week intensive travel course in Thailand. The format was always the flipped classroom, cooperative learning model, where prechosen student groups prepared oral presentations on subjects from the contemporary topics textbook and several guest experts presented seminar-like lectures to the class. Instead of focusing on science basics and fundamentals, which the students were expected to pick up on their own beyond a few class lectures, we discussed contemporary issues in environmental science comparing opposing viewpoints. The travel course additionally involved morning lectures or orientation, afternoon and evening field trips that were coupled with lab experiments in the field, and finally evening student and guest presentations. The outcomes were that students benefitted from being involved in the contemporary issues and learned how to exercise critical thinking and writing. Additionally, especially in the travel course, students gained a much deeper appreciation for how other societies live and exist.

Introduction

It is clear that the flipped classroom format, cooperative learning model, is much more successful at engaging students and insuring a longer term commitment and reflection on the subject matter that goes well beyond the course (*1*). In addition, it refines their public speaking and analytical thinking abilities to a high level when they are obligated almost every week to present oral presentations. At University of Denver, we utilize this model frequently in seminar-style courses, such as freshmen seminars. The description herein involves two courses, one a somewhat more traditional lecture course, the other an international travel and laboratory course. Each is described in separate sections, then evaluated and finally summarized together with the complementary course.

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Environmental Chemistry and Toxicology

Environmental Chemistry and Toxicology was a three credit-hour course on the quarter system that was also part of the environmental chemistry B.S. degree, but also served as an elective for many other science majors. The course was officially described as “a survey of environmental toxicology concepts: animal testing, dose-response data, epidemiology and risk assessment. The course includes ecotoxicology, focusing on the alteration of biological and chemical systems beyond the simple response of an individual to an environmental chemical. The prerequisites are analytical, inorganic, organic chemistry or instructor’s permission.” The environmental science major at our university is quite limited in and too flexible in the choice of chemistry course topics. A student may have just one term of general chemistry and one term of organic chemistry. We even had some freshmen with less chemistry experience who were otherwise very interested in the topic matter. We accommodated these lower division and environmental science students by teaming them up into groups of students with varying backgrounds so that each chemistry ‘novice’ was paired with a senior chemistry major, and occasionally a graduate student, in their group. Additional information was provided to the novice students on a need to know basis.

The class was scheduled for one, three hour evening midweek session in order to avoid the majority of the student conflicts. Refreshments were provided both by the instructor and each student group on an assigned weekly basis. Although a financial donation was offered, each group bore the expense once during the quarter. The lectures were presented by the instructor and by 4-5 guest experts on their current research in environmental toxicology. Some of the topics included: Detecting Small Amounts of Pollutants, Poisons, Bacteria, Particulate Inhalation and Health, Drugs and Pharmaceuticals in Our Drinking Water and Stream Sediment, Pharmacological Toxicology in Real Life, Environmental Health Assessment of Fracking and The Technology Behind Cleaning Up Oil Spills. Each 60-90 minute guest presentation was followed up with unlimited student questions and discussion. The students were required to write three short reaction papers on the guest speaker presentations. In addition we viewed two videos: *Poisoned Waters* (Frontline, PBS) and *Water Resources from the*

Colorado River (Jane Seymour), which were offered as extra credit short paper subjects.

The major part of the course was the student presentations where groups of three were chosen by the instructor with a balance in science-course background, upper- and lower- students and gender. The most senior student helped the environmental science majors, who had minimal chemistry courses as mentioned earlier with the requisite background on a 'need to know' basis. Each group gave three presentations on issues from the book *Taking Sides: Clashing Views on Controversial Environmental Issues* covering the topic areas of Energy Issues, Toxic Chemicals, Principles and Philosophy vs. Politics of the Environment (*2*). Each group contained a rotating moderator, who summarized the subject and the readings, and the other two students argued opposing viewpoints on their assigned issue and included reports from the contemporary news. One of the underlying rules was that student discussion was never truncated. Hence, going for three hours straight, with perhaps one short refreshment break, was never a contentious issue.

In addition, the students were assigned readings from *Environmental Chemistry and Toxicology* by D. G. Crosby, from which the instructor presented lectures ranging from introduction to environmental toxicology, transport and chemodynamics, quantitative toxicology, exposure and risk, pharmacokinetics and pharmacology-toxicology, food additives and pollutants (*3*). Since the total course spanned only 10 weeks including the final examination during the last week, some of the lecture periods were truncated although students were still expected to read and understand the requisite chapters. The final examination was a group presentation and individually written term paper on a topic chosen by each group that was not in the *Taking Sides* book. Each topic was approved by the instructor after group meetings and submission of a topic outline and references. In some years, a short final examination was also administered. The final examination component represented 25-30% of the course grade.

