ACTIVITY 9

Water Quality Design Challenge

LABORATORY

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ACTIVITY SUMMARY

Students work together to design and build a simple water-filtration device. They test their filtered water for turbidity, pH, and simulated contaminants (red food dye). They collaborate with other groups to share results and improve their designs. The process illustrates unit concepts such as iteration, collaboration, and science as a human endeavor.

ACTIVITY TYPE
LABORATORY

NUMBER OF 40–50 MINUTE CLASS PERIODS
3

KEY CONCEPTS & PROCESS SKILLS

1. The development of scientific knowledge is iterative; it occurs through the continual re-evaluation and revision of ideas that are informed by new evidence, improved methods of data collection and experimentation, collaboration with others, and trial and error.
2. Through science, humans seek to improve their understanding and explanations of the natural world. Individuals and teams from many nations and cultures have contributed to the field of science.
3. Scientific optimism enables scientists to solve difficult problems over long periods of time.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations). *(Science and Engineering Practice: Engaging in Argument from Evidence)*

CONCEPTUAL TOOLS

Science as a Human Endeavour

Scientific Advancement

Scientific Optimism

VOCABULARY DEVELOPMENT

desalination
removal of salt from saltwater

MATERIALS & ADVANCE PREPARATION

FOR THE CLASS

- 1 GALLON (3.8 L) CONTAMINATED WATER SAMPLE, COMPOSED OF:
  - 2 cups (470 mL) distilled vinegar
  - ½ cup (110 mL) top soil
  - 6–8 drops red food coloring
  - approximately 3.22 L tap water (fill to achieve final volume of 3.8 L)
- 8 CUPS (2 L) ACTIVATED CHARCOAL (or carbon)
- 2 CUPS (470 mL) BAKING SODA
- 4 CUPS (1 L) COARSE SAND
- 8 CUPS (2 L) FINE SAND
- 4 CUPS (1 L) GRAVEL
- CUPS (OR LARGE SPOONS) TO SCOOP MATERIAL
- SCISSORS
- PAPER TOWELS

FOR EACH GROUP OF FOUR STUDENTS

- 1–2 500 mL PLASTIC WATER BOTTLES, CUT IN HALF
- 4 PIECES OF CHEESE CLOTH, 3 inches x 3 inches
- 1–2 RUBBER BANDS
- 400 mL CONTAMINATED WATER SAMPLE
- BEAKER OF 100 mL CLEAR TAP WATER (control)
- EMPTY 200 mL BEAKER*
- TURBIDITY RATING MODEL CARD
- CONTAMINANT LEVEL RATING CARD
- pH PAPER
- RULER (cm)

FOR EACH STUDENT

- SAFETY GOGGLES
- LAB COAT
- STUDENT SHEET 9.1 "Filtration Design Challenge"

*The size and type of container can vary as long as each group has the same size container with a clear bottom (e.g., a clear plastic cup).

The contaminated water sample should be made ahead of class by combining vinegar, food coloring, top soil, and enough tap water to fill up to the final volume. The plastic bottles for each group can also be prepared in advance by using the scissors to cut each 500 mL bottle in half. The lower part of the bottle should be able to hold approximately 150 mL of liquid. If you have a limited supply of plastic bottles, students can use 1 bottle per group and rinse bottle pieces between iterations.

An estimated amount of the materials needed for one class containing eight groups of four students is listed in the Materials list. They are based on the materials students are likely to use the most. Each student group can be given ⅛ of these amounts in small containers in advance, or each group can independently get materials from a common bin, using scoops.

TEACHER'S NOTE: After materials have been used to filter the water sample, they mix together and cannot be separated for reuse.

Results can vary for this lab, based on materials. For best results or if you have limited access to materials, be sure to test with your materials beforehand and see the following Teacher's Note for general guidelines.

Instructions for rating the turbidity and contaminant level (amount of dye) using the measurement cards are located in Step 3 of the Student Book, but should be reviewed in advance. The measurement cards can be used multiple times if laminated or placed in sheet protectors.

Teacher's Note: About Laboratory Materials

Due to variation in materials, the following guidelines are intended to support the success of the activity.

- The smaller the particle size of the material (sand, charcoal, or baking soda), the slower the filtration will take place, and the better it will be at decreasing the turbidity (reducing cloudiness).
- The smaller the particle size of the activated charcoal/carbon (more surface area), the better it works for removing the contaminant (colored dye). However, extremely fine particles of charcoal in a very thick layer may slow down the speed of filtration significantly. In contrast, larger chunks of charcoal only work if there is a thicker layer and the filtration speed is slower, so the sample does not flow through too quickly to react with the charcoal. A balance between charcoal particle size, layer thickness, and speed of filtration is needed.
- Many of the filter materials can be purchased at an aquarium store, including the activated charcoal. Alternatively, finer charcoal can be purchased online from many science education retailers, or you can grind larger chunks of charcoal into smaller-size particles by using a mortar and pestle.
- Rinse the charcoal with water before giving it to students to reduce black impurities from getting into the filtered water. Likewise, it is important to use clean aquarium gravel and play sand (instead of yard gravel or beach sand because these may add pollutants into the water).
- Baking soda affects the pH, but very little is needed. Too much baking soda will slow down the speed of filtration and cause the pH to become too basic.

