UNIT 1

v 1.0

Student Book

EVIDENCE & ITERATION IN SCIENCE

SCIENTIFIC THINKING FOR ALL : A TOOLKIT

This book is part of the *Scientific Thinking for All: A Toolkit* curriculum that is a high school adaptation of the University of California, Berkeley, "Big Ideas" course titled Sense and Sensibility and Science https://sensesensibilityscience.berkeley.edu/. It was developed by professors Saul Perlmutter, John Campbell, and Robert MacCoun and represents a collaboration among physics, philosophy, and psychology. *Scientific Thinking for All: A Toolkit* was developed by curriculum developers and researchers at the Lawrence Hall of Science, University of California. The initiative is a cooperation between Nobel Prize Outreach (NPO) and Saul Perlmutter. This work is supported by a consortium of funders including Kenneth C. Griffin, the William and Flora Hewlett Foundation, the John D. and Catherine T. MacArthur Foundation, the Gordon and Betty Moore Foundation, and The Rockefeller Foundation.

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UNIT 1
Evidence & Iteration
V1.0 MAY 2023

STUDENT BOOK

THE LAWRENCE HALL OF SCIENCE
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DEAR STUDENT,

Have you ever read a news article and wondered if the information it contained was true? Or had a friend make a claim and wondered if they were right? This curriculum will equip you with ideas and techniques from science that can be applied to everyday life. Your conceptual toolkit will include strategies to help you evaluate information, reflect on your thinking, and make more informed decisions. You will use these tools to ask questions, brainstorm ideas, interpret data, manage trade-offs, and develop solutions.

Scientific tools and techniques can lead to a better understanding of how the natural world works and provide approaches to solving the problems facing individuals, communities, and the environment. Each unit will provide you with additional conceptual tools for your toolkit, and you'll practice applying them to personal and societal issues such as human health, environmental pollution, and energy use. For example, you may consider questions such as: *How much sleep do I need? Is my community's drinking water safe?*

Science offers many useful strategies for learning about the world, including:

1. working together to share observations, questions, and ideas;
2. techniques for making sense of observations and data; and
3. the iteration of ideas by modifying them as new information becomes available

Since it's difficult for anyone to catch their own mistakes, you'll collaborate with your classmates to share your thinking and learn from one another. It is our hope that this science toolkit will empower you to think more clearly about the things you care about, to provide you with strategies for addressing problems, and to help you achieve your personal goals.

Sincerely,
Scientific Thinking for All Program Team

TABLE OF CONTENTS


Evidence & Iteration

UNIT 1

EVIDENCE & ITERATION IN SCIENCE

In this unit, you will explore the nature of scientific evidence as you examine issues related to water quality and water availability. You will learn how advances in scientific tools and technology have enhanced human observations and provided new and more accurate data. Timelines from the history of science will allow you to investigate how multiple lines of evidence have been used to develop scientific knowledge over time. You will study how individuals and teams of people are working together to contribute to an ever-increasing body of scientific knowledge. You can consider the role of science in improving human understanding of the world in which you live and how this can help you make more informed decisions to achieve your goals.

UNIT DRIVING QUESTION

How do people use evidence and iteration of ideas to construct scientific explanations that are relevant to everyday issues, such as water quality?

CONCEPTUAL TOOLS

In this course, conceptual tools refer to scientific ideas and approaches that can be applied to real world situations. Each conceptual tool is further explained in the activity in which it is introduced. The conceptual tools found in this unit are shown here and in each activity in which they appear.

Multiple Lines of Evidence

Shared External Reality

Senses and Instrumentation

Scientific Advancement

Science as a Human Endeavor

Scientific Optimism

Credible Sources

ACTIVITY 1

Skipton's Water

CARD-BASED INVESTIGATION

1 : SKIPTON'S WATER

GUIDING QUESTION

What role can evidence play in decision-making?

INTRODUCTION

Some 1.1 billion people worldwide lack reliable access to freshwater, while a total of 2.7 billion people have very limited access to freshwater for at least 1 month of the year. Some areas of the world have large reservoirs of freshwater, such as Lake Kariba in Zambia and Zimbabwe, the Bratsk Reservoir in Russia, and the Great Lakes in the United States and Canada. Other areas, such as Brazil, receive high levels of freshwater in the form of rain or snow. Parts of the world that have large populations but limited freshwater resources often face severe water shortages. Even within countries with lots of freshwater resources, safe drinking water may not be readily available to all residents. In this activity, you will make a decision about drinking water.

Lake Michigan, one of the Great Lakes, is a source of drinking water for more than 40 million people in the United States and Canada.

CONCEPTUAL TOOLS

PROCEDURE

PART A: EVALUATING EVIDENCE

1 Read the following scenario. See Figure 1.1 for a map of the Skipton area.

Skipton is a medium-sized town near the Mizu River. For many years, Skipton has piped in freshwater for residential use from the larger city of Aquaville. Aquaville is near Lake Timtim, a huge freshwater lake from which Aquaville sources its water. Piping water from Aquaville to Skipton costs the town of Skipton money, and it is money that the town no longer has. Skipton is in debt and working on developing its own water supply directly from Lake Timtim to save money. This process will take a couple of years.

In the meantime, some members of the town have proposed a short-term solution: using water from the Mizu River. Although this will save the town $3 million over 2 years, the river's flow is not large enough to provide a reliable long-term solution. The main source of the river is snow melt from the Clarity Mountains about 100 miles upstream. The water is clear and has no odor. The results of pH tests—which determine if the water is too acidic or basic for residential use—show that the water falls within the recommended range of 6.5–9. It has been routinely tested for microbial contaminants, and bacteria levels are low (within a normal range). The plan is to treat the water with chlorine, which kills most bacteria and viruses, before piping it into homes.

