



Teacher's Guide

Now You See it, Once Filtered, Hope You Don't: An activity on water filtration

Grade Level: Middle & high school

Subject area(s): Chemistry, Environmental Science, Biology, Physical Science

Time required: (3) 90 minute classes

Learning objectives:
Through research and inquiry: 1. Understand the complexity & importance of clean water; 2. Understand how water filtration occurs.

Summary: Water is a valuable natural resource and resides in multiple reservoirs: the cryosphere, geosphere, biosphere, and atmosphere. Water quality is often jeopardized by various contaminants but can be improved by removing contaminants from the water whether they are macro (dirt and debris,) micro (bacteria) or nano (metallic ions and small organic molecules.) Students will work in 4 groups to search the Internet for information related to water and filtration. After this pre-lab, they will compare two filter mediums (activated carbon and zeolite) to determine the efficiency of each. Students will construct and use their own filtration system.

Note: This lab requires Vernier Lab Quest in particular: Vernier Spectro Vis and Vernier Conductivity Probe. It also requires students to use the Jigsaw method to do their Internet research. ^{1, 2}

Lesson Background: As noted in the summary, water is a valuable resource with only 2.5 percent of earth's water available for human consumption. This includes agricultural, industrial, electrical production and household usage. The average American family uses more than 300 gallons of water per day at home. Roughly 70 percent of this use occurs indoors.³ US agriculture accounts for 80% of our water use with this being greater than 90% in western states.³ Water quality is often jeopardized by various contaminants. Water quality can be improved by removing contaminants from the water whether that are macro (dirt and debris,) micro (bacteria) or nano (metallic ions and small organic molecules.) in scope. Currently, several technologies that control water pollution are available: coagulation, foam flotation, filtration, ion exchange, aerobic and anaerobic treatment, solvent extraction, electrolysis, microbial reduction, and activated sludge.⁴ The USGS has an excellent website called Water Quality School that provides much information on water quality topics and US data.⁵

A physical and chemical relationship exists between water contaminants: bacteria, viruses, minerals, ions, molecules, and with the filtration material being used to remove these contaminants. Understanding particle transport and its effect on water quality is a key to evaluating the integrity of water filtration options.⁶

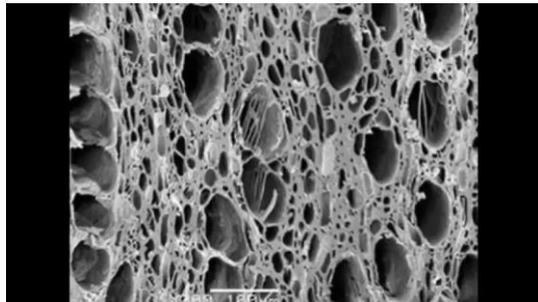


Nanotechnology has been applied to several areas of water purification and treatment including remediation, filtration, purification, and desalination. Nanomaterials and nanoparticles used in water purification and treatment include carbon nanotubes and alumina and cellulose nanofibers. In addition, some systems use nanoscopic pores such as those found in zeolite and activated carbon. These nanotechnologies are being used to filter sediments, bacteria, pathogens, charged particles, and chemical effluents (such as agricultural runoff). Nanofilters have advantages over conventional or micro-filters for several reasons: they have large surface areas (surface area to volume increases with reduced size); they are more efficient, are small in volume, and are easily cleaned.

Commercially available nanofilters include the LifeSaver® bottle which filters materials such as bacteria, viruses, and other water pathogens. The system can filter particles down to 15 nanometers. Stellenbosch University in South Africa developed a tea bag water filter that uses a biocide and activated carbon. LifeStraw has a membrane consisting of microfilters (similar to dialysis filters) that consist of 0.2 micron pores.

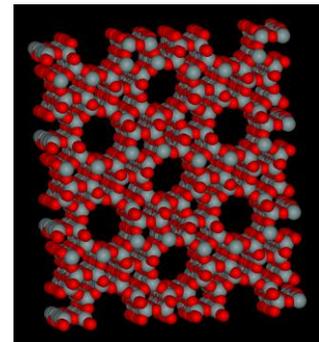
Activated carbon and zeolite, are the two materials used for this water filtration investigation. Both have outstanding properties to purify water by adsorbing contaminants; this is accomplished due to unique micropore structures with high surface areas and their subsequent adsorption properties. Adsorption is the surface-based adhesion of atoms, ions, or molecules of fluids or dissolved solids to surfaces, a Van der Waals interaction.