It is important to note that this was, in part, a writing intensive as well as a critical thinking and discussion intensive course. The overall reaction was that the students were much more engaged than those from a traditional one-way lecture course and that they retained both the knowledge and appreciation for the subject matter long beyond the term period as measured by their daily journals, final examination performance and anonymous student evaluations.

Chemistry and Biology of the Urban and Rural Environment in Thailand

Chemistry and Biology of the Urban and Rural Environment in Thailand was a four- credit, two-week international travel course that was scheduled during our break between Thanksgiving and New Year. The Thailand course also satisfied part of the environmental chemistry B.S. degree requirements and also served as an elective course in the other sciences. The course was described in the advertising brochure from our International Programs office as follows: "One of the best 'test tubes' for studying these broad phenomena

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ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

is a developing country that is on the right road to improving the quality of the environment and human life. In particular, Thailand serves as an excellent model. It is one of the few countries in the ASEAN/Southeast Asian region that has a growing economy, excellent educational system, yet faces the problems of large populations and poorer neighboring countries, while having a unique and beautiful geography. This course emanates from close collaborative exchanges between the instructor and Natural Sciences and Mathematics departments and Chulalongkorn University, Bangkok, which is the premier university in Thailand with a comprehensive curriculum in the sciences, arts, business and law."

As to prerequisites, the course was open to non-science majors who had completed at least two courses of three science requirements in chemistry, biology, physics, engineering or geography, which covered general and organic chemistry, introductory biology or first-year physics or geography courses. There was normally one faculty instructor plus one undergraduate student teaching assistant who had previously done this course in Thailand. The course costs were in addition to the normal tuition (up to $4000 without scholarship assistance) plus travel ($1000-1400), accommodation, food, admission tickets, local guides and transport ($500). The university usually offered some $1000 tuition scholarships and a few at $3000-4000 for students who showed need.

The course was offered four times, initially in Bangkok, Phitsanoluk, and some northern National Parks, which were organized and assisted by Chulalongkorn and Phitsanoluk University environmental chemistry faculty and students. Figures 1 and 2 display some photos of this trip.

Figure 1. Trip to national park in Northern Thailand, view of the sunrise to the distance; students on a field trip.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch007

Two later trips were almost extensively in Northern Thailand (Chiang Rai and the Golden Triangle Region) and the field trips, accommodations and meals were organized by the Viang Yonok Ecoresort (Figure 3). A typical course, excluding the instructor and assistant, totaled around 8-10 students as depicted in Figure 1.

Figure 2. Measuring water quality and pH.

Figure 3. Viang Yonok Ecoresort.

The course schedule, which ran on a seven day basis, involved morning lectures with most afternoons and some all-day excursions. The morning lecture topics included: Overview of environmental science and environmental toxicology, Water pollution: sources, measurements, Principles of pH and how it is involved in rivers, streams and lakes, Turbidity measurements: principles and measurements, Secchi disc, Light and fluorescence: principles and measurements with a ‘black light’ of various flora, insect remains, etc., and Population (control) and disease. Typical afternoon field trips were to national parks, sacred monuments, indigenous Thai villages, elephant sanctuary (elephant rides), natural hot springs, wetlands, etc., where we carried out environmental water measurements and noted the posted levels of various ions, temperatures, etc. Figure 4 depicts some of these activities and sights.

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Figure 4. Chiang Rai area environmental and local sights.

During some years, we also visited the government air and noise monitoring stations in Bangkok. We also did a traffic study of the Bangkok transportation system where student groups took various modes of transport to major historical sites and measured the time, comfort and cost for each leg. The students then reported back about their transportation experience to the whole group that evening. Students measured the pH at various river sites, wetlands, hot springs and swimming pools. We also measured PM10 Particulates in the air in Bangkok and in the national forests. In Chiang Rai, a guest expert transported us on a sunset birdwatching field trip with lectures on the birds of Thailand wetlands and their ecology.

In addition, there were two required readings and student presentations and discussion from *Taking Sides Controversial Issues in Environmental Science*, with topics that were more ecological and ecopolitical as compared to the subjects covered in the environmental toxicology course discussed earlier. Each student group comprised a more senior (science) student who aided in teaching their non-science major group member the requisite fundamentals on a 'need to know' basis. This included the lab and instrumental measurements as well. Every student kept a daily journal in a lab book where all observations and measurements were recorded. Each student was required to write a series of approximately five short lab reports covering field trips, scientific measurements and some of the environmental issues at cultural and historical sites. After returning home, each student was required to take an online final exam consisting of essay questions relating to environmental science, of which were several relevant to Thailand. Students could access resources from the library or the internet but were not allowed to collaborate.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch007

It is important to note that this course was also, in part, writing intensive as well as a critical thinking and discussion course. The overall reaction was that the students were much more engaged than those who experience a traditional one-way passive lecture course and that they retained both the knowledge and appreciation for the subject matter long beyond the term period. Several students gained a deeper, sensitive appreciation for Thai culture, environment, food and the people of a developing country. Overall the students were more engaged, retained the knowledge and came back respecting the values and customs of another culture. One student returned for an extended research project. Figures 4 and 5 depict some of the cultural aspects of the trip.

