Water: No Dirt, No Germs

At the time of Madame Marie Curie's acceptance of the 1911 Nobel Prize in Chemistry, water treatment to provide clean, safe drinking water, was becoming common in many places in Europe and North America. Waterborne diseases, such as typhoid fever and cholera, still have yet to be completely eliminated, although the chemical technology "tools" are available. This activity will raise awareness of the critical use of chemistry to provide one of the most basic human needs, clean drinking water.

Starting with local natural surface waters, students will replicate one or both of the main steps of drinking water treatment--**clarification** and **disinfection**. Younger students will clarify natural surface water and observe disinfection done by their teacher. Older students will both clarify and disinfect natural water.

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Instructions for the Activity (Teacher)

Drinking water chlorination represents a smart use of chemistry in our everyday lives. Small amounts of chlorine are added to large volumes of drinking water help destroy germs, including bacteria and viruses that once killed thousands of people every year. Adding chlorine to drinking water has improved public health in many places in the world today.

Students should work in small groups (4 – 6, or pairs if numbers permit) to treat water from a natural local source. They will carry out one or both of the main steps of water treatment, clarification and disinfection, and then analyse results.

Clarification is the process used to remove solid debris from natural or waste water and involves four steps:

1. **Aeration,** the first step in the treatment process, adds air to water. It allows gases trapped in the water to escape and adds oxygen to the water.
2. **Coagulation** is the process by which dirt and other floating solid particles chemically "stick together" into flocs (clumps of alum and sediment) so they can easily be removed from water.
3. **Sedimentation** is the process that occurs when gravity pulls the particles of floc to the bottom of the container. At a treatment plant, there are settling beds that collect flocs that float to the bottom, allowing the clear water to be drained from the top of the bed and continue through the process.
4. **Filtration** through a sand and pebble filter removes most of the impurities remaining in water after coagulation and sedimentation have taken place.
5. **Disinfection** is the process used to destroy germs in the filtered water. In this activity, chlorine disinfectant will be used to destroy germs chemically (recommended for older students or as demonstration for younger students).

Safety

Safety glasses must be worn at all times during this activity.

The water is not safe to drink.

Direct contact with alum and disinfectant should be avoided.

Materials for Water Clarification

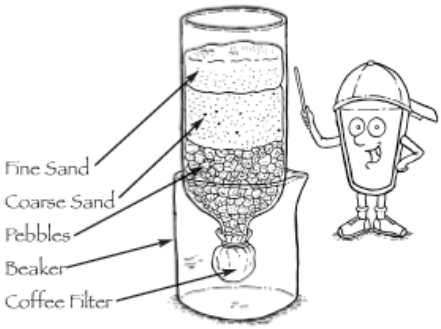
- 2 liters of “dirty” natural water (or you can add 1 cup of dirt or mud to 2 liters of water)
- 3 liters of clean water.
- 1 two liter plastic soft drink bottle with its cap (or cork that fits tightly into the neck).
- 2 two liter plastic soft drink bottles, one with its bottom cut off to use as a funnel and one with the top cut off to use for sedimentation.
- 1 large beaker (with a volume of 500 ml, or 2 cups) or measuring bowl that will hold the inverted two liter bottle or you can use another two liter plastic soft drink bottle with its top cut off so the other bottle will fit inside of it.
- 2 tablespoons of alum
- 1½ cups fine sand
- 1½ cups coarse sand
- 1 cup small pebbles
- 1 coffee filter
- 1 rubber band
- 1 large spoon
- A clock with a second hand or a stopwatch

Procedure for Water Clarification

1. Pour dirty swamp/river/dam water (or the water sample you made by mixing dirt and water) into the two litre bottle with a cap. Describe the appearance and smell of the water, using the Students' Observation Sheet for Water Clarification.
2. Place the cap on the bottle and vigorously shake the bottle for 30 seconds. Continue the aeration process by pouring the water into another bottle or the beaker, then pouring the water back and forth between them about 10 times. Once aerated, gases have escaped (any bubbles should be gone). Pour your aerated water into your bottle with its top cut off.