- Generally, a few centimeters of fine sand, a little baking soda (less than 0.5 cm), and a couple of centimeters of charcoal with particles that are a similar size to the sand works well. If the charcoal is finer, use less of it and more sand.

SAFETY NOTE

This activity models some aspects of the process of purifying drinking water. The water-filtration devices will remove some impurities but will NOT make the water safe to drink.

TEACHING NOTES

Suggestions for **discussion questions** are highlighted in gold.

Strategies for the **equitable inclusion** are highlighted in blue.

GETTING STARTED (10 MIN)

1 **Use the Student Book introduction to highlight the role of trial and error in science.**

- Read the introduction to Activity 9 in the Student Book, either as a class or individually. Connect to students' prior knowledge and ideas about global water accessibility. Remind them of how the Skipton scenario raised the issue of clean water quality accessibility and how cheaper solutions to improve water quality are still needed in many parts of the world.
- After the reading, discuss the following question. Ask, Why do you think it took 10 years to fully develop this desalination unit? Student responses may include ideas such as finding materials that could work successfully but were not expensive could have been a challenge.
- Introduce the concept of trial and error and emphasize to students that trial and error relies on small, step-by step changes, which can be random if no better information is available.

PROCEDURE SUPPORT (40 MIN)

2 **Review classroom safety expectations**

- Remind students to wear lab coats and goggles and to follow all classroom safety rules.
- Point out that while they will be filtering a water sample, the final product will still NOT be safe to drink.

3 **Present the scenario of Skipton found in Procedure Part A.**

- Explain to students that they will be designing a filter device in an attempt to improve three factors of water quality: turbidity, pH, and contaminant level. Red food-coloring dye will be used to simulate contaminants in the water that must be removed.

- In their designs, students must leave 5 cm (2 inches) of empty space at the top of their devices when building them.

  NOTE: This limit is so there is enough room in the upper part of the bottle so the water sample will not overflow.

- If needed:
  - Review the basic setup for the water-bottle device and how to apply the rubber band and cheesecloth around the mouth (as shown in the Student Book).
  - Review the terms turbidity and pH. Remind students that water has an approximate pH of 7 and safe drinking water levels are between 6.5–9.
  - Demonstrate how to rate the turbidity and contaminant level by using the provided Turbidity Rating Model card and the Contaminant Level Rating card, as described in Step 3 in the Student Book.
  - Remind students how to measure the pH by using the pH paper.

- To reduce the use of materials, consider having students work in groups of four. Since this is an inquiry-based lab, you may want to use heterogeneous groups to help support the needs of all learners and encourage all students to participate. Group roles can be divided based on the three different water quality factors, with a different student responsible for testing and improving pH/turbidity/contaminant level, and a fourth student having the role of project manager (including being responsible for getting materials and helping the group to share results and reach consensus).

- Hand out Student Sheet 9.1, "Filtration Design Challenge."

4 Have students do initial tests of the three measures of water quality.

- Students test the initial pH, turbidity, and contaminant level of the sample water by pouring 100 mL of the water sample into the empty beaker.

- To measure turbidity and contaminant level, students need good lighting and to be able to look straight down through the sample.

- If needed, remind students:
  - to stir the sample in the testing beaker right before they measure turbidity.
  - to compare their results to that of the clear tap water.
  - that they can only use, at most, two materials for this first iteration.

5 Have students build their first design iteration and test for the three measures of water quality.

- Student groups work together to select, gather, and construct their water-filtration devices. Support students as needed and provide directions for how you would like them to gather the materials for their groups.

- You may wish to ensure that groups are not all using the same materials for their first designs. This can be accomplished by assigning or encouraging groups to use different materials during their first iterations.

- Remind students to fully rinse out their testing beakers before using them to test their filtered water sample.

- Students should compare their turbidity and contaminant level results to the clear tap water (control). Responses will vary depending on the materials chosen. For instance, if fine sand is chosen, the results will be less turbid (cloudy) and closer to the clear tap water in appearance.

- Students can save the filtered sample from each iteration by using plastic cups. This allows students to compare the saved samples at the end of their experimentations.

- Direct students about how you would like them to dispose of their filtration materials prior to the next iteration.