Figure 5. Thai monk assisting the students in measuring water quality in the wetlands. Some young monks along the Kok River near Myanmar (Burma).

Conclusion

After a review of the challenges, successes and mistakes, several issues surfaced over the years. Cultural insensitivity was a problem in at least two of the four trips. Some students ordered meals that they barely ate, yet made frequent stops to the local store for junk food snacks, which was particularly offensive to our Thai hosts. In future scheduled courses, several predeparture lectures on the culture of Thailand, aspects of cultural insensitivity and the University code of conduct was reiterated. Whether a student had prior travel experience was not a very good correlation, especially those who had visited only western European or English speaking countries. Extremely poor behavior was not a problem; however, some of the rather provincial students stood out as somewhat unappreciative guests to our Thai hosts as noted above. Lastly, one of the trips involved supervising two parallel, but different courses in different geographical regions. This obviously lacked strong faculty member control and guidance at times and the student or additional faculty assistance was not sufficient. The positive outcomes were that students benefitted from being involved in the contemporary issues and learned how to exercise critical thinking and writing. Secondly, especially in the travel course, students gained a much deeper appreciation for how other societies live and exist.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch007

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Chapter 8

An Advanced Organic Chemistry Laboratory Course Incorporating Writing/Reviewing Scientific Manuscripts and Green Chemistry Metrics

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The second-semester organic chemistry laboratory course for Chemistry and Biochemistry majors at the University of Detroit Mercy is a multi-faceted educational experience aimed at training future scientists. Students prepare for writing and editing scientific manuscripts by studying *The ACS Style Guide*, while practicing firsthand usage of Gas Chromatography-Mass Spectrometry (GC-MS), Fourier Transform-Infrared Spectrophotometry (FT-IR), and $^{1}H/^{13}C$ DEPT Nuclear Magnetic Resonance Spectroscopy (NMR) instrumentation for structural data acquisition and interpretation. Emphasis is also placed on integrating concepts from the study of green chemistry into students' manuscripts. Weekly, one half of the course's students perform advanced organic synthetic techniques and accrue their own structural characterization data in efforts to write a full scientific manuscript. The remaining students perform the same synthetic techniques, but rather than writing their own manuscripts, prepare to critically review the "submitted" manuscripts by searching the chemical literature. All students are expected

to maintain a professional laboratory notebooks, adhere to the principles of modern lab safety, and invoke the principles of green chemistry (esp. atom economy calculations) in their writing and reviewing. Weekly projects range from multistep preparations and microwave syntheses to cross-coupling chemistry, click reactions, and guided-inquiry transformations. Students perform these tasks with one random coworker every week, and grade each other with a rubric involving marks for punctuality, willingness to learn/teach, and safety. Anecdotal assessment of learning outcomes shows students are excited to be placed into a controlled, but professional scientific setting for their learning.

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Introduction

Nearly every undergraduate student in a chemistry course receives instruction in both the theory (traditional lecture) and application (traditional laboratory) of chemical principles (*1*). Additionally, most institutions cover general chemical topics first and then continue with more specific topics concerning organic, biochemical, analytical, physical principles (*2*). In taking both of these points together, a large number of undergraduate curricula in organic chemistry contain two semesters of lab experience, the first covering basic skills and the second expanding on these skills through more in-depth treatment. At the University of Detroit Mercy (UDM), this motif is followed in two second-semester lab course tracks: a one-credit course for Biology majors and a two-credit advanced lab for Chemistry and Biochemistry majors. The logistics of the two-credit laboratory course (CHM 2300) with weekly recitation afford an opportunity to give UDM students a unique instructional experience which most importantly incorporates writing and reviewing scientific manuscripts, as well as providing their first exposure to the environmental concepts of green chemistry (*3*).

Herein, the CHM 2300 course is described in its entirety, including basic workings of the course; learning outcomes and assessment strategies; the synthetic preparations used; explanations of the instrumental round robin, guided-inquiry; and summative cross coupling experiment phases of the course; as well as pedagogical conclusions from having taught the course to nearly 200 students over the last six years.