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- SET OF 16 DATA CARDS

FOR EACH STUDENT

- STUDENT SHEET 1.1 "Plan for Skipton's Water"
- STUDENT SHEET 1.2 "Evaluating Data"

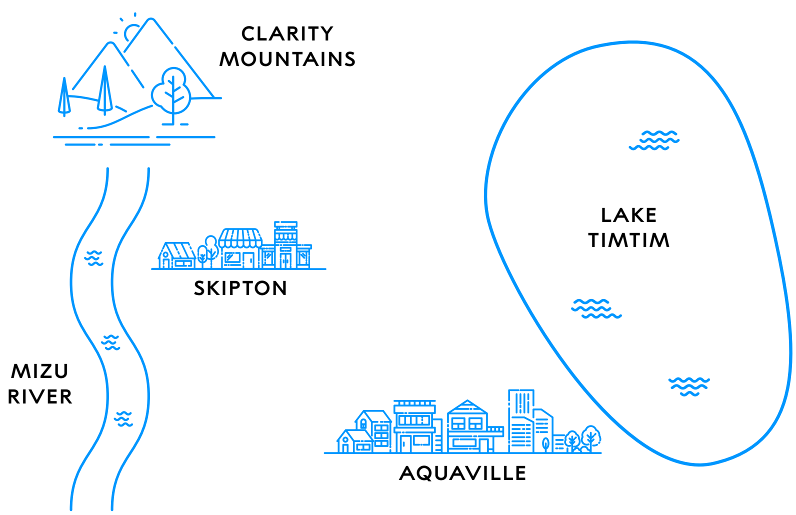


FIGURE 1.1
Map of Skipton Area

PART A: EVALUATING EVIDENCE (CONTINUED)

2 With your group, discuss whether Skipton should use water from the Mizu River for residential use for a period of 2 years.

3 On Student Sheet 1.1, "Plan for Skipton's Water," record:
- your initial decision about the proposal.
- evidence that supports your decision.
- any questions you have.

4 Your group will receive a set of Data cards 1–8. Work together to read aloud the information on each card.

5 As a group, discuss and sort each of the cards based on whether or not it is relevant to using water from the Mizu River.

Remember to listen to and consider the ideas of other members of your group. If you disagree with others in your group, explain why you disagree.

6 On Student Sheet 1.2, "Evaluating Data," record:
- whether the data is relevant to the decision.
- whether it provides evidence that supports or refutes the use of the Mizu River.

7 Based on this new data, record on Student Sheet 1.1 your updated recommendation (even if it remains the same), additional evidence that supports your decision, and any new questions you have.

8 Your group will receive a second set of Data cards 9–16. Work together to:
- read aloud the information on each card.
- discuss and sort each of the cards based on whether or not it is relevant to using water from the Mizu River.

9 Complete Student Sheet 1.2 by recording whether the data is relevant to the decision, and whether it supports or refutes the use of the Mizu River.

10 Based on this new data, record on Student Sheet 1.1 your updated recommendation (even if it remains the same), additional evidence that supports your decision, and any new questions you have.

11 Work with your group to:
- describe other future events that might cause you to change your decision about Skipton's drinking water supply.
- brainstorm additional information you would like to have to help you in your decision-making.

Record your ideas in your science notebook.

12 Share your decision(s) about Skipton's water supply and the evidence supporting your decision(s) with your class.

BUILD UNDERSTANDING

1. How did Skipton's residents' observations of the water compare with the results of water quality tests?

2. In Skipton, many of the water quality tests, such as pH, did not indicate any change in water quality over time. Scientific explanations depend on relevant, accurate, and reliable data.

   - Data is relevant if it is closely connected to or related to the idea or question being considered. For example, your body temperature and how you feel are both relevant to whether you are well. The price of a thermometer is not relevant to your health.

   - Data is considered reliable if it can be reproduced consistently. For example, if you take your temperature at three different times and each time it is 100°F, your temperature data is reliable.

   - Accuracy is the closeness of a measured value to a standard or true value. For example, your parent feels your forehead and says you have a fever. When you take your temperature with a thermometer, it shows a reading of 101°F. Based on data from both human senses and a scientific tool, your temperature data is accurate.

   Were the Skipton water quality test results reliable, accurate, both, or neither? Explain your reasoning.

3. You found out more about the town of Skipton's decision from the Data cards. Did you agree with the town's decision about water from the Mizu River? Support your answer with at least three pieces of evidence from this activity and identify the trade-offs of your decision.

   Evidence is information that helps support or refute a claim or leads to the development of a new claim. A trade-off is an exchange of one valued outcome for another by giving up something that is a benefit or advantage in exchange for another benefit that may be more desirable.

The Build Understanding and Connections to Everyday Life questions are intended to guide your understanding. Some of these questions may be discussed with a partner, be part of a class discussion, or require an individual written response. Your teacher will guide you as to how these questions will be used in your class.

CONNECTIONS TO EVERYDAY LIFE

4. In this activity, the Skipton scenario provided an opportunity to conduct a thought experiment by testing ideas about drinking water without doing additional experiments or your own research. This is a common approach used in many fields of study prior to doing real-world work. What are some situations in your daily life where it might be useful for you to conduct thought experiments?

5. In this activity, you began to investigate the role of multiple lines of evidence in supporting or refuting an idea. Consider what role evidence plays in your own decision-making. Imagine that your friend just told you that caffeinated energy drinks are great for breakfast because they help kids focus. On days when she stays up late and doesn't have an energy drink for breakfast, she sometimes falls asleep in class. Did she provide enough evidence for you to choose having an energy drink for breakfast? Explain why or why not.

EXTENSION

In what ways is the scenario of Skipton similar to or different from your community? In the United States, surface water supplies over 60% of public water systems. Surface water is the water from rain and snow that sometimes accumulates in rivers, lakes, and snowpack (see Figure 1.2). Groundwater, which also comes from rain and snow, accumulates underground and supplies over 30% of public water. Consider the most common source of water in your area and what, if any, are the issues related to water in your community.

