Jeffery Scott Townsend

Aquatic Chemistry

What are some basic physical parameters of water chemistry and how do they affect the aquatic environment?

Chemistry II/ Advanced Placement Environmental Science

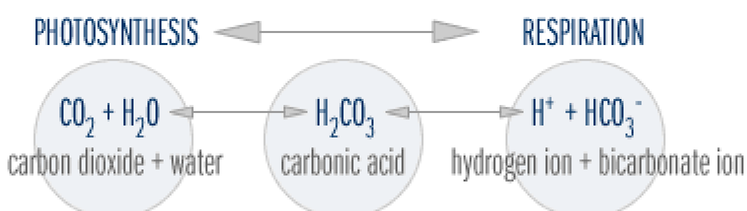
Rationale

As a fellow teacher once told me, "the outdoors is the greatest laboratory." In my past two years of doing environmental science, I definitely find it to be true and to have been an extremely important missing part of my chemistry teaching to that point. This particular lesson focuses on the concepts of dissolved oxygen, pH (and thus H^+ concentration), water temperature, photosynthesis, respiration, turbidity, conductivity, stream flow and many others. By looking at this list, it is easy to see that many concepts from both the physical and life sciences will be explored. Aquatic ecosystems, both lotic and lentic, are very much affected by aspects of their chemical well being. The ability to understand this web of intricate terms is of utmost important as we learn to study the most important of all human resources—water. The skills necessary to use the data collection technology is only the very beginning to the importance of this lesson. The ability to ask appropriate, fruitful questions, collect the appropriate data to support those questions, and the ability to analyze those data in the hopes of drawing conclusions of use to environmental science are all important aspects of this set of lessons.

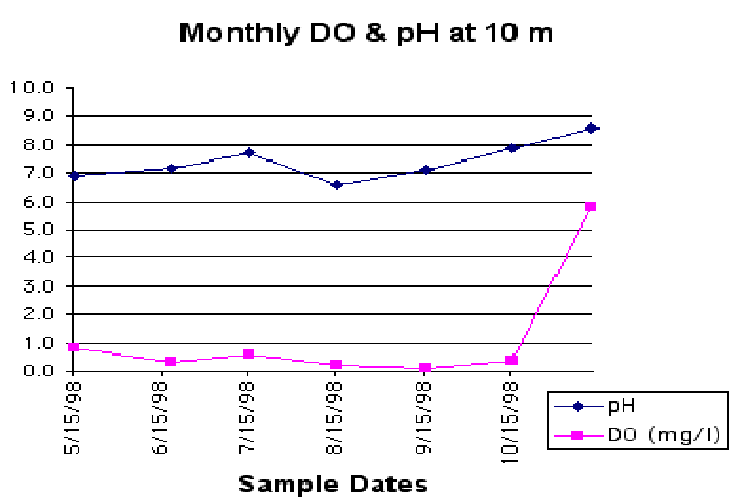
Background

This background information was taken **directly** from the web page, The Water on the Web (waterontheweb.org).

Introduction to Cell Respiration and Photosynthesis for Students



Diagrams courtesy of waterontheweb.org



Photosynthesis

Photosynthesis is one of the most important biological events that occurs on this planet. It is defined as the process by which plants use solar energy to convert the raw materials **carbon dioxide** (CO_2) and water (H_2O) into glucose ($C_6H_{12}O_6$) for use as an energy source. Also during this process, **oxygen** gas is produced as the byproduct that all aerobically-respiring organisms (such as ourselves) are dependent upon. The general chemical equation for **photosynthesis** is:

$6\ H_2O + 6\ CO_2$ + solar energy -------------> $C_6H_{12}O_6 + 6\ O_2$

Following photosynthesis, the glucose constructed within plant cells can then be used as a source of energy and materials for cellular activities such as growth, reproduction and the synthesis of more complex materials such as starch, proteins, and fats. The existence of all naturally-occurring **organic** molecules (any molecule containing carbon, **hydrogen**, and oxygen), and therefore, all sources of energy, can be traced back to the process of photosynthesis. This concept will become very important as we study the flow of energy through ecosystems and the use of energy by humans later in the course.

