

Lesson Plan: Yucky Water! A Water Quality Lab Investigation

Laurie Rogers: Northview High School, Johns Creek, GA, Fall 2013

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Learning Objectives

- To become aware of how chemistry concepts learned in class can be used with a real world application pertaining to water quality.
- To learn how to follow correct experimental procedures to test for pH, dissolved oxygen, nitrates and phosphates in water samples and to interpret and evaluate the data obtained to look for evidence of the source of pollutants.
- To be introduced to environmental science concepts such as watersheds, runoff, and water pollutants, and the implications of eutrophication due to increased nutrient levels.
- To realize the importance of being good stewards for our waterways.

Enduring Understandings for the Lesson:

- The importance of fresh water, sources of water pollution and implications of pollution on the health of our waterways.
- Introduction to the water quality tests to be conducted, what each test measures, how each test is performed and the significance of test results. These tests will include qualitative observations, pH, dissolved oxygen, nitrates and phosphates.

Lesson Overview:

- Students will read a scenario in which they pretend to be interns at an environmental consulting firm and will analyze water samples to attempt to determine the type and cause of a polluted, locally collected water sample.
- Students will do a pre-lab assignment to learn related vocabulary and investigate the importance of water quality testing and sources and effects of water pollutants.
- Students will conduct water quality testing on tap water and stream water (collected by teacher and brought to school).and on samples to which pollutants have been added (fertilizers, household detergents, decomposed organic matter), as well as an “unknown” contaminated water sample. Ideally, students could collect water samples if the school has a stream on-site or within a short walk. If not, students will use samples the teacher collected the day previously.
- Students will answer lab questions, some of which pertain to the chemistry of the tests, and will prepare a report to their fictitious supervisor, in which they will interpret and evaluate test data, and draw conclusions as to the origin of a contaminant in their water samples.

Georgia Performance Standards Addressed:

Unit 1 Characteristics of Science: Habits of Mind

SCSh2. Students will use standard safety practices for all classroom laboratory investigations.

SCSh3. Students will identify and investigate problems scientifically.

c. Collect, organize and record appropriate data.

f. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh4. Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.

SCSh8. Students will understand important features of the process of scientific inquiry.

b. Scientific researchers are expected to critically assess the quality of data including possible sources of bias in their investigations' hypotheses, observations, data analyses, and interpretations.

Chemistry GPS

SC1 Students will analyze the nature of matter and its classifications

b. Identify substances based on chemical and physical properties.

d. Use IUPAC nomenclature for both chemical names and formulas

SC2 Students will relate how the Law of Conservation of Matter is used to determine chemical composition in compounds and chemical reactions.

a. Identify and balance the following types of chemical equations:

• Synthesis • Double Replacement

b. Experimentally determine indicators of a chemical reaction specifically precipitation, gas evolution, water production, and changes in energy to the system.

SC7. Students will characterize the properties that describe solutions and the nature of acids & bases.

a. Explain the process of dissolving in terms of solute/solvent interactions

b. Compare, contrast, and evaluate the nature of acids and bases: pH

Environmental Science GPS

SEV2. Students will demonstrate an understanding that the Earth is one interconnected system.

d. Characterize the components that define fresh-water and marine systems. Abiotic Factors – to include light, dissolved oxygen, phosphorus, nitrogen, pH and substrate.

SEV5: Students will recognize that human beings are part of the global ecosystem and will evaluate the effects of human activities and technology on ecosystems.

e. Describe the effects and potential implications of pollution and resource depletion on the environment at the local and global levels (e.g. water pollution).