Basic Course Design

This advanced organic chemistry laboratory course, like many others of its type, relies on a standard three-hour laboratory session. As a two-credit class, CHM 2300 has two three-hour lab sessions and one one-hour recitation weekly for a 15-week semester. Course enrollment of primarily second-year Chemistry and Biochemistry majors has remained steady at 25 to 30 students for the last six years. Having been required to complete prerequisite course work in Organic Chemistry I lecture and lab, students are expected to have a minimum intermediate mastery of the following skills: volatile organic chemical safety, glassware and equipment, notebook convention, compound transfer and storage, simple distillation, fractional distillation, thin-layer chromatography, liquid-liquid extraction, recrystallization, and melting point analysis. Students are expected to come to class prepared with department-approved safety goggles, a lab notebook with carbon page duplicates, and a copy of *The ACS Style Guide* (*4*). Each week in the course begins with a recitation meeting where handouts and synthetic preparations are distributed, in conjunction with holding mini-lectures and discussion sessions to supplement ongoing lab work. The teaching team for the course includes one instructor/professor and up to four undergraduate teaching assistants (TAs) who have successfully completed the course in previous years.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

Phases of the Course

Throughout the 15-week semester, CHM 2300 goes through four distinct phases: introductory, instrumental round robin, guided-inquiry, and final reaction project (Figure 1). Each phase is designed to build on its predecessor, culminating in the final reaction project. During the introductory phase of three weeks, students are oriented to the course by reviewing the syllabus and performing reading assignments in *The ACS Style Guide*, the comprehension of which is assessed by four short quizzes. The students are taken on an "instrument tour" to familiarize them with UDM's NMR, GC-MS, and FT-IR instrumentation. Students also participate in mini-lectures with active learning exercises on the subjects of reporting structural characterization analytical data, searching the chemical literature, green chemistry atom economy metrics, and plagiarism. The introductory phase ends with instrumental practice sessions where students are instructed in sample preparation and acquisition methods for NMR, GC-MS, and FT-IR using off-the-shelf organic compounds.

The next phase of the course covers four weeks and is colloquially titled the "Instrumental Round Robin." During this time, course enrollees are randomly split into two groups and perform one new synthesis per week in lab. The synthetic preparations all have unique "green" approaches detailed elsewhere in this chapter and can be completed in one three-hour laboratory session. Recitation occurs just prior to the week's first lab session, so this time is primarily used for specific hazard training and pre-lab discussions. The second three-hour lab session is entirely used for product thin-layer chromatography (TLC), melting point analysis (if applicable) and instrumental characterization. During the second lab session, each student pair is given one of four experiments to run: ^{1}H NMR, ^{13}C DEPT NMR, GC-MS or FT-IR. These techniques will rotate over the four-week round robin so students will have specific experience using each instrumental technique at least once before the next phase of the course. Outside of the lab, half of the students write full *Organic Letters*-style (*5*) manuscripts. Students in the other half of the class record their analytical data and green chemistry metrics (both worksheets are graded) in preparation for their duty the following week: review of the first group's "submitted" manuscripts. An observed weakness of this teaching method is that one half of the course must write first, while the other reviews first. Though this has not been shown to affect performance on writing/reviewing assignments from the perspective of the end of the course, students who edit first inevitably score better on their first writing assignment, having seen examples of student writing before beginning their own. To preclude any bias, the instructor can weigh marks from this part of the course so as to not allow for any unfair advantage. Student reviews are not part of student writer grades, but student reviews are graded. Both writing and reviewing activities are assessed through separate rubrics (Figures 2 and 3) distributed to students during the introductory portion of the course.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

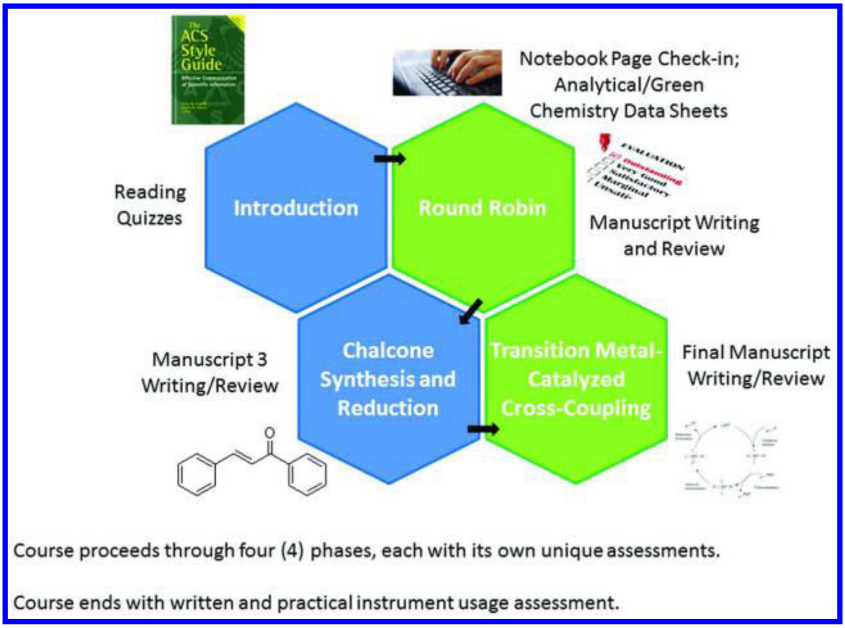

Figure 1. Visual syllabus for CHM 2300.