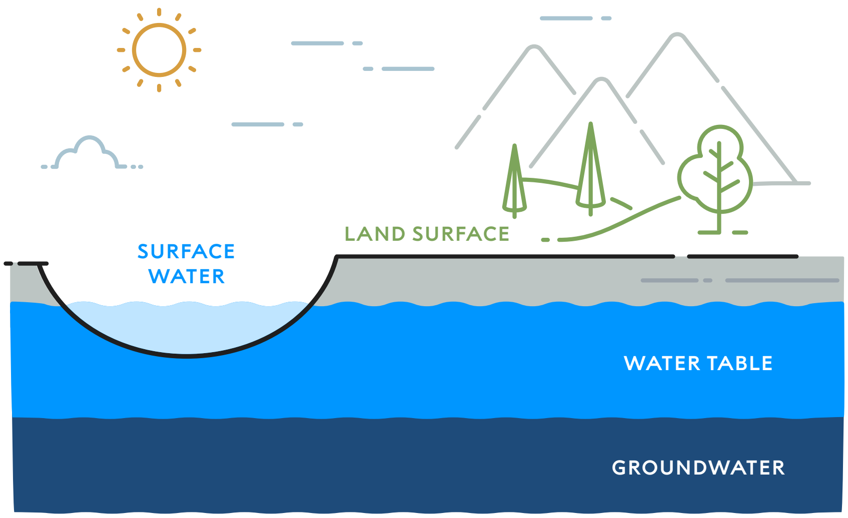


FIGURE 1.2
Water Sources

KEY SCIENTIFIC TERMS

accuracy
evidence
multiple lines of evidence
relevant
reliable
trade-off

ACTIVITY 2

Validating Measurements

LABORATORY

In many countries, tap water is clean and drinkable without further filtering.

2 : VALIDATING MEASUREMENTS

GUIDING QUESTION

How do people collect information about the physical world?

INTRODUCTION

The safety of drinking water is determined by many factors, including biological, chemical, and radiological. Most countries today regulate and routinely test drinking water for multiple water quality indicators, including turbidity and pH. Humans can tolerate water in a range of pH levels, with pH levels from 4–11 considered drinkable with minimal health effects. However, pH levels outside of 6.5–9 affect the solubility and toxicity of chemicals such as heavy metals in drinking water.

In the last activity, some of Skipton's residents observed a change in the turbidity of their water. Turbidity is a measure of how clear the water is and indicates the presence of suspended particles, such as soil or algae. People in Skipton made visual observations of the water with their senses and then collected scientific measurements of the drinking water. In this way, people used their senses to make a judgment that could be validated by scientific tools and techniques. Validation is a process of determining the accuracy of a measurement. For example, you smell smoke. You then hear the sound of a smoke alarm, a tool that validates the observation of your senses. In this activity, you will use your senses to evaluate a water sample and then use additional techniques to validate pH measurements of different liquids.

> If you need to review the concept of pH, you will find a Scientific Review at the end of this activity.

CONCEPTUAL TOOLS

SENSES & INSTRUMENTATION

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- 100 mL BEAKER OF RED-CABBAGE JUICE
- DROPPER BOTTLE OF AMMONIA
- DROPPER BOTTLE OF DISTILLED WATER
- DROPPER BOTTLE OF VINEGAR
- CUP OF DRINKING WATER SAMPLE
- pH PAPER WITH pH SCALE
- pH METER WITH PROBE
- CUP OF WATER
- EMPTY CUP
- PAPER TOWEL

FOR EACH PAIR OF STUDENTS

- 5 BEAKERS LABELED A–E
- 10 mL GRADUATED CYLINDER
- SHEET OF WHITE PAPER
- DROPPER
- STIR STICK

FOR EACH STUDENT

- SAFETY GOGGLES
- LAB COAT

SAFETY NOTE

You will be making observations of household chemicals with your senses. You should make observations using only sight and smell. Do not eat or drink any chemicals.

PROCEDURE

PART A: USING YOUR SENSES

1 You will be investigating 4 liquids: distilled water, drinking water, ammonia, and vinegar. Copy the following table into your science notebook.

TABLE 2.1
OBSERVATIONS

LIQUID	APPEARANCE	ODOR	PREDICTED pH
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			

2 Use your graduated cylinder to add 10 mL of each liquid into 4 beakers (labeled A–D). Then:

NOTE: Be sure to rinse the graduated cylinder with water before using it to measure the next liquid.

a make observations of the appearance of each sample and record your results in Table 2.1.

b smell each sample by wafting—gently waving your hand across the liquid to push the odor toward your nose—and record your results in Table 2.1.

3 Make a prediction of the pH of each liquid.

a Use the observations made with your senses to predict the pH of each liquid. (You may want to first consider whether the liquid is an acid, a base, or neutral.)

b Based on your prior knowledge and your senses, discuss with your group how accurately you can predict the pH of each liquid.

PART B: DETERMINING pH WITH RED-CABBAGE JUICE

4 Red-cabbage juice can be used to test pH because it changes color depending on if a liquid is acidic or basic. You will determine the pH of the four liquids, using red-cabbage juice. Copy the following table into your science notebook.

TABLE 2.2
TESTING pH WITH RED-CABBAGE JUICE

LIQUID	FINAL COLOR	APPROXIMATE pH RANGE	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			
E. CONTROL (CABBAGE JUICE)		7	NEUTRAL

The plant pigment of a red cabbage can be used to make a pH indicator.

5 Place your beakers on top of a sheet of white paper.

6 Add 4 mL of red-cabbage juice to the liquids in each of the 4 beakers: A–E. Note that Beaker E will contain only cabbage juice and will serve as your control.

7 Use a stir stick to stir the liquids in Beaker A and then rinse the stir stick in water.

8 Observe any color change that occurs by comparing the color of Beaker A to the control in Beaker E. Record your color observation in Table 2.2.