Respiration

Energy is defined as the ability to do work. The cells of all organisms, and therefore, all organisms, require a continuous supply of energy for the performance of their daily, vital activities. Carbohydrates, especially glucose, generally provide this energy through the process of respiration. Simply stated, respiration is the release of energy from energy-storing compounds. It is represented by the chemical equation:

$C_6H_{12}O_6 + 6\ O_2$ ----> $6\ CO_2 + 6\ H_2O$ + energy (**heat**, light, ATP, etc.)

You should be careful to notice that the process of cellular respiration is essentially the reverse of photosynthesis. The catabolic breakdown (burning) of glucose requires the presence of oxygen and yields energy and **carbon dioxide**. This process is generally the same when any organic molecule is respired (or burned) whether it is glucose in a living animal or plant cell, wood in a fire, or gasoline in a car. The breakdown of any energy storing chemical releases carbon dioxide as a byproduct, which may then be used by plants in the photosynthetic process.

Dissolved Oxygen

Why Is It Important?

Like terrestrial animals, fish and other aquatic organisms need **oxygen** to live. As water moves past their gills (or other breathing apparatus), microscopic bubbles of oxygen gas in the water, called **dissolved oxygen** (DO), are transferred from the water to their blood. Like any other gas **diffusion** process, the transfer is efficient only above certain concentrations. In other words, oxygen can be present in the water, but at too low a concentration to sustain aquatic life. Oxygen also is needed by virtually all **algae** and all **macrophytes**, and for many chemical reactions that are important to lake functioning.

Reasons for Natural Variation

Oxygen is produced during **photosynthesis** and consumed during respiration and **decomposition**.

Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference alone can account for large daily variations in DO concentrations. During the night, when photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition, DO concentration may steadily decline. It is lowest just before dawn, when photosynthesis resumes.

Other sources of oxygen include the air and inflowing streams. Oxygen concentrations are much higher in air, which is about 21% oxygen, than in water, which is a tiny fraction of 1 percent oxygen. Where the air and water meet, this tremendous difference in concentration causes oxygen molecules in the air to dissolve into the water. More oxygen dissolves into water when wind stirs the water; as the waves create more surface area, more diffusion can occur. A similar process happens when you add sugar to a cup of coffee - the sugar dissolves. It dissolves more quickly, however, when you stir the coffee.

Another physical process that affects DO concentrations is the relationship between water temperature and gas **saturation**. Cold water can hold more of any gas, in this case oxygen, than warmer water. Warmer water becomes "saturated" more easily with oxygen. As water becomes warmer it can hold less and less DO. So, during the summer months in the warmer top portion of a lake, the total amount of oxygen present may be limited by temperature. If the water becomes too warm, even if 100% saturated, O_2 levels may be suboptimal for many species of trout.

Background Continued

The Water on the Web webpage holds a plethora of information that would support the lesson even more, but it isn't necessary to list any background information beyond what is listed here to get a basic introduction to the chemistry needed to be successful in teaching this lesson.

Goals and Objectives:

The student will be able to:

1. List several basics parameters of water chemistry (pH, DO, turbidity, conductivity, temp, etc)
2. Produce a concept map showing inter-relations of the terms
3. Use graphing calculators, interfaces, and appropriate probes to collect data regarding water quality
4. Analyze data collected using microcosms in a guided inquiry experiment
5. Propose a question to be investigated using water quality parameters
6. Collect and analyze their own student-generated data in an open inquiry situation
7. Communicate their conclusions, implications, further questions with the classroom community

As a result of these skills, and the sequence of the 5E Learning Cycle, the students will hopefully be able to construct knowledge in their minds that will allow them to see the systems and interactions involved in aquatic ecosystems, both biotic and abiotic.

NAAEE Guidelines for Learning

This lesson sequence would be an early step in an environmental science class with the purpose of raising awareness. It is hoped/assumed that the students, upon constructing their own knowledge about aquatic ecosystems, would be able to extend and focus their energies towards an action approach in the local community. The following are the 9-12 guidelines and how they were addressed, especially assuming if the ENTIRE lesson was completed:

Strand 1

A. Develop, modify, clarify, and explain questions that guide environmental investigations of various types, and identify factors that influence the questions they pose.