Both the writer and reviewer rubrics include a "feedforward" section so that the instructor can mention items that may not specifically appear in rubric areas. In addition, after having been instructed in the area of plagiarism, students are expected to adhere to an upload deadline using the SafeAssign (*6*) application in BlackBoard. Student performance is not graded on the results of the SafeAssign manuscript evaluation, but rather whether on they met the deadline for timely submission. SafeAssign data are used near the middle of the term in a one-on-one meeting with each student to discuss what the application does and how this relates to the concepts of plagiarism and academic integrity. During the round robin phase, students have two chances to both write and review, giving the instructor draft-style data to focus feedback as students learn from their previous errors.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

CHM 2300 Winter 2015
Organic Chemistry Laboratory II

Writer Rubric

Name ____

Experiment Reaction 2B – Wittig Olefination

Category	Points
Title reflects the manuscript's content and emphasis accurately and clearly.	0 1 2
Byline and **Affiliation** are listed correctly.	0 1
Abstract briefly states the purpose of the work reported, indicates the theoretical or experimental plan used, summarizes the principal findings and points out major conclusions.	0 1 2
Introduction clearly states problem and the reasons for study.	0 1 2
Introduction gives a concise and appropriate background.	0 1 2
Content of **Introduction** reflects careful consideration of questions on preparation handout.	0 1 2
Introduction demonstrates continuity from previous work to the work reported. Details are given regarding experimental plan and transition to experimental section is logical and smooth.	0 1
Experimental Details includes General section giving sufficient details about materials and methods.	0 1 2
Experimental Details includes unambiguous Synthetic Procedures with Physical Characterization Data section which would make reproduction possible and reasonable.	0 1 2
Experimental Details includes appropriate Synthetic Procedures with Physical Characterization Data section with analytical data.	0 1 2
Experimental Details includes appropriate Caution section which states precautions and risks for multiple reagents used in the experiment. At least one MSDS citation is included for a reagent used in the synthesis.	0 1 2
Results summarizes the collected raw data and their statistical treatment in prose.	0 1 2 3 4
Green Chemistry metrics are correctly calculated in **Results**.	0 1 2 3
Discussion interprets and compares results correctly and objectively.	0 1 2 3
Green Chemistry metric and practical data are addressed by way of suggestions for "greening" the synthesis in **Discussion**.	0 1 2 3

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

Category	Points
Assignment of ^{1}H and ^{13}C DEPT NMR data in **Discussion** is correct.	0 1 2 3 4
Conclusion puts discussion into the context of the original problem.	0 1 2
Acknowledgements recognizes people, organizations and financing for the work.	0 1
References are reputable, relevant to the work at hand and published in 2013 or 2014; photocopies for three (3, not counting the prep ref, any MSDS refs or any refs for Green Chemistry metric source data) are included.	0 1 2 3
Manuscript has been reviewed by SafeAssign by 11:59 pm EST the night prior to the hard copy due date.	0 1
ACS Style is adhered to with regard to grammar, punctuation, spelling, voice, editorial considerations, units of measure, nomenclature, chemical conventions, references and citations.	0 1 2 3
ACS Style is adhered to with regard to non-textual elements (figures, schemes, charts, equations, tables and structures).	0 1 2 3
TOTAL	/50
SafeAssign Matching Percentage	/100
Pre-Lab Notebook Pages	0 1 2 3 4 5 6 7 8 9 10
FEEDFORWARD COMMENTS	

Figure 2. Writer rubric used to grade student's ability to assemble a scientific manuscript.

CHM 2300 Winter 2015
Organic Chemistry Laboratory II

Reviewer Rubric

Name ____

Experiment Reaction 1A – Microwave Acetylation of Salicylic Acid

Category	**Points**
Synopsis consists of a paragraph describing the overall content of the manuscript.	0 1 2
Synopsis does not contain any opinion or criticism.	0 1 2
Commentary criticizes the manuscript as a whole and points out most major and minor strengths and weaknesses.	0 1 2 3 4
Commentary identifies the major and minor content errors within the manuscript to the best of the reviewer's ability.	0 1 2 3 4 5
Commentary is composed of overall constructive criticism.	0 1 2 3
Formatting details major and minor weaknesses of manuscript and delineates them by manuscript section, referring to specific paragraphs and lines.	0 1
Formatting adheres to standards set by ACS Style Guide.	0 1 2 3 4
Formatting addresses any errors in author's assignment of ^{1}H and ^{13}C DEPT NMR data.	0 1 2 3 4 5
Conclusion summarizes reviewer's opinion of the manuscript in one sentence.	0 1
Recommendation makes reasonable final judgment.	0 1
Recommendation final judgment is supported by major criticisms.	0 1 2
TOTAL	/30
FEEDFORWARD COMMENTS	

Figure 3. Rubric of student reviewer used to grade another student's ability to edit and comment on a scientific manuscript.