CCGPS Literary Standards

L9-10RST3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

L9-10RST4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9–10*

L9-10WHST4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Grade Level: High School 9-12 (Chemistry class)

Materials:

- Access to internet for out-of-class research
- Water quality testing kits:
 - LaMotte test kit: Shallow water precision monitoring series, Code 5854-01. This kit contains supplies for performing dissolved oxygen test and pH
 - Universal Indicator solution (Flinn Scientific, 500 mL bottle, U0002) & color comparison chart
 - Nitrate and phosphate test kits: several options depending upon available funds: Freshwater Pollution Test Kit, Flinn AP5953 from www.flinnsci.com
Nitrate test kit – color cube model N1-11 or N1-14 from www.Hach.com

Phosphate test kit – color cube model or PO-19 from www.Hach.com
 PondCare Master Liquid Test Kit available through www.Amazon.com

- Basic laboratory glassware (beakers, test tubes) & safety equipment (splash goggles, gloves)
- Water samples (tap, stream, and polluted, see Teacher Notes at end of lesson).

Time Needed:

- Assign pre-lab homework 2 days before lab
- 15 minutes to review pre-lab homework and to introduce activity day before lab
- 60-minute class period for lab activity
- 15 minutes for post-activity class discussion the day after lab
- Outside class time for students to answer pre-lab and lab analysis questions and write report

Background Information:

Freshwater flowing across the earth's surface and into streams, rivers, lakes, and wetlands is one of our most precious resources. Freshwater is continuously purified and recycled through the water cycle. The region into which surface water drains is called a watershed. Surface runoff is water that does not evaporate into the atmosphere or soak into the ground. This system works wonderfully; however, water systems can be overloaded with contaminants.

Water pollution is any chemical, physical or biological change in water quality that harms living organisms and makes it unsuitable for intended uses. Point sources of pollution can be traced to a specific location, for example, sewage treatment plants, while nonpoint sources cannot be traced to a single discharge site, for example, runoff from croplands or lawns. The addition of nutrients to waterways is called eutrophication, and can derive from natural sources (organic decay) and human sources (fertilizer, pesticides, sewage, mining and industrial discharge, and urban runoff from substances such as motor oil).

It is important to test the water in our streams, rivers and ponds to monitor the health of the watershed. Water is tested for dissolved oxygen content, which is a measure of the amount of oxygen dissolved in the water that is available for respiration by aquatic organisms. Acidity is a measure of the hydrogen ion concentration of a solution and is expressed as pH which is $-\log[\text{H}^+]$ with a scale of 0-14, with 7 as neutral, <7 acidic, and >7 basic. Nitrogen and phosphorus are necessary nutrients for plant growth, and a measure of nitrate (NO_3^-) and phosphate (PO_4^{3-}) concentration above acceptable limits can tell us if there is pollution. The pollutants that could originate from a golf course, subdivision and farmland are organic matter such as grass clippings, fertilizer runoff containing nitrogen and phosphorus, and animal waste. A forest could have decaying organic matter runoff, and a restaurant which lacks proper sewage disposal could have contamination from phosphate-containing cleaning agents and detergents.

Nutrient overload of a waterway produces excessive growth of algae and other aquatic plants, which increases the demand for oxygen, depleting the supply of dissolved oxygen. Increased photosynthesis also decreases the carbon dioxide concentration, leading to an increase in pH above the healthy range. A pH that is too low or too high can kill aquatic organisms. Decomposition of excessive growth of aquatic plants by aerobic bacteria also depletes the supply of dissolved oxygen. This oxygen depletion can kill fish and other aquatic organisms.

Prior student knowledge includes safe and proper chemistry lab technique, ability to write and balance chemical equations, and an understanding of chemical reactions, acidity and solubility.

Learning Procedure:

Refer to attached Student Lab Sheet for activity details, instructions and evaluation.

Evaluation:

Refer to scoring checklist included at end of lab sheet. A teacher key is included for lab questions. Students will be evaluated on the following:

1. Vocabulary and pre-lab questions completed
2. Complete lab sheet with lab analysis questions thoughtfully and accurately answered.
3. Written report assessed for writing skills, strength of argument and supporting evidence.

Extensions:

1. Research “green” alternatives to traditional fertilizers, pesticides, and cleaning products and cite the advantages and disadvantages of using these compared to traditional products.
2. Research the operation of a traditional water treatment plant and investigate new technology.
3. Compare current and historic pollution levels of the local river and account for differences.
4. Research the world-wide availability of clean drinking water, and discuss challenges faced.
5. Review local river water quality data from EPA or GA Adopt a Stream and comment on findings.