Activated carbon consists of numerous pores that adsorb impurities in water. How porous is activated carbon? One gram can have a surface area of approximately 3000 square meters (32,291 square feet). The quantity and distribution of the pores will determine the quality of the activated carbon. The more micropores the greater the surface area on which to adsorb the contaminants. Activated carbon has been treated to produce an extensive network of pores and an extremely high micropore surface area with a calculated range of



300 to 2000 m²/g. These pores subsequently provide adsorption sites for chemical contaminants in fluid conditions.⁷ In selecting activated carbon as a water filter, contaminant, pore, and particle size should be considered.

Zeolite is considered to be an excellent mineral for water treatment because it is non-toxic and absorbent. It is known to adsorb many heavy metals and ammonia. Zeolite is an aluminosilicate that contains water in the spaces between the aluminum and silica molecules (tetrahedra). This water moves easily in and out of the crystal. Consequently, any molecule similar in size to water or smaller can sieve through the spaces to remove molecules of a particular size. The ability to selectively sort molecules based primarily on a size exclusion process is due to a regular pore structure of molecular dimensions. Common cations are loosely connected in the zeolite



crystal structure directing potential for ion exchange.⁸ Micropore surface area is calculated to be 500 – 800 m²/g⁹.

Sources:

1. The Jigsaw Classroom. Accessed at: <https://www.jigsaw.org/>
2. The Jigsaw Method Teaching Strategy. Misty Hance published on Teach Hub.com. Accessed at: <https://www.teachhub.com/teaching-strategies/2016/10/the-jigsaw-method-teaching-strategy/>
3. Irrigation and Water Use. US Department of Agriculture: Economic Research Service. Accessed at: <https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/>
4. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment—A review Amit Bhatnagar and Mika Sillanpää. Chemical Engineering Journal 157 (2010) 277–296.
5. Water Science School. US Geological Survey. <https://www.usgs.gov/special-topic/water-science-school/science/water-quality>.
6. Madden, A.S. et.al., “Welcome to Nanoscience I nterdisciplinary Environmental Exploration. NSTA Press, 2011.
7. Activated Carbon Technologies PTY LTD “Carbon Basics” (July, 2013) <http://www.activatedcarbon.com.au/carbonbasics.htm>
8. Minerals Education Coalition “Zeolite” (July, 2013) <http://www.mineralseducationcoalition.org/minerals/zeolites>
9. Vyas, R. K., Kumar, S. & S. “Determination of micropore volume and surface area of zeolite molecular sieves by D-R and D-A equations: A comparative study.” (July, 2013) [http://nopr.niscair.res.in/bitstream/123456789/9528/1/IJCT%2011\(5\)%20704-709.pdf](http://nopr.niscair.res.in/bitstream/123456789/9528/1/IJCT%2011(5)%20704-709.pdf)

Pre-requisite Knowledge: Students should know how to use the Vernier LabQuest;

Materials: (per group of 4)

- distilled water
- distilled water wash bottles
- filtration apparatus
 - ring stand
 - 2 compression disks to stabilize LP record or other material used for disk
- 2 LP records (or stable material cut into a disk) with 7 ¼” holes drilled at equal intervals
- beakers
- (2) 100 ml beakers to carry solid materials back to their lab station
 - solid materials
 - 60 ml Zeolite (10 ml required per filtration)
 - 60 ml Activated Carbon (10 ml required per filtration)
- (9) - 50 ml beakers for solutions. 1 to collect each solution from the shared materials bench to be rinsed and reused, and the other beakers to capture the filtrate.
 - 2 sets of the Prepared Solutions for each of the filter materials test:
 - 1. Activated Carbon
 - 2. Zeolite



- contaminant solutions:
 - 10 ml of Distilled Water for the Control
 - 10 ml of 0.5 M Copper Sulfate used to get rid of algae CuSO_4
 - 10 ml of 0.5 M Iron Oxide (Fe_2O_3)
 - 10 ml of 0.5 M Calcium Nitrate $\text{Ca}(\text{NO}_3)_2$
 - 10 ml of 0.5 M Magnesium Nitrite $\text{Mg}(\text{NO}_2)_2$
 - 10 ml dilute Pesticide Solution .5 ml per L
 - 10 ml prepared *Lactobacillus acidophilus* solution
- 12 large volume pipettes
- 1 pair of scissors
- 1 permanent marker for labeling
- label tape
- Vernier Lab Quest
- Vernier Spectro Vis to be shared with the whole class
- Vernier Conductivity Probe
- 1 Petri dish prepared with nutrient agar
- bacteria incubation oven
- labeled waste receptacle: “Bacteria Waste” and “Solution Waste”
- cotton swabs or similar to transfer bacteria to petri dish

Advance Preparation:

- Prepare the 6 contaminant solutions
- Rinse and hydrate all filtration materials
- Collect filtration apparatus materials
- *Lactobacillus acidophilus* capsules can be purchased from a scientific supply company such as Ward Scientific. Make the stock solution according to package directions.
- Activated carbon and zeolite can be purchased at Aquarium pet stores or online.