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Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

Moreover, during the round robin phase, students are randomly assigned weekly partners in efforts to expose all course enrollees to the realities of modern science from the perspective of collaborative learning. Students are prepped before the round robin phase with a handout that details the main learning outcomes of this activity: how to learn from those more experienced than themselves and how to teach those less experienced than themselves. Students are advised that a purposefully unprepared student places both her/his marks, her/his partners' marks, and others' safety at risk by not taking the privilege of organic laboratory work seriously. In efforts to reward those who choose to treat their lab time as an excellent learning opportunity, a rubric was generated with points awarded for punctuality, willingness to learn, willingness to teach, and safety-mindedness. Students grade their partners at the end of each lab session. Students' earned points are totaled at the end of the course and depending on the sum, their final grades in CHM 2300 may be affected positively, negatively, or not at all.

The largest portion of the CHM 2300 course, lasting five weeks, is dedicated to the synthesis and transfer hydrogenation of a disubstituted chalcone (bis-aromatic ketone/enone). With another new, randomly-assigned partner, students are expected to generate a disubstituted chalcone structure using a green procedure, hydrogenate the chalcone using phase-transfer conditions, and then characterize both molecules using TLC, mp analysis, NMR, GC-MS, and FT-IR (Figure 4). Versions of this experiment has been reported for guided-inquiry learning (*7*, *8*). The phase-transfer transformation is unpredictable and subtle changes in temperature/stoichiometry affect the number and type of products generated. Students are informed that neither the instructor nor TAs know what the outcome of their reduction reactions will be, and that it is their job to use their accrued green chemistry and instrumental knowledge to discover the structure(s) of their hydrogenated products. At the end of this course segment, all students are expected to write a full scientific manuscripts detailing their methods and findings.

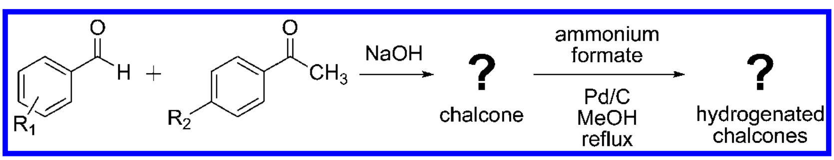

Figure 4. Synthesis and hydrogenation of a disubstituted chalcone.

With up to 15 pairs of student workers, each with two products to characterize, there are nearly 200 individual instrumental characterizations to run. This portion of the course can be done, synthetically speaking, in two lab sessions, but uses the remaining eight for student-led instrumental procedures and group meetings with the instructor. Students are encouraged to ask questions of the instructor and/or TAs throughout the entire process, and also rely on each other for review-style feedback on their manuscripts prior to submission. A distinct (but similar to round robin, see Figure 2), rubric is used to grade student work. This rubric

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ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

is worth 100 points and de-emphasizes manuscript sections students should have mastered by this point in the course (byline, affiliation, experimental details, and acknowledgements). The second rubric also adds emphasis to manuscript sections such as introduction, results, and discussion to that finer evaluation is possible.

The final phase of the course involves a last reaction project. Over the course of three weeks, students are expected to use their summative knowledge from the term to perform a transition metal-catalyzed cross coupling reaction and characterize the resulting product using structural characterization methods and green chemistry metrics. Students are not allowed to ask for instructor or TA help with synthesis, data acquisition, or analysis during this phase, and are made aware of this fact from the beginning of the course to encourage cooperative learning. Students are prepared with mini-lectures on transition metal organometallic catalysis and specific hazards, but little else. Unbeknownst to students, multiple synthetic methods for the generation of similar products are distributed and the final manuscript rubric specifically calls for a comparison of green chemistry atom economy metrics across groups. Students are again encouraged to work with each other on refining their writing by peer-review. Another specialized rubric is used to assess submitted student work, this time emphasizing collaborative and in-depth green chemistry data comparison.