3. Add two tablespoons of alum to the aerated water. Slowly stir the mixture for 5 minutes. Describe the appearance and smell of the water, using the Students' Observation Sheet for Water Clarification.
4. Allow the water to stand undisturbed in the container (see photo to the right). Observe the water at 5 minute intervals for a total of 20 minutes. Write down what you see - what is the appearance of the water now? Use the Students' Observation Sheet for Water Clarification to note your observations.
5. Construct a filter from the bottle with its bottom cut off as follows (see illustration left):

   a. Attach the coffee filter to the outside neck of the bottle, using a rubber band. Turn the bottle upside down placing it in a beaker or cut-off bottom of a two liter bottle. (IF USING THE CUT-OFF BOTTOM OF A TWO LITER BOTTLE, PUNCH A SMALL HOLE IN THE SIDE OF THE BOTTLE TO PERMIT AIR TO ESCAPE.) Pour a layer of pebbles into the bottle - the filter will prevent the pebbles from falling out of the neck.
   b. Pour the coarse sand on top of the pebbles.
   c. Pour the fine sand on top of the coarse sand.
   d. Clean the filter by slowly and carefully pouring through 3L (or more) of clean drinking water. Throw away the water that has passed through the filter.
6. After a large amount of sediment has settled on the bottom of the bottle of swamp/river/dam water, carefully - without disturbing the sediment - pour the top two-thirds of the swamp/river/dam water through the filter. Collect the filtered water in the beaker/plastic bottle.
7. Compare the treated and untreated water. Has treatment changed the appearance and smell of the water?
8. Check with your teacher if you can also do the additional activity on measuring turbidity of the "dirty" water, the clarified water and your household drinking water.



[1] *Based on U.S. Environmental Protection Agency activity at: http://www.epa.gov/safewater/kids/flash/flash_filtration.html*

Procedure for Water Disinfection

Why is Disinfection Necessary?

Filtered water is clear of many visible particles but contains many invisible live germs that can make people sick. Chlorine is used in many water treatment facilities to destroy harmful germs and small particles of organic matter. In this part of the activity, we'll be measuring "free available" chlorine. "Free available" chlorine is the level of chlorine available in water to destroy germs and organic matter. Water treatment plants add enough chlorine to destroy germs plus a little bit more to fight any new germs that are encountered before the water reaches your home, for example. This small extra amount is known as the "chlorine residual" and it can be detected using chlorine test strips.

Materials needed for Water Disinfection

- Liquid laundry bleach (sodium hypochlorite)
  CHECK the bleach concentration – see the Bleach Conversion Table, p12
- About 10 chlorine test strips
- One eye/medicine dropper or disposable pipette
- One large spoon
- A clock with a second hand or a stopwatch

Safety

Safety glasses must be worn at all times during this activity.

The water is not safe to drink.

Direct contact with bleach should be avoided.

Senior high school students may be allowed to carry out this activity. Class demonstrations are recommended for junior classes.

Procedure for Water Disinfection

1. Dip a chlorine test strip into 500 ml (approximately 2 cups) of the clear liquid obtained from the filtration activity (the "filtrate") above and use the product color-code chart to estimate the "free available" chlorine level of the liquid. Record the level of chlorine in the filtrate in the table on the Students' Result Sheet for Water Disinfection.
2. Add 2 drops of bleach to the filtered liquid, stir gently for 5 seconds, and repeat the test strip reading immediately. Record your results in the table. Keep adding 2 drops at a time, and record the number of drops added, until a chlorine level registers on the test strip. As chlorine bleach is added to the filtered water, chlorine is being used up in destroying harmful germs, so it could take a few additions of bleach before a chlorine residual can be observed.
3. Once the chlorine residual is noted, wait 10 minutes WITHOUT ADDING MORE BLEACH and again record the free available chlorine level.
4. If the chlorine residual disappears over the course of 10 minutes, add two more drops and see if a free chlorine level reading of at least 1 – 3 parts per million can be measured 10 minutes after adding the chlorine. (If after 2 drops and 10 minutes, no chlorine residual is noted, increase the number of drops by 2, trying 4 drops. Wait 10 minutes and check for the chlorine residual. If no chlorine residual appears, increase the number of drops to 6, etc., until a chlorine residual can be noted after 10 minutes.) When this happens, you have added enough chlorine bleach to destroy many of the germs in the water, leaving a small excess of chlorine.
5. Calculate the total number of drops used for the disinfection and report it to help determine the class average.