This su-bstrand was addressed because, at the end of the guided inquiry/explore stage, the students were asked to think of a reasonable question from the previous activities they could address in a real-life investigation.

B. Design investigations to answer particular questions about the environment—even developing approaches for investigating unfamiliar types of problems and phenomena.

Although several students were unfamiliar with several of the big ideas in aquatic chemistry, they developed enough of an autonomy to find topics to investigate further such as limnology. For example, one group noticed that in the temperature vs. gill beat rate lab, the fish kept swimming to the top of the jar at certain temperatures. This prompted them to use the water depth sampler to look at temperature at various depths of the lake. They could then follow that up with data obtained from a fisherman's sonar apparatus and look at fish numbers vs temperature and depth. Open inquiry, with the correct background, can lead to really great investigations.

C. Locate and collect reliable information for environmental investigations of many types. Know how to use sophisticated technology to collect information, including computer programs designed to address, gather, store, and display data.

Although nobody in the class was familiar with the calculator based laboratory equipment, they quickly picked up how to use it in such as way they could perform several different types of investigations. If enough time was possible, the students would have gotten very serious opportunities to take a good look at their data.

D. Apply basic logic and reasoning skills to evaluate completeness and reliability in a variety of information sources.

This is the most difficult to do with high schoolers, but this learning curve would be very beneficial to helping students get a feel for what scientists have to do all the time. How we collect data, what we do with it, how we look at it, and the extent of its meaningfulness are things even graduate students have a hard time with. In a prolonged situation such as this, I believe the students would be getting some really great experience working with data.

E. Organize and display information in ways appropriate to different types of environmental investigations and purposes.

Had we had time, we would have gotten to analyze our open inquiry data, organized it, and presented our conclusions to the class. This type of thing really doesn't get to happen in most classrooms. Everybody talks about it, but I doubt that many people do it. If the knowledge and desire are there by the teacher, this is still hard to happen because of the same thing that stopped me from getting this far with my students—time constraints!

F. Create, use, and evaluate models to understand environmental phenomena.

This is huge and I love it! We can't always go to the stream or the lake to collect data. If we can we may not always have the necessary prerequisite skills to know what to do when we get there. That is why I used the idea of a microcosm to introduce the content AND the skills needed. We learned a lot of information using small fish, elodea, and mason jars to represent an aquatic ecosystem. Given the time, at any point during the investigations, I would have LOVED to have talked about the attributes and limitations of my models.

G. Use evidence and logic in developing proposed explanations that address their initial questions and hypotheses.

I really wished we could have gotten this far, but time killed us. Allowing students to analyze their own data would have been huge. This is crucial in true open inquiry because this allows them to look back to their initial questions, think about data (how we collected it and analyzed it), discuss what it means, and most importantly I think, what

Strand 1 Conclusion: It is very ambitious to say a lesson pertained to all six subsections of Strand 1, but with the inclusion of guided and open inquiry taught with respect to the explore and extend stages of the 5E learning cycle respectably, it is obvious to see all parts of these science skills can be covered. Although it is much easier said than done, it is very possible to allow students to use these skills through the use of open inquiry.

Strand 2.1 The Earth as a Physical System

A. Apply their understanding of chemical reactions to round out their explanations of environmental characteristics of everyday phenomena.

This would be easy to see in the lesson, especially during the explain stage of the learning cycle when photosynthesis/respiration is discussed. These attributes are also intertwined with several other chemical processes as well.

B. Apply their knowledge of energy and matter to understand phenomena in the world around them.

This lesson doesn't talk about energy specifically in terms of thermodynamics, but the gill beat rate vs. water temperature vs. dissolved oxygen lab in the explore stage addresses the effect of heat on the amount of dissolved oxygen in water (ppm) and the ultimate effect it has on fish metabolism.

2.2 The Living Environment

C. Understand the living environment to be comprised of interrelated, dynamic systems.

The entire purpose of this lab is to show, on an advanced level of understanding, that there is a very connected, dynamic relationship between living and nonliving components of an ecosystem, whether in the macroscale or in a microcosm.

C. Account for environmental characteristics based on their knowledge of how matter and energy interact in living systems.