Course Learning Outcomes and Assessment

Learning outcomes and their assessment have been mentioned piecemeal previously in this chapter, but are listed here divided into four subcategories: organic lab techniques, instrumentation, writing/reviewing scientific manuscripts, and green chemistry. With regard to lab techniques, upon successful completion of the course, students will be able to perform advanced organic chemical lab techniques, including syringe use, inert atmospheres, and air-/water-sensitive reagent handling; effectively explore the principles behind observed organic chemical phenomena; construct and maintain a professional laboratory notebook; and conduct themselves safely in a laboratory setting where volatile chemicals are used and stored. A pre-lab notebook check-in and the lab partner are used to measure student achievement in this subcategory. With regard to instrumentation, at the culmination of the course, students should be able to acquire and analyze spectroscopic data from GC-MS, FT-IR, and NMR. Graded analytical data sheets, scientific manuscript writing/reviewing, and an end-of-term written instrument usage exam are used to assess learning.

The main purpose of student coursework outside of the laboratory is the writing and reviewing of peer scientific manuscripts. As described before, these are written/reviewed in the style of an *Organic Letters* submission with multiple facets of their assembly and review covered in other outcome areas. Specific to writing and reviewing, students are expected to search the chemical literature, write a cogent scientific manuscript, and properly review peer manuscripts; as well as formulate strategies to locate, evaluate, and apply information, especially that which is found in the chemical literature. The rubrics found in Figures 2 and 3 are used to assess student learning in this area.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

The last learning outcome subcategory in CHM 2300 involves green chemistry. In a general sense, since this course is their first exposure to green methods in UDM's formal curriculum for Chemistry and Biochemistry majors, students are expected to overlay the 12 principles of green chemistry with regard to their existing chemical knowledge, specifically through the lens of organic synthetic atom economy metrics. The rubrics found in Figures 2 and 3 are again used to assess student learning in this subcategory; however, green chemistry data sheets prepared by round robin reviewers can also be used to this end.

Synthetic Preparations with Emphasis on Green Chemistry

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

The Pollution Prevention Act of 1990 established a national policy to prevent or reduce pollution at its source whenever feasible (*9*). The Pollution Prevention Act also provided an opportunity to expand beyond traditional Environmental Protection Agency (EPA) programs and devise creative strategies to protect human health and the environment. Green chemistry is the use of chemistry for pollution prevention, but more specifically, it involves the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Pedagogical goals concerning green chemistry are important because it has been shown to be a highly effective approach to pollution prevention by applying innovative scientific solutions to real-world environmental situations. The 12 principles of green chemistry provide a road map for chemists to implement green chemistry.

When the version of the CHM 2300 course reported here was originally conceived, the extent of green chemistry training envisioned for students was primarily influenced by the American Chemical Society's Green Chemistry Institute (*10*). Since its inception, GCI has worked with academic, government, and industry sectors to promote the development and implementation of science and technology across disciplines to avoid the generation of hazardous wastes. The ACS has articulated its support of green chemistry in its statements on sustainability and environmental protection. Pedagogical goals in the early 2000s were simply stated and easily executed, derived from Anastas and Warner's *12 Principles of Green Chemistry* (*3*): cut down on waste, reduce toxicity of reagents, use less energy, make use of catalysts. As the rubrics shown in Figures 2 and 3 came into focus over several years, the sophistication with which students were expected to explore and learn the principles of green chemistry also increased. Much like green chemistry's outgrowth from the US Environmental Protection Agency's Pollution Prevention Act of 1990, the complexity of tracking green chemical concepts in a synthetic lab has only become more intricate.

With these ideologies in mind, two major course design items were considered in the generation of CHM 2300. First, from the synthetic perspective, generalized "green" methods and lab activities were emphasized (*11*). Locating and testing syntheses which feature solventless transformations, microwave oven heating, mechanochemistry, and alternative catalysts/reagents became a leading priority. This is even seen in the guided-inquiry procedure for the synthesis of disubstituted chalcones(7b), as the originally-published preparation(7a) could hardly be considered green! A plethora of traditional and modern synthetic procedures was procured for use in the course: aldol, Michael, nucleophilic acyl substitution, Wittig, Diels-Alder, Grignard, catalytic hydrogenation, reductive amination, Darzen condensation, electrophilic/nucleophilic aromatic substitution, Sonogashira, Suzuki, and click chemistry. Students have been practically instructed in hazardous waste management, reagent toxicity and environmental impact, energy efficiency, and modern catalysis. When students composed their manuscripts or reviews, these general standards were to be evaluated qualitatively, with an expectation of accumulative learning throughout the course. The final reaction project, with its direct comparison of methods to generate the same (or similar) products, is a culmination of this comparison approach.

Over time, assessed learning outcomes in the area of green chemistry showed only incremental growth for the entire semester, even for the most dedicated students. In a way, students had reached the zenith of understanding qualitative green chemistry, but had no other requirements to help steer their learning. At this point in the course design, a second major element was introduced: that of quantitative atom economy calculations.