9 Repeat Steps 7 and 8 for Beakers B–D, making sure to rinse the stir stick between liquids.

10 Use your observations and the information in Table 2.3, “pH Indicator Scale for Red-Cabbage Juice,” to determine approximate pH of the liquid and to identify it as acidic, basic, or neutral. Record this information in Table 2.2 and then empty and rinse your equipment.

TABLE 2.3
pH INDICATOR SCALE FOR RED-CABBAGE JUICE

APPROXIMATE pH RANGE	ACIDIC, BASIC, OR NEUTRAL?
1-2	ACIDIC
3-6	ACIDIC
7	NEUTRAL
8-9	BASIC
10-11	BASIC
12-13	BASIC
14	BASIC

PART C: DETERMINING pH WITH pH PAPER

11 pH paper has been treated with one or more acid-base indicators that change colors at different pH levels. Copy Table 2.4, "Testing pH with pH Paper," into your science notebook.

TABLE 2.4
TESTING pH WITH pH PAPER

LIQUID	PAPER COLOR AFTER TESTING A LIQUID	pH	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			

12 Add 15 mL of distilled water to Beaker A. Then add 15 mL of each of the remaining three liquids to Beakers B–D, as listed in Table 2.4.

13 Test the pH of each liquid by:

- a dipping one end of the pH paper into a beaker and then removing it.
- b placing the pH paper on a white paper towel.
- c comparing the color of the paper to the pH scale of the provided pH paper.
- d recording your color observation in Table 2.4.

14 Use your observations and the information on the pH indicator scale to record the pH of each liquid and to identify it as acidic, basic, or neutral.

PART D: DETERMINING pH BY USING A pH METER

15 pH meters have an electrochemical probe that can be used to measure pH. To make sure that it is testing pH accurately, it may need to be calibrated using distilled water. For this reason, it cannot be used to take the pH of distilled water. Follow your teacher's instructions for calibrating your pH meter.

16 Copy Table 2.5, "Testing and Comparing pH with pH Probes," into your science notebook.

TABLE 2.5
TESTING AND COMPARING pH WITH pH PROBES

LIQUID	PREDICTED pH	pH FROM CABBAGE JUICE	pH FROM PAPER	pH FROM METER
A. DISTILLED WATER				
B. DRINKING WATER				
C. AMMONIA				
D. VINEGAR				

17 Test the pH of each liquid by:

- a following your teacher's instructions for using your pH meter. With many meters, you will first depress the dispenser button on the top of the electrode until a click is heard. You may need to wait until the reading is steady. (There is sometimes a READY indicator, or the meter beeps.)
- b recording the pH in the last column of Table 2.5.
- c rinsing the probe before using it to take the next pH reading.

18 Complete Table 2.5 to compare your pH results from Parts A–D. Discuss your findings with your group.

19 Compare your pH measurements with those of other groups.

20 Follow your teacher's directions for cleanup.

BUILD UNDERSTANDING

① Explain how using pH probes (or pH paper) did or did not validate the use of red-cabbage juice as a pH indicator. Support your answer with evidence from your experimental results.

HINT: Consider how similar or different the resulting pH values were for each tested liquid.

② Scientific explanations depend on relevant, accurate, and reliable data.

- **a** Compare the pH measurements you made, using different tools. Describe how accurate your measurements of pH were in this activity.
- **b** Compare your pH measurements with those of other groups. Based on your comparisons, describe how reliable your measurements of pH were in this activity.

③ What does this activity tell you about data from human senses vs. scientific testing?

④ Beginning in the 1920s, electrochemical probes, such as the one shown here, began to be used to measure pH more accurately. Advances in technology have resulted in miniature devices that can test pH inside living cells. Why would these technologies be preferred over color indicators such as pH paper and cabbage juice?

pH meter with probe

⑤ Levels of pH decrease as temperature increases: a 10°C (50°F) increase in temperature will reduce the pH by 0.2. In order to reduce energy use and save money, a factory sited along the Mizu River in Skipton releases treated wastewater back into the river at a temperature of 27°C (80°F) and a pH of 6.3. The average temperature of the river is 18°C–24°C (65°F–75°F) in the summer and 2°C–7°C (35°F–45°F) in the winter. The factory supervisor calculates that as the water cools, it will result in an acceptable pH.

Should the local government require additional treatment of the wastewater before it is released? Support your answer with at least three pieces of relevant evidence from this activity and identify the trade-offs of your decision.

HINT: You may want to first review the introduction and Scientific Review for this activity.

CONNECTIONS TO EVERYDAY LIFE

6. Rita makes a recipe, using a large glass measuring cup that holds up to 3 cups of liquid. Her final dish never turns out quite right. Explain how she could validate the accuracy of her measuring tool.

7. Suppose you are using a thermometer to track the temperature in your home, but you suspect it is not working. How could you validate its temperature reading?

EXTENSION

Are you wondering about the quality of your own drinking water? Most public water services provide information about local drinking water quality. Ask an adult in your household for the name of your public water service and look up more information about local water quality and treatment. Or you may want to purchase a commercially available home water quality testing kit to test levels of pH, bacteria, and other water quality indicators.

KEY SCIENTIFIC TERMS

pH
turbidity
validation

SCIENTIFIC REVIEW: pH

The pH scale measures the relative concentration of hydrogen ions (H+) and is an indicator of how acidic or basic a solution is. A high concentration of hydrogen ions indicates a low pH (basic), and a low concentration of hydrogen ions indicates a high pH (acidic). The pH scale ranges from 1–14, where 1–6 is classified as acidic, 7 as neutral (neither acidic nor basic) and 8–14 is classified as basic. Lemon juice, with a pH of 2, is acidic. Bleach, with a pH of around 12, is basic. The pH of drinking water is expected to be within a range of 6.5–9 (see Figure 2.1).