This statement is very similar to my statement in 2.2 C. It is of utmost importance that students realize the relationship and interactions within, between, and among systems. This sequence of labs were the first piece of that puzzle in a series of investigations.

2.3 Humans and Their Societies; Strands 3 and 4

This sequence of lessons did not address Strand 2.3, Strand 3, or 4, which goes towards student action to fix things or get involved in environmental action projects. Speaking in context, this lab would eventually hopefully lead to some big issues the students could address down the road. I'm a firm believer that true awareness will lead to better actions. A group of educated students will do much better in accomplishing an action goal than a group without the necessary education and/or content.

National Science Education Standards

Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.

I'm not addressing the NSES specifically, but this is one example of a broad standard that would be addressed by this lesson. One of the focuses of the lab is what happens to carbon atoms as they initially start as part of CO_2 *molecules, get photosynthesized, become part of an organisms respiration, undergo an equilibrium situation in water to produce carbonic acid, etc. Carbon, among many other atoms, are very important in this process.*

Indiana Core Content—Environmental Science (Advanced)

Env.1.10 Identify and measure biological, chemical, and physical factors within an ecosystem.

I could once again list several IN standards that could be covered in this lesson, but 1.10 seems to wrap it up best. A student that understands some basics of how these three big ideas fit together will be well served in learning about environmental science.

It is apparent that I haven't used any standards outside of science content areas. This is on purpose. The lesson sequence I chose to teach is not truly an environmental education lesson. It is an environmental science lesson. The two are not the same. I see this lesson happening fairly early in an AP environmental science class, after the students have had semesters in chemistry, physics, and biology. As a result of my studying environmental education, I truly believe the term often used, "awareness to action," is a no-brainer. The awareness part, at the high school level, is best obtained by rigorous scientific action by the students. As a result, I believe they will be better prepared to undertake an action plan that will gain respect and attention from their adult peers.

Procedure:

This lesson plan includes many pedgagogically sound practices in science education including, guided inquiry, open inquiry, scientific modeling, process skills, cooperative learning, and the learning cycle.

This lesson was taught to teachers, thinking about how they would teach to students:

Engage (Elicit Information):

What are some things that do not allow us to do true open inquiry with out students? This is a question I will ask to my participants. Hopefully I will get answers such as: time, cost, motivation, student responsibility, and necessary materials to conduct the investigations. This is one of the purposes of this lab is to show teachers they can collect some complicated data with the graphing calculator/interface technology. I then review types of inquiry (ask questions).

The second part of my engage involves having the students make concept maps on whiteboards given a list of about eight basic water chemistry words: water chemistry, pH, DO, biotic, abiotic, photosynthesis, respiration, conductivity, turbidity, or any of a large range of important words.

This gets the students (teachers) thinking about both the content (chemistry) and the context (pedagogy) on the labs they are getting ready to do.

Explore:

This is a complicated, multi-part sequence of the lesson that is going to lay the groundwork for content and skills needed to complete the elaboration phase of the lesson. The students will need to get to know the handhelds and how to use the instruments to collect data. There will be 2 CBL's per group. There will be a short walk-through to show how to turn on, set up, and prepare the technology for data collection.

Part 1: Photosynthesis/Respiration Lab

This is divided into two, 30 minute segments, with 3 data collection points at the beginning, at the 30 minute mark, and at the 60 minute mark. Each group will set up a microcosm using a mason jar as specified:

Jar A	Jar B	Jar C
3 Goldfish	9 sprigs of elodea	9 sprigs elodea, 3 Goldfish
Fill with water	Fill with water	Fill with water

Be sure to draw pictorial reminders on the board reminding the students the proper setup. While the photosynthesis/respiration lab is in its two periods of down time, it is good for the instructor to move on to explain how to do parts 2 and 3 of the exploration.

- Why do you think we are setting up the microcosms the way we are?
- Do you foresee any particular problems with this setup?
- Anything we need to be careful about?