Student Observation Sheet

Water Clarification (Complete the following tables using the “dirty” water you have collected.)

Date of sample collection	
Temperature of water when collected	
Type of water: fresh (pond, river, stream or swamp) or estuarine	
Describe where you found the water	

Water Appearance

Appearance and smell before the start of treatment	
Appearance after aeration	
5 minutes after adding alum	
10 minutes after adding alum	
15 minutes after adding alum	
20 minutes after adding alum	
Appearance and smell after filtration	

Water Disinfection

(Use 500 mL of your **filtered water** for this activity.)

Bleach added	**Free Available Chlorine**		
	Number of drops	**Colour of chlorine test strip**	**Free available chlorine/ parts per million**
No bleach	0		
Number of drops added until residual bleach present (**Step 2**)			
After 10 minutes (**Step 3**)			
Number of drops to give residual chlorine after 10 minutes. (**Step 4**)			
Total number of drops			

Conclusions

1. Compare the treated and untreated water. Has treatment changed the appearance and smell of the water?

2. Do you think your clarified water is safe to drink? Give a reason for your answer.

3. Do you think your filtered and disinfected water is safe to drink? Give a reason with your answer.

Class Results Sheet

NAME OF SCHOOL _____

LOCATION OF SCHOOL _____

Group number	Type of water	Description of water source	Average number of drops of bleach added*
1			
2			
3			
4			
5			
Average			
Concentration Conversion (check if required Table p12)			

Observation Sheet (*Trial results*)

Water Clarification (Complete the following tables using the "dirty" water you have collected.)

Date of sample collection	*October 3, 2010*
Temperature of water when collected	*24 °C*
Type of water: fresh (pond, river, stream etc.) or estuarine	*Fresh, swamp*
Describe where you found the water	*In a wetland adjacent to Rock Creek in Brockville, Ontario*
Water Appearance	
Appearance and smell before the start of treatment	*Murky with individual small particles visible; smelled sulfurous.*
Appearance after aeration	*Less murky than when first collected; clumps of suspended sediment visible.*
5 minutes after adding alum	*Very much clearer than when first collected, with fewer clumps of suspended sediment visible, a few large pieces of twigs floating on the surface, and a few very small organisms swimming.*
10 minutes after adding alum	*Continues to become clearer; more sediment settling; a few pieces of twig still floating on the surface. Some of the smallest organisms have stopped swimming; others continue.*
15 minutes after adding alum	*No more noticeable change from at 10 minutes.*
20 minutes after adding alum	*No more noticeable change from at10 minutes*
Appearance and smell after filtration	*Clear light brown liquid; smell still present.*

Water Disinfection (Use 500 mL of your **filtered water** for this activity.)

Bleach added	Free Available Chlorine

	Number of drops	**Colour of chlorine test strip**	**Free available chlorine/ parts per million**
No bleach	0	*No colour*	*0*
Number of drops added until residual bleach present (**Step 2**)	*4*	*Purple*	*1.0*
After 10 minutes (**Step 3**)	0	*No colour*	*0*
Number of drops to give residual chlorine after 10 minutes. (**Step 4**)	*18*	*Purple*	*1.0*
Total number of drops	*22*		*1.0*

Conclusions

1. Compare the treated and untreated water. Has treatment changed the appearance and smell of the water?

   After the treatment the water is clear and most of the smell has gone.