Resources:

Georgia Adopt-a-Stream resources for chemical monitoring

http://www.georgiaadoptastream.com/db/manuals.asp#Bio_Chem

Background on the Winkler method for dissolved oxygen content determination

http://serc.carleton.edu/microbelife/research_methods/environ_sampling/oxygen.html

Safe Drinking Water information <http://www.safewater.org/>

Give Water a Hand

<http://www.uwex.edu/erc/gwah/>

Environmental Protection Agency – water science pages

<http://www2.epa.gov/science-and-technology/water-science>

<http://safewater.supportportal.com/ics/support/default.asp?deptID=23015&referrer=http://www.epa.gov/ogwdw/faq/faq.html>

Water- What ifs? Water quality testing information

<http://www.ncsu.edu/sciencejunction/depot/experiments/water/index.html>

National Institute of Health – water pollution

<http://www.niehs.nih.gov/health/topics/exposure/water-poll/>

US Geological Survey – surface water quality related to its fitness for use

<http://www.usgs.gov/science/science.php?thcode=2&term=1125>

National Resources Defense Council – water information

<http://www.nrdc.org/water/>

Miller, G. Tyler. Environmental Science, 11th edition. Thomson Learning, Inc., Belmont, CA, 2006

LaMotte Dissolved oxygen water quality test instructions

<http://www.lamotte.com/images/pdf/instructions/7414.pdf> L

Chemistry

Name: _____ Period: ____

Yucky Water! A Water Quality Lab Investigation (student lab sheet)**Objective:**

The purpose of this lab is to become aware of how chemistry concepts learned in class can be used with a real world application pertaining to water quality. Students will read a scenario in which they pretend to be interns at an environmental consulting firm and will analyze water samples to attempt to determine the type and cause of a polluted, locally collected water sample. To do this, students will learn how to follow correct experimental procedures to test for pH, dissolved oxygen, nitrates and phosphates in various water samples and to interpret and evaluate the data obtained to look for evidence of the source of pollutants of their sample. In completing this investigation, students will also be introduced to environmental science concepts such as watersheds, runoff, and water pollutants, and the implications of eutrophication due to increased nutrient levels, and will realize the importance of being good stewards for our waterways.

Scenario:

One day, you are hanging out along the banks of your beloved local stream, playing fetch with your dog Muffin. You notice that when your dog comes out of the water, she smells slightly more “doggy” than usual, and you wonder if maybe the water is contaminated in some way. You just happen to have a clean container handy, and so you decide to wade out to take a sample of the stream water. You wonder where possible contamination may be coming from, and remember that upstream there is a golf course, a farm, an upscale subdivision, a forest, and a restaurant with a suspicious pipe emptying soap suds into the stream. Is it possible that one of these is contaminating the water? Luckily, you have the means to investigate this as you have just started an internship as a technician with an environmental consulting company. You approach your boss, and, dazzling him with your chemistry knowledge, convince him to let you do some water quality monitoring to try to determine the problem. However, this is all brand new to you, so first you have to do some background research on water pollution, and gather baseline data on local water quality (both “clean” and “contaminated”) and then analyze your sample to try to determine the type of pollutant and the source. Fortunately, you have some fellow interns to help you with the testing! Your boss tells you that he will expect a full report with your recommendations. What a challenge! Time to get to work!

Part A: Pre-lab questions (please answer in ink in complete sentences on paper and attach)

Vocabulary: Define the following terms as they relate to water:

- | | |
|--|-----------------------------|
| 1. freshwater aquatic ecosystem | 6. dissolved oxygen content |
| 2. watershed | 7. acidity |
| 3. surface runoff | 8. pH |
| 4. point & nonpoint pollution sources | 9. nitrates |
| 5. natural and cultural eutrophication | 10. phosphates |

Background information: Answer the following questions:

1. Why is it important to chemically test for water quality?
2. What do results for the testing of pH, dissolved oxygen, nitrates & phosphates tell us about the health of a waterway?
3. List some naturally occurring and man-made sources of freshwater pollution.
4. What water pollutants could originate from a golf course, farm, subdivision, forest & restaurant?
5. What are the negative effects of water pollutants on aquatic ecosystems?