Safety Information: Direct students to use the bacteria solution with care, wash hands before leaving the classroom. All waste need to be discarded in the containers marked “Bacteria Waste” or Solution.

Teaching Strategies or Troubleshooting Tips: The objective of the lab is straight forward: compare two filter materials for their ability to remove several water contaminants. However, the materials list is cumbersome. To simplify the procedure, groups of 4 will be subdivided into groups of 2. This division expedites the data collection; each pair will be responsible for either the carbon or the zeolite filter tests.

Suggested Instructional Procedure:

Time	Activity
Day 1	Pre-lab activities
90 min	Introduce students to the topic of the earths’ water reservoirs and water as



	a resource in jeopardy. Provide the jigsaw pre-lab web search expectations. See Jigsaw resources if you are not familiar with this method of learning. Each group will have 4 members. Each member will serve as an expert and be assigned the biologic, ground water chemistry, or geologic web search. The last member will serve as the lab technician. Experts find their information and review their understanding with like members from the different groups. Groups will reconvene and share their findings.
Day 2	Students complete lab
10 min	Students answer warm-up questions.
65 min	Distribute <i>Student Worksheets</i> to students. Students follow procedures.
15 min	Clean up.
Day 3	Students analyze data and present results
90 min	Create a poster or PowerPoint to present data and analysis.

Pre-Lab Jigsaw:

Scientists work in cohort of many scientific domains. The pre-lab material will focus on the includes biologic, chemical, and geologic background. Jigsaw cooperative groups conduct pre-lab web searches and are divided into biology, chemistry, and geology. Each group will share and create a poster of their pre-lab information with the class. All students should be privy to the investigation intricacies to meet the challenge of understanding and designing a working filter capable of purifying stream or simulated saltwater collections. The four groups will perform the following:

1. **The biology group** is responsible for finding specific information on pathogenic waterborne microorganisms.
2. **The chemistry group** is responsible for presenting the chemistry of water including identifying the elemental constituents of ground water, their periodic table position, and size of each elemental constituent.
3. **The geology group** is responsible finding specific geologic information on each filtration material and presenting SEM images of filtration materials to the class while explaining the filtration characteristics of each image.
4. **The technical group** is responsible for constructing the filtration apparatus reading and understanding the lab procedure, collecting and labeling all materials, and calibrating the Vernier spectrometer to prepare it for data collection.
5. **All Groups:** find and save Scanning Electron Microscope (SEM) images of zeolite and activated carbon.

Day 2 warm up questions:

1. What is the objective of the lab?
2. Review your reasoning to determine which filter material will filter which water contaminant: bacteria, pesticide, nitrate, nitrite, copper, iron, calcium, or magnesium ions.

Directions for the activity are in the Student Guide below.



Assessment:

Rubric for Jigsaw Activity			
Excellent	Very Good	Good	Fair
Recorded content correct and highlighted the important information.	Recorded content was mostly correct and mostly highlighted the important information.	Recorded content was somewhat correct and somewhat highlighted the important information.	Recorded content was not correct and did not highlight the important information.
Information shared to group was clear & concise.	Information shared to group was mostly clear & concise.	Information shared to the group was somewhat clear & concise	Information shared to group was not clear or concise.
Student worked as a team player in the group.	Student mostly worked as a team player in the group.	Student somewhat worked as a team player in the group.	Student did not work as a team player in the group.
Group presentation to class, was clear, organized and correct.	Group presentation to class was mostly clear, organized, and correct.	Group presentation to class was somewhat clear, organized, and correct.	Group presentation to class was not clear, organized, and correct.

Final Laboratory Report - Adapted from: [Sample Laboratory Report Rubrics | CRLT \(umich.edu\)](#)

Laboratory Report—10 points possible

- Introduction (2 points)
- Background (1 pt): Is context provided for the study?
- Plausible prediction (1 pt): Are explicit predictions made that follow from the question?