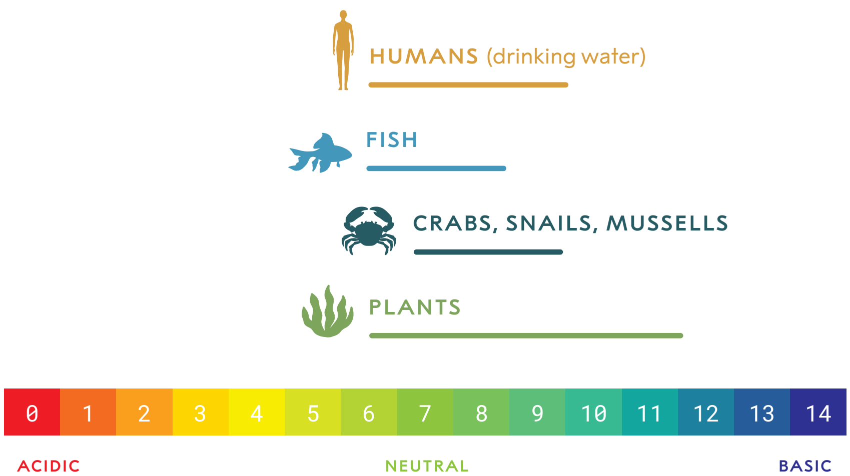


FIGURE 2.1
pH scale with ranges for living organisms

ACTIVITY 3

Scientific Advancement

CARD-BASED INVESTIGATION

3 : SCIENTIFIC ADVANCEMENT

GUIDING QUESTION

What role does new technology play in the development of scientific ideas over time?

INTRODUCTION

In the case of Skipton, the only indicator of something unusual in the drinking water was its turbidity. Outbreaks due to drinking water contamination can be a result of many different factors, as shown in the following graph. The field of science has made progress in identifying the cause of such outbreaks as well other scientific discoveries about water, as shown in Figure 3.1. In this activity, you will explore how technological advances have contributed to the development of scientific knowledge over time.

CONCEPTUAL TOOLS

SHARED REALITY

SENSES & INSTRUMENTATION

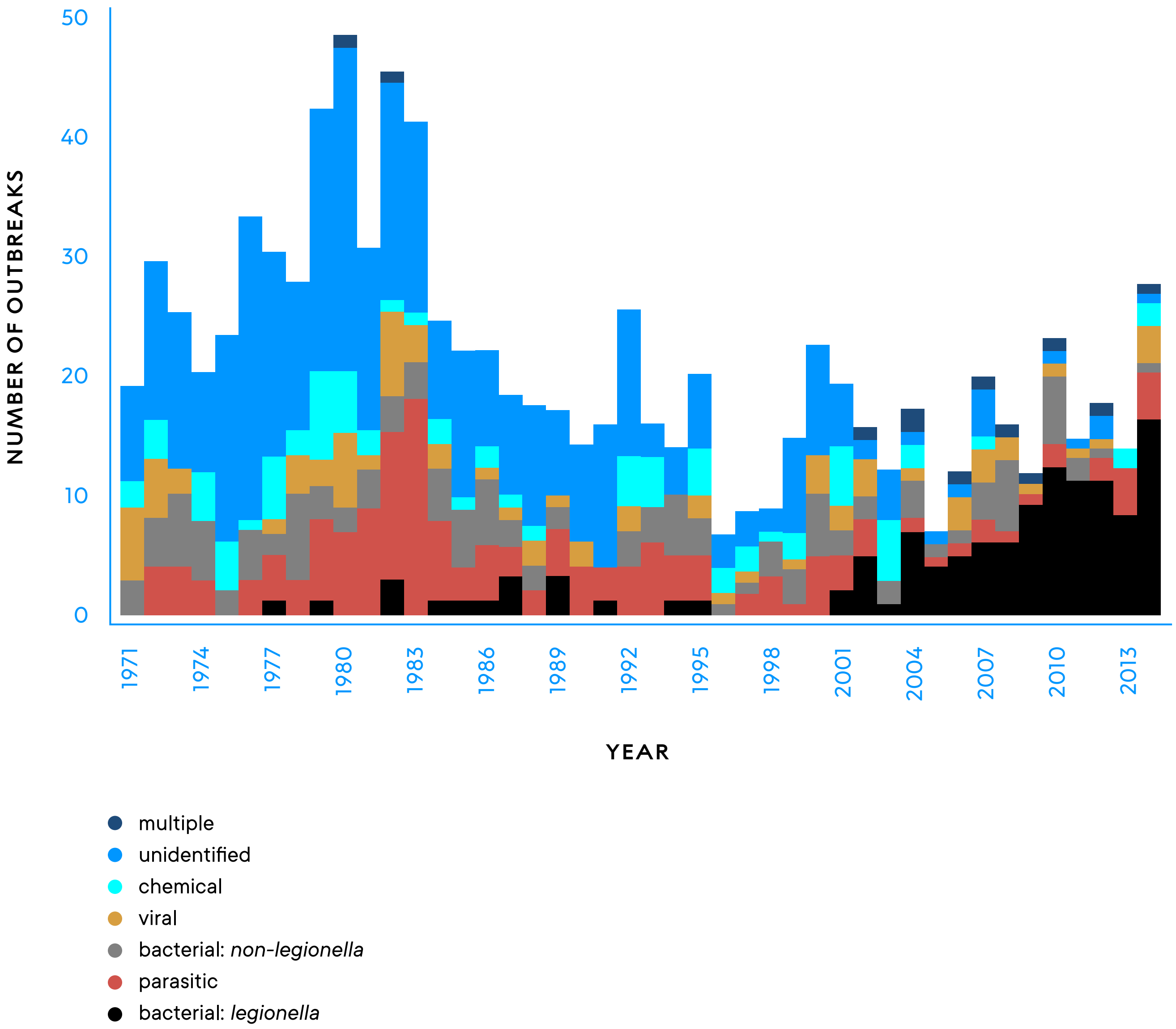
SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

FIGURE 3.1

Causes of Drinking Water Outbreaks in U.S.