2. Do you think your clarified water is safe to drink? Give a reason for your answer. *I do not think the water is completely safe to drink now. I think there are still germs in the water that will multiply over time.*

3. Do you think your filtered and disinfected water is safe to drink? Give a reason with your answer.

   The water should be safer to drink now because enough bleach for some not to be used up. But I would not drink it because it was a school experiment done in a school lab not a food preparation area.

Class Results Sheet

NAME OF SCHOOL:

LOCATION OF SCHOOL:

Group number	Type of water	Description of water source	Average number of drops of bleach added*
1	*Swamp*	*Rock Creek wetland*	*22*
2	*Swamp*	*Rock Creek wetland*	*24*
3	*Swamp*	*Rock Creek wetland*	*22*
4	*Swamp*	*Rock Creek wetland*	*18*
5	*Swamp*	*Rock Creek wetland*	*18*
Average			***21***
Concentration Conversion (check if required Table p12)			***not required***

* Since this is an average figure, the result will not necessarily be an even number.

Example for river water: Four groups in a school reported the minimum number of drops as

7, 6, 8 and 8 respectively. The numerical average is 7,25 but significant figures, as determined by the number of drops added, will require results to be reported as 7 drops.

Additional Information about the Experiments

Safety Precautions

Safety glasses should be worn at all times during these activities. It should be emphasized that neither the clarified water nor the disinfected water will be safe to taste or drink. The students should be made aware of this at the start of the activity. Contact with the solid substances (alum and calcium hypochlorite) should be avoided. The household bleach should be handled with care.

Materials and Equipment Listing

Materials needed for Water Clarification

1. 2 Liters of “dirty” natural water. The water can be collected from a stream, pond, river or swamp (or you can add 1 cup of dirt or mud to 2 liters of water). Don’t try to collect “clean” water – the water should be murky.
2. 1 Two liter plastic soft drink bottle with its cap (or cork that fits tightly into the neck).
3. 2 Two liter plastic soft drink bottles, one with its bottom cut off to use as a funnel and one with the top cut off to use for sedimentation.
4. 1 large beaker (with a volume of 500 ml, or 2 cups) or measuring bowl that will hold the inverted two liter bottle or you can use another two liter plastic soft drink bottle with its top cut off so the other bottle will fit inside of it.
5. 1 tablespoon alum
6. 1½ cups fine sand (white play sand, beach sand or fine building sand)
7. 1½ cups coarse sand (multi-purpose sand)
8. 1 cup small pebbles (washed, natural color aquarium rocks work best)
9. 1 coffee filter
10. 1 rubber band
11. 1 tablespoon (for the alum)
12. 1 large spoon (for stirring)
13. A clock with a second hand or a stopwatch

Notes on Materials Procurement:

1. Water Samples: The water samples can be collected in plastic drink bottles or in any other suitable container. For comparison with the treated water, it will be more suitable if the container is made of a transparent material.

   The local natural water source sample to be reported to the Global Experiment Database might come from a river, lake, large pond or an estuary. The activity is not suitable for sea water. Do not try and collect the "best" water from the water source; it should be murky. It can be collected from just beneath the surface of the water source. Try to find a source that is a recognizable landmark that will be identifiable by students from other schools for comparative purposes. Collect the water sample as close to the time the class will be carrying out the activity as possible.

2. Alum, or potassium aluminum sulfate, is readily available and is inexpensive. In some countries it can be found in supermarkets, in the spice aisle. In others, it can be bought in pharmacies.

3. Although the procedure for water clarification specifies using 2 L cold drink bottles, smaller bottles will also be suitable.

4. Although white play sand or swimming pool sand will be ideal, it can easily be replaced with clean fine building sand used for plastering of walls.

5. The multipurpose sand should have a larger grain size and can be the building sand used in concrete mixtures.

6. Small aquarium rocks can be replaced with washed natural pebbles, approx.1 – 2 cm in diameter.

Materials needed for Water Disinfection

- Chlorine laundry bleach (approximately 6% sodium hypochlorite solution – see Bleach Converter Table below if your bleach is more dilute than 6%)
- About 10 chlorine test strips
- One eye/medicine dropper
- One large spoon (for stirring)
- A clock with a second hand or a stopwatch

Notes on Materials

Chlorine Test Strips: Common pool test strips that measure free available chlorine (and typically pH as well) can be used for this exercise. Students will dip the test strip into the water to be monitored and then wait 15 seconds before matching the color of the appropriate square on the test strip to the free chlorine color guide. Approximately 10 test strips will be needed.