Results (2 points)

- Graphs, charts, tables (1 pt): Are all relevant figures included? Are figures and axes labeled appropriately? Do they only contain appropriate information? Are the tables redundant with the figures?
- Description in text (1 pt): Does the text adequately describe the results of the study?

Discussion (5 points)

- Are the results related back to the pre-lab question and predictions? (1 point)
- Is the general significance of the study discussed? (0.5 pts)
- Responses to questions in lab handout (1 point per question, 3 questions total)
- Did the discussion refer back to information learned from the Jigsaw activity? (1 pt)
- Independent thought (0.5 points): Did the student contribute ideas besides those discussed in lab?

Additional Resources:

- Nanotechnology in Water Purification. Accessed at: https://en.wikipedia.org/wiki/Nanotechnology_for_water_purification
- Nanotechnology in Water Treatment. UN Division of Sustainable Development. Accessed at: https://sustainabledevelopment.un.org/content/documents/12857Policybrief_Water.pdf
- LifeStraw. Accessed at: <https://lifestraw.com/pages/how-our-products-workirky>
- LifeStraw Filtered Dirty Water Under a Microscope. YouTube. Accessed at: <https://www.youtube.com/watch?v=l4ido-pGUfE>
- LifeSaver® bottle. Wikipedia. Accessed at: https://en.wikipedia.org/wiki/LifeSaver_bottle



- Tea Bag Filter Cleans Water with Nanotechnology. DW Made for Minds. Accessed at: <https://www.dw.com/en/teabag-filter-cleans-water-with-nanotechnology/a-6224975#:~:text=Teabag%20filter%20cleans%20water%20with%20nanotechnology%20A%20new,disposable%20filter%20can%20purify%20one%20liter%20of%20water>
- The Lifesaver Bottle Will Save Millions Of Lives : Michael Pritchard at TEDxGateway. Accessed at: <https://www.youtube.com/watch?v=CYa85fcpVjY>
- Stellenbosch University's Hope Project patents 'tea bag' water filter. Accessed at: <https://newatlas.com/tea-bag-water-filter/16373/#:~:text=Stellenbosch%20University%27s%20Hope%20Project%20has%20p,roduced%20a%20disposable,any%20significant%20impact%20on%20water-related%20health%20issues%20globally.>
- Tea Bag Water Filtering. CNBC Africa. Accessed at YouTube: <https://www.youtube.com/watch?v=NLUII4e7fxs>
- The Science behind Activated Carbon Water Filters. CB Tech. Accessed at: <https://www.carbonblocktech.com/the-science-behind-activated-carbon-water-filters/>
- Activated Carbon and Water Filter. Fred Reiff, Water Quality and Health Control. Accessed at: <https://waterandhealth.org/safe-drinking-water/activated-carbon-water-treatment/>
- How Is Zeolite Water Treatment Media Used In Water And Wastewater Treatment? Nick Nicholas, Water Online. Accessed at: <https://www.wateronline.com/doc/how-is-zeolite-water-treatment-media-used-in-water-wastewater-treatment-0001>
- Zeolite – A Superior Water Purification Material. Dennis Abraham Thazhamon, Water Conditioning and Purification International Magazine. Accessed at: <https://wcponline.com/2021/03/15/zeolite-a-superior-water-purification-material/>

Next Generation Science Standards:

Middle School

- MS-ESS3 A: Natural Resources
- MS-ESS3 C: Human Impact's on Earth Systems

Science & Engineering Practices: Analyzing and interpreting data.

High School

- HS-ESS2 C: The Roles of Water in Earth's Surface Processes
- HS-ESS3 A: Natural Resources
- HS-ESS3 C: Human Impacts on Earth Systems
- HS-PS1B: Chemical Reactions

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Student Worksheet
Now You See it, Once it's Filtered, Hope you Don't
(with Answers in Red)

Safety

Use the bacteria solution with care, wash your hands before leaving the classroom.
All waste need to be discarded in the containers marked "Bacteria Waste" or Solution.
Make sure all glassware is very clean before beginning the activity.

Introduction: Imagine hiking in the backwoods of big, beautiful Wyoming. At your midday break, you are thirsty for a cool drink of water or even a swim in the nearby lake. The water looks inviting and sparkles in the hot afternoon sun. However, unbeknownst to you, a diseased elk carcass lies submerged in the water just up shore from your position. Water quality, especially untreated water, should never be taken for granted. How is water filtration related to nanotechnology? Some systems use nanoscopic pores such as those found in zeolite and activated carbon. These nanotechnologies are being used to filter sediments, bacteria, pathogens, charged particles, and chemical effluents (such as agricultural runoff). Nanofilters have advantages over conventional or micro-filters for several reasons: they have large surface areas (surface area to volume increases with reduced size); they are more efficient, are small in volume, and are easily cleaned.