1971-2014



Mars rover *Curiosity* explores the surface of the planet Mars, gathering data and sending it back to Earth.

PROCEDURE

PART A: DEVELOPING TIMELINES OF SCIENCE

1 Your group will investigate two separate timelines that address the development of scientific thinking: (1) about water on the planet Mars and (2) about imaging. You and your partner will investigate one of these timelines. You will start by receiving 3 Timeline cards from your teacher.

   a Work together to determine the sequence of these three events.

   b Describe why you think these events happened in this sequence.

   c Record your ideas in your science notebook.

2 Ask your teacher for the rest of the cards for your timeline. Work with your partner to read and sort these events in the order you think they occurred. Record the sequence in your science notebook.

3 Discuss with your partner why you think these events happened in this sequence and record your ideas in your science notebook.

4 Ask your teacher for Student Sheet 3.1a or 3.1 b, "Timeline Dates," and compare your sequence with the historical sequence. Reorder your cards as needed and correct your sequence in your science notebook.

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- 2 SETS OF TIMELINE CARDS

FOR EACH STUDENT

- STUDENT SHEET 3.1A OR 3.1B "Timeline Dates"
- STUDENT SHEET 3.2 "Timeline Analysis"

PART B: ANALYZING TIMELINES OF SCIENCE

5 Work with your partner to identify a sequence in the timeline where a new scientific tool or experiment led to a new observation. Record this information on Student Sheet 3.2, "Timeline Analysis."

6 Work with your partner to:

   a identify a sequence in the timeline where an observation led to a new idea. Record this information on Student Sheet 3.2.

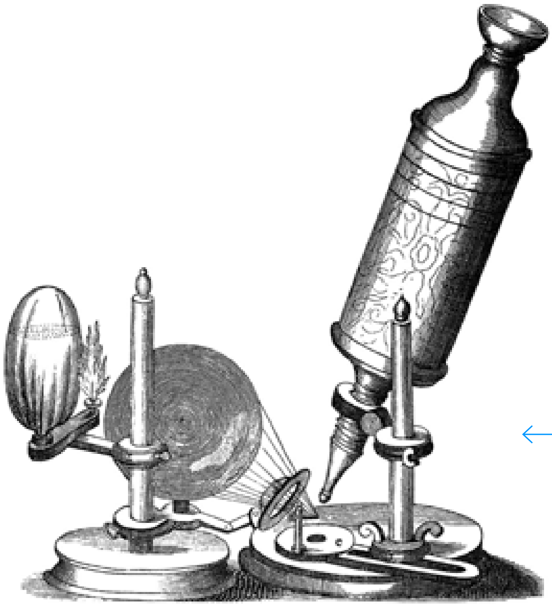
   b discuss what previous observations were also required for this new idea to be developed.

7 Work with your partner to identify a sequence in the timeline where an explanation was revised based on new evidence. Record this information on Student Sheet 3.2.

8 Work with your partner to identify a sequence in the timeline where an idea was later rejected or updated by the scientific community. Record this information on Student Sheet 3.2.

9 Discuss with your partner how science has advanced human understanding of this topic over time. Use the information from your Timeline cards as evidence for your thinking.

10 You and your partner will share your work with another pair who has a different set of Timeline cards. Share the most important aspects of your timeline with the rest of your group.



English scientist Robert Hooke helped design this early microscope. The light from the oil lamp was diffused by the water to provide better illumination for the specimen.

BUILD UNDERSTANDING

1. Consider the following ways in which scientific ideas are revised:

   - introduction of new evidence
   - improved methods of data collection and experimentation
   - collaboration with others
   - trial and error

   Which of these were represented in the timeline you investigated? Support your answer with examples from your timeline.

2. Explain how new scientific tools and techniques can lead to new insights and questions.

3. Scientific advancement is the progress of science toward more accurate, reliable, and complete explanations of phenomena. Did the timeline you investigated represent scientific advancement? Support your response with at least three examples from your timeline.

CONNECTIONS TO EVERYDAY LIFE

4. Today, people and teams around the world are able to easily communicate. What impact do you think this has on the speed of scientific discovery and technological innovation? Explain your thinking.

KEY SCIENTIFIC TERMS

scientific advancement

ACTIVITY 4

Testing Local Water

FIELD TRIP

4 : TESTING LOCAL WATER

GUIDING QUESTION

How can technology improve people's ability to collect information about the natural world?

INTRODUCTION

Skipton's residents who had concerns about their water quality observed some cloudiness in their water. However, they could not gather information about the cause of the turbidity based on their senses alone. People cannot directly observe many phenomena—such as chemicals or microscopic parasites—without the use of scientific tools. Technology can enhance the collection and analysis of such observations. Today, data on many water contaminants can be measured in micrograms per liter, or how many 0.000001 grams of the contaminant are in a liter of water. Some water contaminants may not be harmful at such low levels, while others are dangerous even in these tiny amounts. That's why different water contaminants have varying legal limits. In this activity, you will investigate the water quality of a local water body, using your senses and scientific tools, such as the Secchi disk shown in Figure 4.1.