Green chemistry concerns are related to reaction optimization with respect to materials and energy, waste reduction from all sources, and overall minimization of toxicity and hazardous processes. The fundamental concept centers on ongoing efforts to optimize key parameters that govern reaction performance. To accomplish a perfectly green reaction, some parameters must be minimized while others must be maximized. Green metrics refer to calculations that can be performed that numerically represent (and allow for easy minimization or maximization of) these parameters, and most are based on the mass of compounds used. Atom economy is the second of the 12 principles of green chemistry, and since Anastas and Warner specifically listed their ideas in order of importance, students can easily ascertain the significance of this fundamental standard.

First proposed in 1991 (*12*), atom economy calculations are a clear-cut method for judging the green efficacy of any transformation that entails knowledge no deeper than unit conversion of moles, grams, and milliliters. By comparing and contrasting percent yield, percent atom economy, percent experimental atom economy, and percent yield multiplied by percent experimental atom economy, students are able to straightforwardly establish the "greenness" of different transformations quickly (*13*). Reactions can almost always be compared in their percent yield for baseline efficiency, students can use atom economy calculations to evaluate the effectiveness of a synthesis that takes into account waste at the molecular level, atom by atom. If an atom in a starting material becomes an atom in a product, it is termed "utilized." If not, the atom is termed "unutilized." Measuring moles and masses of utilized and unutilized atoms reveals a transformation's true chemical cost and simply rationalizes matters of scale. Often, only one training session is needed for students to see the vast differences in laboratory syntheses, especially when it comes to the consequences of using solvents and catalysts in organic transformations. Directly relating two percentages, even after a little mathematical manipulation, is a meaningful way for students to make connections between synthetic theory and its practice.

Publication Date (Web): November 30, 2015 | doi: 10.1021/bk-2015-1214.ch008

Assessing student work in both qualitative green chemistry and atom economy calculation areas shows a number of results which all point toward fulfillment of the original green chemistry learning outcome. Students' "trust" in percent yield as an over-arching synthetic metric often gives way to a more nuanced understanding of yield data, as evidenced by scores in the writing rubric (Figure 2, see sections labeled as "green chemistry"). As stated above, by the end of CHM 2300, most students are able to determine which transformation method might be better to generate a specific product from the perspective of minimizing solvent use and maximizing catalyst use. Good students almost always show marked score improvement in the area of synthetic "greening" over the length of the semester, as well. In each submitted manuscript, students are required to write (or review) possible methods to make the performed synthesis greener. Underdeveloped responses blame loss of product through lab technique (spills, vessel transfer errors) for poor atom economy while more advanced students learn the intrinsic economy of the process at the scale performed.

Of course, the synergistic nature of the 12 principles makes any single green chemistry metric incomplete, and several holistic measurements exist (*14–16*). Some of these incorporate complex, individualized calculations for each of the 12 principles, but each addresses the pedagogical aspect of green chemistry by helping students visualize the green and not-so-green aspects of every chemical process. In CHM 2300, atom economy calculations attend to the principles of atom economy, solvents, derivatives, and catalysis. Considerations of health/toxicity, environmental persistence, energy consumption, and reagent renewability also need to be integrated for students to build a comprehensive appreciation for green chemical analysis. Whether students can demonstrate this level of understanding in their final project manuscript is an excellent metric for fulfillment of the green chemistry learning outcomes described previously in this chapter.

Conclusion

Direct use of assessment data from grading rubrics shows that students struggle with the differences between results and discussion manuscript sections. Data also shows that students tend to write their abstract section before the body of their manuscripts, causing incomplete or incoherent abstracts. Making the transition from the background information in their introduction section to experimental details is annually problematic, as well. These data have prompted changes in point distribution on both the writer and reviewer rubrics, as most students tend to respond to low marks by correcting their errors on future drafts. Moreover, students pass on the lessons from their own writing errors as reviewers, giving weaker students richer feedback in a shorter turnaround time.

Anecdotal assessment of learning outcomes in CHM 2300 shows students are excited to be placed into a controlled, but professional scientific setting for their learning. Over the years, students have commented on the independence such a course attempts to cultivate, but they also enjoy the chance to collaborate in their learning. Students welcome the chance to use modern instrumentation and appreciate detailed rubrics for their writing/reviewing; and timely feedback

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in these areas seems to strengthen their scientific writing at a rapid pace. Most importantly, all students satisfy the learning outcomes associated with green chemistry at some level, with the majority of enrollees mastering the concepts of atom economy and their application to the world of organic synthesis.

Overall, CHM 2300 at the University of Detroit Mercy is a multidimensional organic chemistry laboratory course whose design and execution are detailed in this chapter. Others may wish to consider the pedagogical elements reported here if their aim is to incorporate the use of environmental concepts into an advanced undergraduate course.

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Subject Index

A

D

E

In Chemistry and the Environment: Pedagogical Models and Practices; Lanigan, et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2015.

G

I

S

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