Part 2: Gill beat rate vs. temperature of goldfish (to be done between microcosm readings 1 & 2)

This lesson is a simple setup of a lidless mason jar, a goldfish, and a temperature probe/cbl. The students are given a task to find the effects of temperature on the rate of a fish's gill beat (a way of looking at respiration). Be sure to give reasonable temperature parameters, collecting data at 15, 20, 25, 30, and 35 degrees Celsius. This isn't to stifle student scientific creativity, but mainly a way to make sure the temperature range that is not harmful to the fish is used. It is recommended to have the groups operationally define the variables so class data can be pooled on the front board. Besides that, leave the experimental design to the students as much as possible. The true inquiry is going to come from the data analysis, however.

- How is this a different situation from Part 1?
- Are you having any difficulties in measuring/quantifying variables?
- Are there any things we should have discussed as a class or defined before doing this?

Part 3: Dissolved O_2 vs. temperature (to be completed between microcosm readings 2 &3)

This lesson is an extension of the gill beat rate. It is probable that several students will automatically write off the fish's metabolism changes in varying water temperatures. Performing the same lab without the fish while using the DO probe usually leads to several "Aha" moments.

- Do you see anything here that would allow you to make inferences about part 2?
- Does this make you think of anything you'd like to explore further?

Continuation of Part 1:

At the final collection of data from the microcosms, the students then clean up and sit down with their data. There are usually some very interesting trends (or not) to be observed and analyzed by the students. This can lead to in-depth discussions about photosynthesis/respiration and the effects on dissolved CO_2, O_2, pH, etc. It is good to let each group present their data on the overhead with the calculator attachment, on the board by means of a drawing, or through a projector by means of a computer and a data analysis/graphing program. With enough time, this could allow for some really great discussions about what all the collected data really within and among groups.

- Some people see this as a perfect lab for talking about photosynthesis/respiration. Do you agree? Do the data support it?
- Does this make you think of any questions you'd like to explore further?

Explain:

In an ideal world, the teacher doesn't have verbatim notes already prepared, but lets the notes come out of the class discussion, student preconceptions, questions asked, and observed weaknesses in content areas. If time would have permitted, I would have gotten into a much more elaborate discussion about the different chemical parameters. I would plan on basing my lecture or discussion based on what I observed in the first two stages. Had I prepared any notes before the lesson, I would insert them here or attach them at the end of the lesson. Some items I'd be sure to discuss would be:

- Simple photosynthesis/respiration equations involving CO_2
- Discussion of temperature vs. DO vs. gbr graphs
- The effect of CO_2 levels in an aquatic system (increase CO_2, lower pH & vise versa)
- Differences in dissolving between a gas (such as O_2) and a solid (such as NaCl)
- The pH scale
- Hydrogen ion concentration
- Turbidity and its effects on photosynthesis (optional)
- Conductivity and water quality (optional)
- Any limitations to our models (microcosms)
- Other topics as needed for this sequence to promote open inquiry investigations for elaboration stage
- Some more usability of the calculator topics

Elaborate:

This is to be a true open inquiry. We have looked at microcosms, but as any pharmacist will tell you, a medicine will act completely different in a culture than it will in the dynamics of the human body. We can assume the same problem exists with our microcosms. A lake or a stream may yield significantly different results.

It will be up to the students to take the information learned in the earlier stages and choose either a true experiment or a naturalistic study to investigate (in the form of a question), collect data, analyze it, formulate a conclusion, if possible, start over, collect more data, or any other dynamic process a scientist would have to do in this situation. I will also lay out a large array of aquatic chemistry books so they will be able to do a short literature review if time allows. This is a very important part of research that teachers often leave out. In the end, if time permits, the students will do a short 15 minute presentation to the class by whatever means they choose (calculator projector, in focus, poster, discussion, etc) to explain the nature of their investigation, their methodologies, data analysis, problems, implications, and MOST IMPORTANTLY, further questions for long-term research. This stage is the scariest for teachers because it may definitely take them out of their comfort zones and it may require more freedom than some students deserve to have. This would be up to the teacher. In doing this with students, there is no substitution for adult supervision.

Timeline:
Engage/Brainstorm 15-25 minutes
Explore 1-1.5 hours
Explain .5-1.5 hours
Extend Anywhere from 3-4 hours to several class periods or weeks. It all depends on where you want to go. Of course, long-term investigations offer the teacher SEVERAL opportunities to bring the class back together for needed lectures and discussions as they arise.