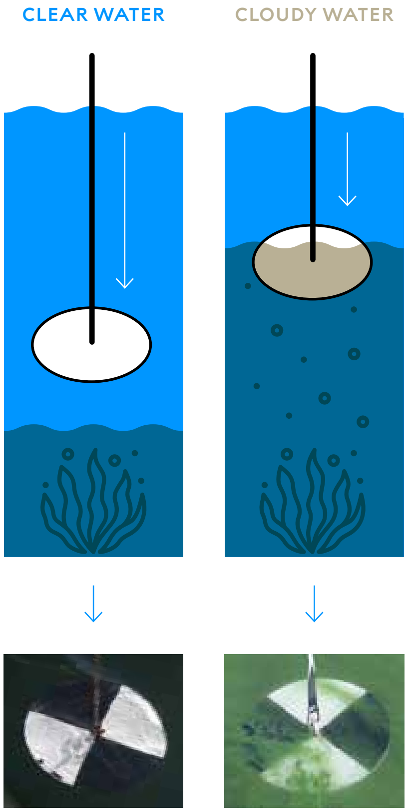
CONCEPTUAL TOOLS

SENSES & INSTRUMENTATION

SCIENCE AS A HUMAN ENDEAVOUR

FIGURE 4.1
Secchi Disk

A Secchi disk is one way to gather data on the turbidity of a large body of water. It is a white disk attached to a rope with centimeter (or inch) intervals marked along its length. It is lowered into the water until it can no longer be seen from the surface. The depth at which the disk disappears provides a measurement of the water's turbidity. Secchi disc measurements can vary from 53 meters at the Mediterranean Sea to 1–2 cm at Spirit Lake, Washington, after the 1980 Mount St. Helens volcanic eruption.



MATERIALS LIST

FOR THE CLASS

- ACCESS TO A LOCAL WATER BODY (such as a lake)

FOR EACH GROUP OF FOUR STUDENTS

- 18% GRAY-SCALE CARD
- DISTILLED WATER SAMPLE (in clear container)

FOR EACH PAIR OF STUDENTS

- pH PAPER WITH pH SCALE
- SMARTPHONE WITH HYDROCOLOR (or similar) APP

PROCEDURE

1 In your science notebook, make a table like Table 4.1, "Testing Local Water."

TABLE 4.1
TESTING LOCAL WATER

WATER SAMPLE	OBSERVATION OF ODOR AND APPEARANCE	INITIAL WATER QUALITY ASSESSMENT AND REASONING	pH	TURBIDITY	FINAL WATER QUALITY ASSESSMENT AND REASONING
DISTILLED WATER (CONTROL)				<0.1 NTUs	
LOCAL WATER BODY					

2 You will be investigating water quality at a local water body, such as a lake.

a After you arrive at the site, take a few minutes to listen and observe. Note plant and animal life, soil type, presence of rocks, and anything else in the area.

b Share your observations with a partner and discuss whether any of your observations could be relevant to water quality.

3 Examine the control and the water in your local water body. Then in Table 4.1, record your observations of the odor and appearance of both water samples.

4 Based on your initial observations, discuss with your group what you can conclude about the water quality of your control and your local water body.

5 Test the pH of each water sample and record your results in your table.

Researcher and Hydrocolor app developer Thomas Leeuw calibrating his app by taking a photo of the sky.

6 Use the HydroColor app to measure the turbidity of your local water body. Turbidity is measured in nephelometric turbidity units (NTUs). A low NTU reading indicates clearer water, while a high NTU reading indicates water with more suspended particles.

The U.S. Environmental Protection Agency (EPA) requires drinking water to have a turbidity measuring no higher than 0.3 NTUs. The HydroColor app measures on a scale of 0–80 NTUs and also provides a concentration of suspended particulate matter in grams per cubic meter.

a Find a location where you can look down into the water at depth. Open the app and select "Collect Data."

b Select Gray Card to take a photo of the 18% gray scale.

c Select Sky to take a photo of the sky.

d Select Water to take a photo of the water. (Avoid shadows, bubbles, and debris.)

e Select Analyze Images. Name your file to save your data.

f Find your turbidity reading in the table and record this value in Table 4.1.

7 a Compare your pH and turbidity values with

- the pH ranges described in the Scientific Review of pH in Activity 2
- the turbidity limits shown in Table 4.2, "Regional Turbidity Limits."

b As a group, discuss what your pH and turbidity values indicate about the water quality of your local water body.