Bleach Conversion Table (*For bleach concentrations less than 5-6%*): Household laundry bleach concentrations vary from place to place.

Your Bleach Concentration	divide your number of drops by…

5-6%	1
4%	1.5
3%	2
2%	3
1%	6

Web Resources

Water Science and Technology For Students and Educators (US Environmental Protection Agency)
Water Treatment Process (U.S. EPA)

A Public Health Giant Step: Chlorination of U.S. Drinking Water (Water Quality & Health Council)

Water Science for Schools (U.S. Geologic Survey)

Chlorine Chemistry: Essential to Health in the Developing World (American Chemistry Council)

The Secret Life of Bleach YouTube video (Google title) (American Chemistry Council)

Student Learning Outcomes

Science Process Skills

- Observing and comparing the appearance of untreated and treated water.
- Measuring free available chlorine in terms of quantitative data using colour matching methods.
- Recording of the scientific data and observations in an appropriate manner.
- Interpreting data in terms of environment and nature of the water involved.
- Asking scientific questions about water treatment and water in the environment.
- Carrying out scientific investigations by selecting and controlling variables.

Chemical Background

- Aeration as a tool in water treatment – the role of oxygen.
- Coagulation as a chemical tool to clarify water.
- Filtration as a physical tool to clarify water
- Chemical reactions that involve chlorination of water.
- The role of chlorine indicators.

Learning outcomes for Primary Classes

In primary schools the activity provides an excellent opportunity for students to use simple equipment and develop a useful skill of recording observations. No quantitative processing of data is required; should the disinfection be done as a demonstration, the teacher can assist with processing data.

The topic of water treatment is one of the important chemical ideas that is firmly embedded in students' experiences of drinking water and waterborne diseases.

It provides a good example when distinguishing between physical and chemical processes and is one of the early experiences students have with filtration.

Students can usefully learn that clear water (as in the filtrate obtained in the experiment) is not necessarily safe to drink.

Learning outcomes for Junior High School

In addition to the learning outcomes mentioned for primary schools, the role of aeration during clarification can be included. A more detailed discussion on coagulation as a chemical process and filtration as a physical process can be given.

Learning outcomes for Senior High School

The explanations can include properties of chlorine, the role of the sodium or calcium hypochlorite and the link between the experiments and industrial water treatment.

Extension Activities

Measuring turbidity (recommended for students of all ages)

Materials needed

- A flashlight.
- A flat-bottomed drinking glass.
- Samples of unfiltered water (the original untreated water), filtered water (the filtrate from the clarification) and home drinking water.

Procedure

1. Pour equal volumes of unfiltered, filtered and home drinking water into a flat-bottomed transparent drinking glass.

2. Move the glasses of water into a dark room and place them on a flat surface.

3. Place the flashlight against the side of each container and shine a beam of light through each of the samples. Look at the path of the flashlight beam.

4. How does the path of the flashlight beam through filtered water compare to that through unfiltered water? How does the filtered water compare to tap water?

5. Now pour half of the filtered water out and replace it with home drinking water. Examine the effect by shining the flashlight through the glass. How many times must you repeat this dilution before you can see no difference between the filtered water and the tap water?

Other suggestions (recommended for older students)

These activities provide students with opportunities to gain a deeper understanding of the concept of water treatment.

- Variation in free chlorine – Measurement of variation in free chlorine in swimming pool water during regular events – e.g., change in temperature, after rain etc.

- Variation in free chlorine – Monitoring of free chlorine in home drinking water over a period of time (very little variation should be measured in urban areas).

- The role of metal salts in coagulation – the role of the Al^{3+} ion.