Safety: Splash goggles, gloves, long hair tied back, follow correct procedures for handling glassware and chemicals, dispose of waste in waste containers as instructed by teacher.

Materials:

- “Clean” water samples: tap water, river water
- “Polluted” water samples: contaminated with dishwashing detergent, fertilizer, decaying organic matter (leaf litter) and an “unknown” contaminated sample
- Sample bottles and 150 mL, 250mL Beakers
- Test tubes, pipets, stoppers and test tube rack
- Tape & sharpie marker for labeling
- LaMotte test kit: Shallow water precision monitoring series, Code 5854-01. This kit contains supplies for performing dissolved oxygen test and pH
- Universal Indicator solution (Flinn Scientific, 500 mL bottle, U0002) & color comparison chart
- Nitrate and phosphate test kits

Procedure:

1. Working in assigned lab groups of 3 students at numbered stations, each group is assigned a different sample # 1-5 (refer to data table) to analyze. There will be 2 groups doing each of these 5 samples so duplicate data will be recorded. Each group will also be assigned a 6th sample “Unknown” A-C. Results for samples #1-5 will be posted by each group in the master chart on the board, and students will share and record all class data in the data table below.
2. Follow all procedures carefully and clean up your lab station as instructed.
3. First test sample #1-5 designated to your group. Secondly, obtain an “unknown” sample A-C from your teacher, record your unknown’s identifying letter, and repeat the tests for this sample.
4. **Observe the water samples** designated to your group, and record observations. Note clarity, color, odor, and the presence of any suspended solids or surface film.
5. **To determine pH**, fill the pH test tube to 10mL line with water sample and add 10 drops of universal pH indicator. Cap and invert 5 times to mix. Insert test tube into appropriate color comparator, and match sample color to color standard. Record the pH.
6. **To test for dissolved oxygen content:**
 1. Take care not to introduce air into the sample while adding the reagents.
 2. Remove the cap from the bottle and add 8 drops of both manganese (II) sulfate and potassium iodide azide solutions. Cap the bottle and invert several times. Allow the precipitate that forms to settle to the bottom of the bottle.
 3. Add 8 drops of 50% sulfuric acid, cap and invert gently until the precipitate has dissolved. The solution should be a yellow-brown color if dissolved oxygen is present.
 4. Fill the titration tube to the 20mL line with sample.
 5. To fill the titrator tube, depress the plunger of the titrator and insert into the top of the sodium thiosulfate titrating solution. Invert and slowly withdraw the plunger until the large ring is set to the zero line. taking care expel air bubbles. Right the bottle and withdraw the titrator.
 6. Insert the tip of the titrator into the opening of the titration tube cap. Depress the plunger to dispense solution until the color changes to a very pale yellow. Swirl to mix. Carefully remove the titrator & cap, add 8 drops of starch indicator and the sample should turn dark blue. Return the cap to the titration tube, insert the titrator and continue titrating until the solution becomes colorless. Read the test result directly from the scale where the large ring meets the titrator barrel. Record as ppm dissolved O₂.
7. **To test for nitrates:** (follow instructions below or as given by teacher)

1. Fill the test tube to the 5mL line with the sample.
 2. Add one Nitrate test tab from its blister pack, cap and mix by inverting for two minutes to disintegrate the tablet. Wait 5 minutes for the pink color to develop.
 3. Compare the color of the sample to the Nitrate color chart and record as ppm Nitrate (note: if test gives results as ppm N, multiply by 4.4 to convert to nitrate ppm)
- 8. To test for phosphates:**
1. Fill the test tube to the 10 mL line with the sample.
 2. Add one Phosphate Test tab from its blister pack. Cap and mix by inverting until the tablet has disintegrated. Wait 5 minutes for the blue color to develop. If the sample remains colorless, record the result as 0 ppm.
 3. Compare the sample color to the Phosphate color chart. Record result as ppm Phosphate.
- 9. Repeat the tests for your unknown sample.**