6 **In Procedure Part B, student groups collaborate with one another.**

- Students can first visit other groups who used the same materials to compare their results.
- Students can then visit groups who used different materials, so they can gather new information.

7 **In Procedure Part C, have students build their second iterations, retest water quality, and compare results before proposing a third iteration.**

- Inform students that they can now use up to three materials for this second design.

- Remind them to fully rinse out their testing beakers before using them to test their filtered water samples.

- Direct students on how you would like them to dispose of their filtration materials.

- Students should compare their turbidity and contaminant level results to the clear tap water (control). If students saved a sample of filtered water from the first iteration, they can also compare their samples.

- Student groups should collaborate with other groups and share results.

SYNTHESIS OF IDEAS (10 MIN)

8 **Facilitate a class discussion about which design materials worked best and how collaboration between groups affected the outcome.**

- Ask, What is an advantage of using iteration to solve problems or search for answers to scientific questions? How do you think iteration is different from trial and error? Ideas to emphasize include:
  - Iteration can speed up the design and discovery process.
  - A simple trial-and-error process is random, while an iterative process relies on analyzing your results based on the finding of each cycle.
- Ask individuals to summarize which materials worked best. Ask, What is the optimal design of the water-bottle filter, based on the combined results of all the groups? (Materials, layers, thicknesses, order of the layers, etc.) Generally, the best design will include a very small amount of baking soda to adjust the pH, just enough activated charcoal to remove the red dye without greatly slowing down the filtration process, and fine sand on the bottom to prevent very small particles of other materials from going through the cheesecloth.
- You may want to ask students to come up with ideas for improvements or what iterations they would like to test next to make an even better filter.
- Ask, How did collaboration affect your ability to iterate? How would the design process been affected if you had all been working in separate rooms and could not have shared results? Ideas to emphasize include that:
  - Collaboration can speed up the design and discovery process.
  - It can be more difficult to catch mistakes and confirm that your results are relevant, reliable, and accurate.
- You can use Build Understanding item 3 to formatively assess a student's thinking about the strengths and limits of gathering data from scientific technology alone.

EXTENSION (10-30 MIN)

9 **Use the Extension as an opportunity for advanced learning.**

Students can discover the roles of iteration, collaboration, and scientific advancement in the development of the Internet by doing online research. Student research can be facilitated by providing specific website links, such as:

https://www.scienceandmediamuseum.org.uk/objects-and-stories/short-history-internet

https://www.internetsociety.org/internet/history-internet/brief-history-internet/

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **During this design challenge, you collaborated with other teams to share your findings. Imagine your group had been working alone and was not able to receive feedback or share results with other groups. Explain how this would have affected:**

   - **the iteration process.**
   - **your success at finding materials that improved water quality.**

   Without collaboration, the process of iteration would have been a lot slower. It would have taken us a lot longer to find out which materials worked better for the different measures of water quality because we would have needed to test all of them ourselves. Collaboration also allowed us to compare and confirm our results with other groups so we could be more sure of our conclusions/design ideas.

2. **Water treatment involves the use of chemical additives as well as filtration. Which process(es) do you think would have been more useful in addressing Skipton's water quality issues in Activity 1? Explain your reasoning.**

   Residents observed a change in turbidity, which could have been addressed by improved filtration to remove particles from the water. Evidence also suggested that the cause of illness might have been Cryptosporidium in the tap water, which probably would be killed by chemicals such as chlorine.

3. **What are the advantages and disadvantages of using iteration to develop scientific knowledge?**

   Advantages of iteration are that an idea can be tested multiple times. This increases both accuracy and reliability. Iteration can build on prior scientific findings and support collaboration with others. Disadvantages of iteration are that it takes more time to continually retest ideas and more resources.

CONNECTIONS TO EVERYDAY LIFE

4. **You follow a cookie recipe and end up with bland, burnt cookies. Describe how you could use iteration to perfect the recipe.**

   I would increase the amount of sugar to make the cookies less bland. I would also lower the baking temperature to try to prevent them from getting burnt. After seeing what happened, I could continue to make adjustments such as further lowering the baking temperature or adding chocolate chips if the cookies were still too bland.

5. **A friend of yours is developing a new video game. Describe ways in which she could use iteration and collaboration to improve the graphic design, user experience, and storyline of the video game.**

   She can try the game or recruit her friends to try her first version to evaluate how good the graphics, story, and experience are for players. Based on feedback, she could try to update those features and ask her friends to review it again. She could continue this process until the game has no more suggested improvements.