Water is a valuable resource with only 2.5 percent of earth's water available for human consumption. This includes agricultural, industrial, electrical production and household usage. Water quality is often jeopardized by various contaminants. Water quality can be improved by removing contaminants from the water whether they are macro (dirt and debris,) micro (bacteria) or nano (metallic ions and small organic molecules.) in scope. Water filtration is one way to purify drinking water. Your challenge is to investigate the filtration capabilities of two common filters: *Activated Carbon and Zeolite*. To understand the functionality of these materials as well as the common contaminants associated with fresh or well water you will conduct a pre-lab investigation to better formulate a predication of which filter is superior.

Day 1: Pre-Lab Jigsaw:

Your group will be divided into four categories. Your teacher will explain how to perform a Jigsaw activity. Each member of your group will perform Internet research on one of four assigned topics. At the end of the activity, your group will present your research results and compare and contrast them with other class groups.

Groups:

1. **The biology group** is responsible for finding specific information on pathogenic waterborne microorganisms.
2. **The chemistry group** is responsible for presenting the chemistry of water including identifying the elemental constituents of ground water, their periodic table position, and size of each elemental constituent.



3. **The geology group** is responsible finding specific geologic information on each filtration material and presenting SEM images of filtration materials to the class while explaining the filtration characteristics of each image.
4. **The technical group** is responsible for constructing the filtration apparatus reading and understanding the lab procedure, collecting and labeling all materials, and calibrating the Vernier spectrometer to prepare it for data collection.
5. **All groups:** find and save Scanning Electron Microscope (SEM) images of zeolite and activated carbon.

Day 2 Water Filtration Testing:

Question: Based on the Day 1 research and the SEM images of Activated Carbon and Zeolite, which filter material do you think will capture the most bacteria, pesticide, iron, or copper?

Make a Prediction:

Both filter materials have micro pore sizes, both have high micro surface areas, both too have adsorptive properties, the SEM images however, literature indicates that zeolite targets transition elements for ion exchange. Of the two Zeolite will be better at filtering Copper and Iron, and the Carbon will be better at filtering the bacteria and other ions.

Materials:

- distilled water (DI)
- rinse bottle with DI
- filtration apparatus
 - Ring Stand
 - 2 stabilizer washers
 - 2 LP records (or sturdy round material cut into disk) with 7 - ¼” holes drilled at equal intervals
- Beakers :
- (2) 100 ml beakers to carry solid materials back to their lab station
 - solid materials:
 - 60 ml Zeolite (10 ml required per filtration)
 - 60 ml Activated Carbon (10 ml required per filtration)
- (9) - 50 ml beakers for solutions. 1 to collect each solution from the shared materials bench to be rinsed and reused, and the other beakers to capture the filtrate.
 - 2 sets of the Prepared Solutions for each of the filter materials test:
 - 1. Activated carbon
 - 2. Zeolite
 - contaminant solutions:
 - 10 ml of Distilled Water for the Control
 - 10 ml of 0.5 M Copper Sulfate used to get rid of algae CuSO_4
 - 10 ml of 0.5 M Iron Oxide (Fe_2O_3)
 - 10 ml of 0.5 M Calcium Nitrate $\text{Ca}(\text{NO}_3)_2$
 - 10 ml of 0.5 M Magnesium Nitrite $\text{Mg}(\text{NO}_2)_2$
 - 10 ml dilute Pesticide Solution .5 ml per L
 - 10 ml prepared *Lactobacillus acidophilus* solution



- 14 large volume pipettes
- 1 pair of scissors
- 1 permanent marker for labeling
- Label tape
- Petri dish with nutrient agar
- Cotton swabs or similar to transfer bacteria to petri dish



Completed filtration apparatus

Procedure:

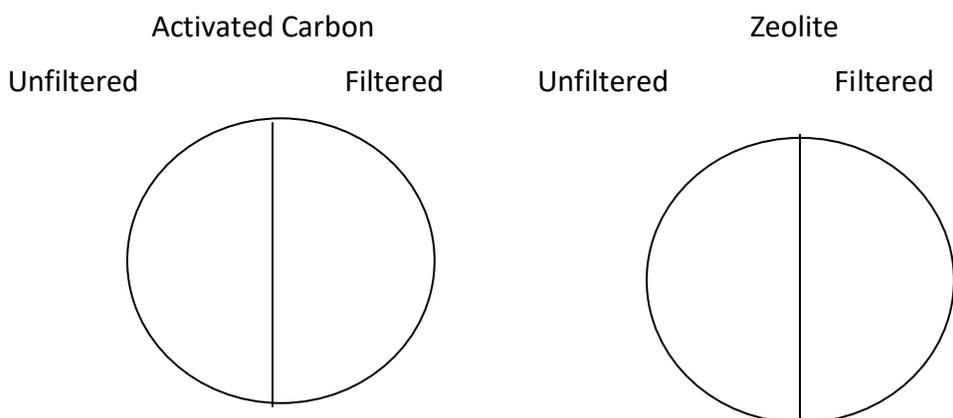
1. Collect all materials and inspect them for cleanliness, wash if necessary.
2. Using scissors, cut off the top nob portions of 14 large pipettes and discard the cut portion.
3. Construct the filtration apparatus as pictured above.
4. Label and fill 7 pipette columns with rinsed activated carbon. Set in apparatus each of the 7 filter material and solution type:
 - 10 ml of Distilled Water for the Control
 - 10 ml of 0.5 CuSO_4
 - 10 ml of 0.5 M Fe_2O_3
 - 10 ml of 0.5 M $\text{Ca}(\text{NO}_3)_2$
 - 10 ml of 0.5 $\text{Mg}(\text{NO}_2)_2$
 - 10 ml dilute Pesticide Solution .5 ml per L
 - 10mL prepared *Lactobacillus acidophilus* solution
5. Label and fill 7 pipette columns with rinsed zeolite. Set in apparatus each of the 7 filter material and solution type:
 - 10 ml of Distilled Water for the Control
 - 10 ml of 0.5 CuSO_4
 - 10 ml of 0.5 M Fe_2O_3
 - 10 ml of 0.5 M $\text{Ca}(\text{NO}_3)_2$
 - 10 ml of 0.5 $\text{Mg}(\text{NO}_2)_2$



- 10 ml dilute Pesticide Solution .5 ml per L
 - 10mL prepared *Lactobacillus acidophilus* solution
6. Use the filtrate from the bacterial solution to inoculate your petri dish. Place in incubation oven set at 37° and leave overnight. Incubate 12 to 36 hours.
 7. Review the data table to organize your thoughts and expectations and to determine your data collection and analysis. You have available the Vernier LabQuest Spectro Vis and Conductivity Probe. How will you use these to collect data? Think back to the Jigsaw activity to help guide your data collection. Record the data in the table below.

Record Your Observations:

48 Hour Bacteria Inspection



Absorption Spectra	Control No Action Required	Activated Carbon	Zeolite
Control			
Fe			
Cu			
Pesticide			
Nitrate			
Nitrite			
Hardness			

Analyze the Results:

You will write a final lab report incorporating your results. Examine your data in the table above and determine which of the two materials worked best to remove the contaminants. Did one work better with certain pollutants? You should relate these results to particle size of the pollutant. Connect the results to what you learned in the Jigsaw activity. Include in your analysis answers to the following:



1. What is the compelling evidence that either filter will or will not filter bacteria from the water. *Bacterial presence or absence, as compared to the control after inoculation and incubation with the filtrate from each medium, carbon and zeolite, would show the effectiveness of each filter. If the bacteria grows on the filtered portion of the agar plate, the filter did not capture the bacteria, if no bacteria grow this is indication that the filter was successful in capturing the bacteria.*
2. Why are the controls so important? *The bacteria control is important because it confirms that bacteria are present and viable. The controls for the elemental solutions do two things, they are needed to calibrate the spectrometer and are used to assess if there is a change in concentration of the element being tested. A decrease in the element concentration would imply the filter is effective. No change would mean the filter is not effective.*
3. What factors affect the filtration success of the two materials, activated carbon and zeolite ? *Three physical and chemical conditions determine the effectiveness of each filter. The micro pore structures size coupled with high surface areas and its subsequent adsorption properties are the filter dynamics, but the size relationship between the pore sizes of the material and the size of the contaminant also determine the results.*
4. Would you expect nanoparticles of zeolite and activated carbon to be more or less efficient? Explain your answer. *They would both be more efficient because they would have a greater surface area for the pollutants to react with. With decreased size of a material there is an increase in the surface area to volume ratio.*
5. What other pollutants would you want to include in the testing and why? *Answers will vary but may include lead, plastic particles, silver....*