Data Table:

#	Water sample	Group #	Appearance	pH	Dissolved O ₂ (ppm)	NO ₃ ⁻ (ppm)	PO ₄ ³⁻ (ppm)
1	Tap water						
2	“Clean” stream water						
3	“soapy” water						
4	“fertilizer” water						
5	“organic matter” water						
6	Unknown sample ID: _____						

Standards	Appearance	pH	Dissolved O ₂ (ppm)	NO ₃ ⁻ (ppm)	PO ₄ ³⁻ (ppm)
(taken from GA Adopt a Stream, GA EPD)	Clear, colorless, odorless	6.0 – 8.2	>5 ppm	<4.4 ppm (clean) >44 ppm (unsafe)	<0.03ppm (clean) >0.1 ppm(unsafe)

Part B: Analysis questions: (please answer in complete sentences in ink on paper and attach)

1. Refer to the chart of water quality standards. How do class results compare for each parameter tested of samples 1-5? Explain discrepancies.
2. What do you think your group's unknown sample was contaminated with? Explain your reasoning. Can you say conclusively that your contamination was from a specific source? Why or why not?
3. What errors could have occurred during the performance of this lab? What impact would these errors have on results? How can these errors be minimized during future testing?
4. a. Write the balanced chemical equations for the reactions that took place during the dissolved oxygen test. (Note: all ionic compounds are in aqueous solutions)
 - i. Manganese(II) sulfate + potassium hydroxide \rightarrow manganese (II) hydroxide + potassium sulfate
 - ii. Manganese(II) hydroxide + oxygen gas + water \rightarrow manganese (III) hydroxide
 - iii. Manganese(III) hydroxide + sulfuric acid \rightarrow manganese (III) sulfate + water
 - iv. Manganese(III) sulfate + potassium iodide \rightarrow manganese(II) sulfate + potassium sulfate + iodine
 - v. Sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$) + iodine \rightarrow sodium tetrathionate ($\text{Na}_2\text{S}_4\text{O}_6$) + sodium iodide
 b. Challenge! Using Hess's Law of summation, write the net overall equation for steps 1-4 of this procedure.
5. How would you expect the dissolved oxygen content to vary with water temperature? Explain your reasoning at the molecular level (Hint: think in terms of kinetic energy of the gas molecules as temperature changes).
6. Suppose the water is suspected of being contaminated with high levels of Fe^{3+} or Pb^{2+} ions from a scrap metal junkyard.
 - a. What aqueous solutions could be added to the contaminated water to form precipitates to help identify the presence of the contaminant ions? What type of chemical reaction is this?
 - b. What results would you expect for each type of contaminant? Write chemical formulas for possible precipitates.
7. Brainstorm! What can you and other individuals do to help maintain the health of our waterways?

Part C: Report:

In a separate document, prepare a typed memo to your fictitious internship boss, outlining the following:

- a. The problem
- b. A summary of your methodology (detailed steps of each procedure not required)
- c. Testing results and identification of contaminant(s)
- d. Your evaluation

Grading Evaluation checklist is on next page.

Grading Evaluation checklist:

Item	Points Available	Points earned
Vocabulary	10	
Pre-lab background questions	10	
Data table complete	15	
Analysis questions	(35 total)	
1 Results discussion?	5	
2 Contaminant identification?	5	
3 Error analysis?	5	
4 DO test equations?	8	
5 DO & water temperature?	2	
6 Metal ion contaminants?	5	
7 Actions to reduce pollution?	5	
Report	(30 total)	
Concise, logical writing style, correct grammar & spelling, memo style	5	
Problem clearly stated	5	
Discussion of methodology, results & identification of contaminant(s)	10	
Strength of argument & supporting evidence	10	
Total Points	100 / 100	/100
<i>Teachers Comments:</i>		

Teacher Notes:**Sample preparation:**

Obtain stream water samples the day before the lab.

To prepare contaminated samples:

“Soapy” water: to 3L of water, add 5mL dish detergent containing PO_4^{3-} or add .005g of Na_3PO_4 .