REFERENCES

Myers, L. (2022, April 29). MIT researchers build portable desalination unit that generates clean water at the push of a button. Designboom. Milan, Italy. Retrieved from https://www.designboom.com/technology/mit-researchers-portable-desalination-unit-generates-clean-water-04-29-2022/

National Aeronautics and Space Administration (NASA) Education, Jet Propulsion Laboratory, California Institute of Technology. Water filtration challenge. Retrieved from https://www.jpl.nasa.gov/edu/teach/activity/water-filtration-challenge/

TABLE 9.1
DESIGN FOR WATER-FILTRATION DEVICE

MATERIAL AND THICKNESS (IN cm)	FIRST ITERATION (INITIAL)	SECOND ITERATION (REVISED)	THIRD ITERATION (PROPOSED)
Material 1 (top layer)			
Material 2 (bottom/middle layer)			
Material 3 (bottom layer)	*none*		

TABLE 9.2
RESULTS FROM WATER QUALITY TESTING

	TURBIDITY RATING (0–5)	CONTAMINANT LEVEL RATING (0–5)	pH (1–14)	ADDITIONAL NOTES OR OBSERVATIONS
Water sample *before* filtration				
Water sample *after* Iteration 1 (2 layers)				
Water sample *after* Iteration 2 (3 layers)				

 SAMPLE STUDENT RESPONSE

TABLE 9.1
DESIGN FOR WATER-FILTRATION DEVICE

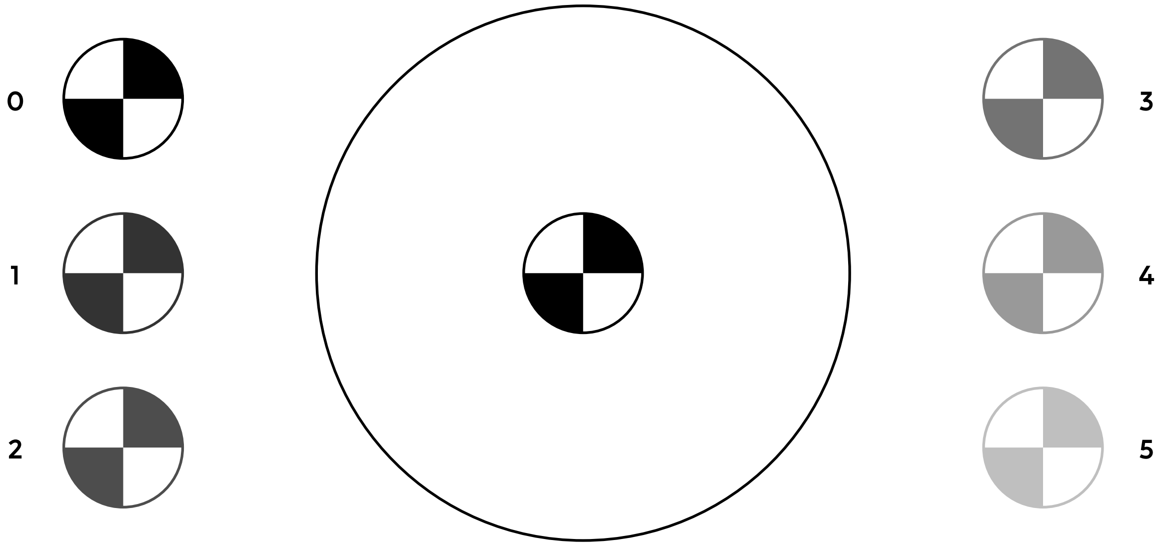
MATERIAL AND THICKNESS (IN cm)	FIRST ITERATION (INITIAL)	SECOND ITERATION (REVISED)	THIRD ITERATION (PROPOSED)
Material 1 (top layer)	*fine sand, 3 cm*	*charcoal, 2 cm*	*charcoal, 1 cm*
Material 2 (bottom/middle layer)	*baking soda, 1 cm*	*baking soda, 0.5 cm*	*baking soda, 0.2 cm*
Material 3 (bottom layer)	*none*	*fine sand, 3 cm*	*fine sand, 4 cm*

TABLE 9.2
RESULTS FROM WATER QUALITY TESTING

	TURBIDITY RATING (0–5)	CONTAMINANT LEVEL RATING (0–5)	pH (1–14)	ADDITIONAL NOTES OR OBSERVATIONS
Water sample *before* filtration	*4*	*3*	*3*	*The color measurement was hard to make because of the high turbidity of the sample.*
Water sample *after* Iteration 1 (2 layers)	*0*	*2.5*	*9*	*The cloudiness was gone. It took a long time. The pH is way too high now.*
Water sample *after* Iteration 2 (3 layers)	*0*	*0.5*	*8*	*The red color disappeared, but a tiny amount of black charcoal went through. The pH was closer to neutral.*

Turbidity Rating Model Card

PLACE YOUR WATER SAMPLE BELOW



Contaminant Level Rating Card

PLACE YOUR WATER SAMPLE BELOW