No specific question can really be premeditated. Yet another reason why teachers are cautious of inquiry.

Evaluation:

The BIG final evaluation will be the students' group presentations. In this cooperative learning, heterogeneous situation, the group will act as a unit and "sink or swim" together for their grades. No pun intended. See attached rubric sheet for summative evaluation of presentation.

Evaluation of objectives:

Acceptable performance for each of the lesson's objectives (as numbered) would include (please refer to lesson objectives for numbers):

1. I may ask them at the end of the lesson, or at the beginning of the day to list as many chemical factors as they can in 3 minutes and state how they affect the aquatic community.
2. Observing how they inter-relate the important terms in the "eliciting information" stage using a concept map. This will be used to see what I need to do during the lesson.
3. I will observe this the entire time. It is of utmost importance they know how to use the equipment to collect the data. They will need to actually collect valid data with the probes.
4. Through the use of probing questions and teacher proximity, I will ask them to discuss their data as they complete the "explore' and "extend" phases.
5. Give an acceptable, researchable question within our constraints to explore.
6. Collect reasonable data that matches their questions
7. Give clear, concise descriptions of what they did and how they interpreted it when sharing with their classmates.

Research Design Guidelines and Criteria (taken from Dr. Akerson, Indiana University)

Group name: __________________ Members: _________ _________ __________
Date:

The research presentation will be assessed on the following elements:

/8 Problem Statement The problem statement is clear, and the problem is specific. Evidence is cited for assertions made. Language is used that is understandable.

Purpose. The purpose is clear and stated near the beginning of the paper

Background/Theory. An effective literature review is used in the area of the research that's presented in a meaningful way to support the problem. At least 3 outside resources have been cited in the study.

Research Questions: Questions are clearly staged and easy to find. There are a sufficient number to address the purpose, but not too many to confuse the focus.

/6 Procedures:

Data Collection. Data sources are clearly described. A data collection timeline is included.

Data Analysis. A method of analyzing the data is included. Analysis & reliability? The data analysis is appropriate for the research question and the data collected.

Also include: Relationship to purpose—a discussion shoing how data collection, procedures and analyses address the purpose of the study.

Relationship to literature—can you relate everything to the lit review

/6 Outcomes:
Conclusions and Implications. Discuss the outcomes of the study, and their implications for action. Are your outcomes of importance to environmental science or public awareness and action? Do your outcomes agree with your literature cited?

/6 Presentation Quality. Presentation is organized and easy for the audience to follow. Speaker uses visual aids (overheads, powerpoints) to organize and make points. Should not be handwritten. Should be spell checked. Handouts are optional but encouraged.

/30

This assessment would also include two critiques of other groups at 10 points each. (50 points total assessment).

Resources (rough version)

Water on the Web (**www.waterontheweb.org**).

Water Quality for Freshwater Organisms. Robert Brosa. **http://www.col-ed.org/cur/sci/sci28.txt**

Water Quality with Calculators. Robyn Johnson. Lab manual from Vernier Software and Technology.

Photosynthesis and Respiration Worksheet

Taken directly from WaterontheWeb.org

Name(s): ____

Date: ____________________

Data Collection

1. What occurred in each microcosm?

Data Management and Analysis

2. Describe the results of your microcosm work.

Interpretation of Results

3. Were your results consistent with the equations for photosynthesis and respiration? Why or why not? (Refer to the reading: **Introduction to Cellular Respiration and Photosynthesis**)

4. What trends did you observe in the WOW data you collected in surface water over the course of a complete day?

5. Hypothesize why it is common for oxygen to be abundant near the surface and nearly-depleted near the bottom of the lakes in summer. Did the lake you selected show this pattern?

6. Describe the relationships that exist between oxygen and pH levels in the profile you graphed.

7. Were the trends observed in WOW data consistent with the equations for photosynthesis and respiration?

8.Using the "**Understanding Lake Ecology**" section or a text, diagram the carbon cycle in the lake you sampled using WOW data. Be sure to include primary producers, **primary consumers**, **secondary consumers**, **tertiary consumers**, and decomposers.