“Fertilizer” water: to 3L of water, add 10 mL of liquid household fertilizer

“Organic matter” water: to 3 L of water, add 250 grams of decaying leaves, grass clippings collected in advance. Cap and shake vigorously and let settle.

“Unknown” water: prepare 1 L of 3 types each: A containing detergent, B containing fertilizer, and C containing a mixture of the 3 contaminants.

Answer Key:

Part A: Pre-lab questions: Refer to background information as discussed in class before the activity

Part B: Lab Analysis Questions:

1. Student answers will vary
2. Student answers will vary.
 - a. Unknown sample A contained high levels of phosphate, which may have been derived from the restaurant’s dishwashing wastewater.
 - b. Unknown sample B contained high levels of nitrate, which may have been derived from the fertilizers used on the golf course or subdivision lawns.
 - c. Unknown sample C contained low levels of dissolved oxygen which may have been derived from the decaying organic matter from the forest as the bacteria consume oxygen. Nitrates and phosphates from the fertilizers and detergents stimulate growth of algae which produces CO_2 during photosynthesis, lowering pH, and can also contribute to low DO, due to oxygen consumption during the decay process.
3. Errors: stream samples not collected at time of testing which impacts dissolved oxygen testing, inaccurate measurements, not following procedure exactly, individual variation in color comparison determination, inconsistency in relying on data from other groups, limited supplies and time meant that students could not do duplicate tests themselves, etc.
4. Balanced equations:
 - i. $\text{MnSO}_4 (\text{aq}) + 2\text{KOH} (\text{aq}) \rightarrow \text{Mn}(\text{OH})_2 (\text{aq}) + \text{K}_2\text{SO}_4 (\text{aq})$
 - ii. $4 \text{Mn}(\text{OH})_2 (\text{aq}) + \text{O}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l}) \rightarrow 4 \text{Mn}(\text{OH})_3 (\text{aq})$
 - iii. $2 \text{Mn}(\text{OH})_3 (\text{aq}) + 3\text{H}_2\text{SO}_4 (\text{aq}) \rightarrow \text{Mn}_2(\text{SO}_4)_3 (\text{aq}) + 6\text{H}_2\text{O} (\text{l})$
 - iv. $\text{Mn}_2(\text{SO}_4)_3 (\text{aq}) + 2\text{KI} (\text{aq}) \rightarrow 2 \text{MnSO}_4 (\text{aq}) + \text{K}_2\text{SO}_4 (\text{aq}) + \text{I}_2 (\text{l})$
 - v. $2 \text{Na}_2\text{S}_2\text{O}_3 (\text{aq}) + \text{I}_2 (\text{l}) \rightarrow \text{Na}_2\text{S}_4\text{O}_6 (\text{aq}) + 2 \text{NaI} (\text{aq})$

Summation: $8\text{KOH} (\text{aq}) + \text{O}_2 (\text{g}) + 6\text{H}_2\text{SO}_4 (\text{aq}) + 4\text{KI} (\text{aq}) \rightarrow 6\text{K}_2\text{SO}_4 (\text{aq}) + 2 \text{I}_2 (\text{l}) + 10\text{H}_2\text{O} (\text{l})$

5. Gas solubility increases as temperature decreases, so colder water would have a higher O_2 content than warmer water. As temperature increases, the kinetic energy of the dissolved gas molecules increases, and more are able to escape from the solution and return to the gas phase.
6. A double displacement reaction could be conducted. To precipitate the lead(II) ion, add an aqueous solution of potassium iodide, and lead(II) iodide precipitate (PbI_2) would form. Filter the solution to remove the precipitate, and then add an aqueous solution of sodium phosphate to precipitate the iron(III) ion to form iron(III) phosphate (FePO_4).
7. Student answers will vary. Responses can include using “green” detergents, no fertilizers or pesticides on lawn, clean up after pet waste, discard all wastes appropriately, don’t pollute near waterways, join an environmental group, raise awareness at school about water pollution, etc.

Part C: Report: Student answers will vary.