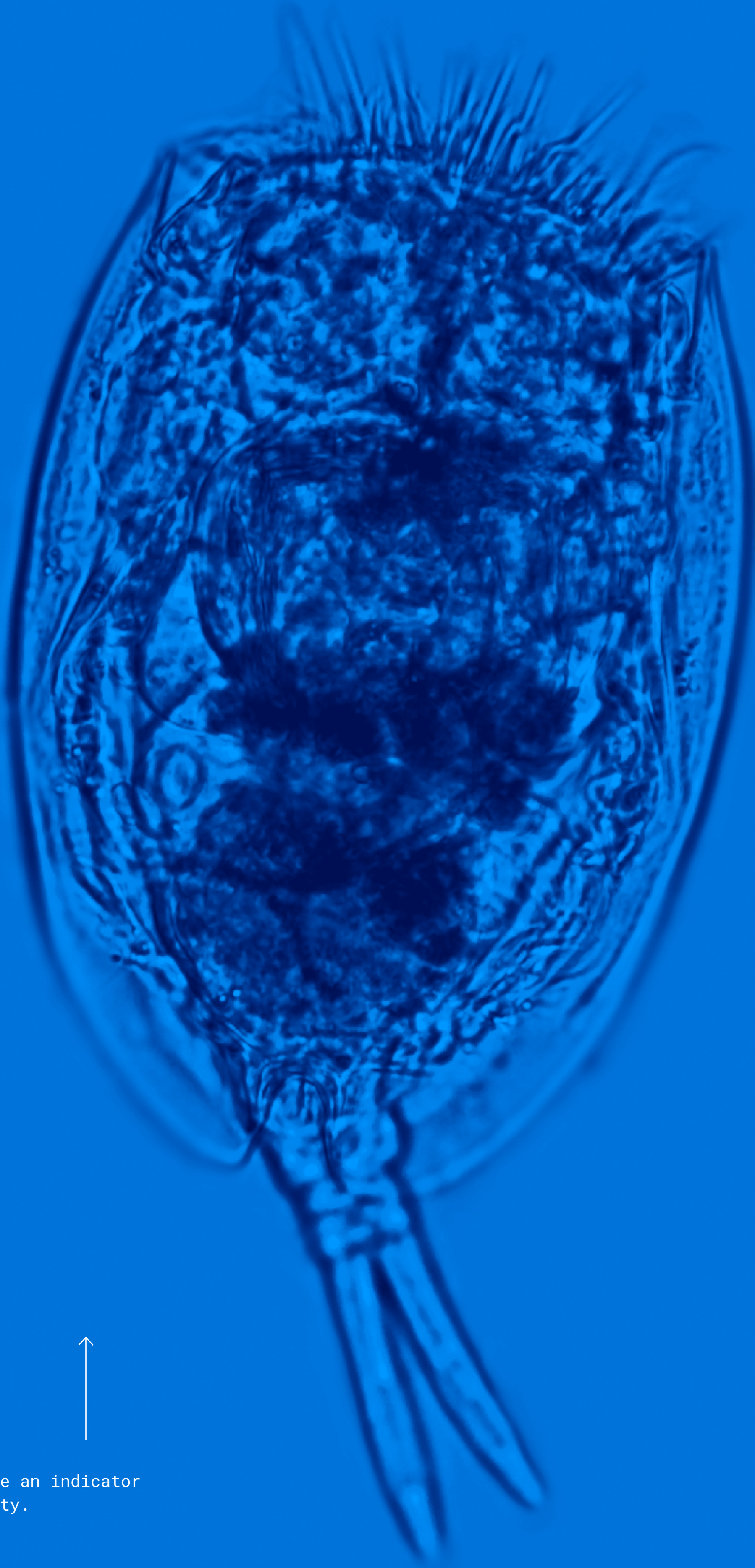
TABLE 4.2
REGIONAL TURBIDITY LIMITS

PURPOSE / LOCATION OF WATER	TURBITIDY (MAXIMUM LIMIT IN NTUs)	LIMITS SET BY
DRINKING WATER	< 0.3 NTUs	U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)
RECREATION	5 NTUs	AMERICAN WATER WORKS ASSOCIATION
TROUT WATERS	10 NTUs	STATE OF NORTH CAROLINA
NON-TROUT STREAMS	25 NTUs	STATE OF NORTH CAROLINA
NON-TROUT LAKES	50 NTUs	STATE OF NORTH CAROLINA

8 Work with your group to use data from both your senses and your measurements to evaluate the water quality of each sample. Record your final water quality assessment in Table 4.1.

EXTENSION

Interested in gathering more evidence about your local water body? Combine data from your senses with the use of a scientific tool by examining water samples under a microscope. Bioindicators are organisms used to monitor the health of an aquatic ecosystem. Certain species of algae and microorganisms are typically found in cleaner water, while other organisms, such as the bacteria *E. coli*, can indicate the presence of fecal matter in an aquatic system. Use your microscope observations to further evaluate your local water quality.



Rotifers can be an indicator of water quality.

BUILD UNDERSTANDING

1. What was the difference between the information you were able to discover with your senses alone compared to the information you were able to discover with the pH and turbidity tests?

2. *Cryptosporidium* is a microscopic parasite that can cause gastrointestinal illness in humans and animals. At one stage of its life cycle, it can become part of the solids suspended in the water column. Which water quality test—pH or turbidity—would be a more valid test for the presence of this organism in drinking water? Explain.

3. Do you have enough evidence to determine if your local water body could meet drinking water quality standards, such as the ones listed in Table 4.3? Why or why not? Address strengths and/or limitations in the evidence in your response.

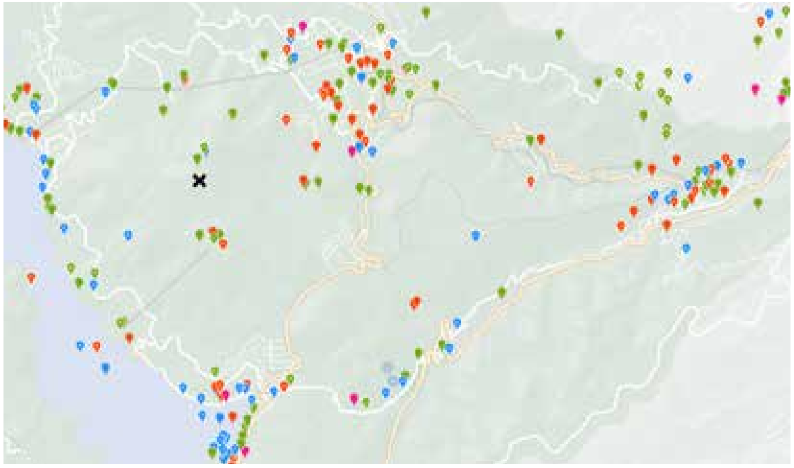
TABLE 4.3
SOME DRINKING WATER QUALITY STANDARDS

WATER QUALITY TEST	MAXIMUM ALLOWABLE LIMIT
CRYPTOSPORIDIUM PARASITE	0
E. COLI BACTERIA	0
LEAD	0
NITRATES	10 mg/L
pH	6.5–9
TURBIDITY	< 0.3 NTUs

CONNECTIONS TO EVERYDAY LIFE

4. Technology is being used to collect scientific data in many ways. In the iNaturalist app, users contribute observations of plants and animals, which can then be identified through photos. The app generates maps that show where different species were observed. Biologists can use the app to track biodiversity and animal ranges.

   The following map is an example of an iNaturalist map from Fuji Hakone Izu National Park in Japan. It is a mountainous area with many hiking trails. Look carefully at the map and notice the pattern of data. Would it be valid to use this data to determine the habitats of local plants and animals? Why or why not?



iNaturalist map

- plants
- vertebrates
- invertebrates
- fungus and lichens

5. Today there are an increasing number of apps that provide opportunities for citizens to contribute data or access information about the natural world. One such app is the U.S. Environmental Protection Agency's Bloomwatch app. It educates users about algal blooms—the rapid growth of algae that results in a layer of greenish scum on the surface of a body of water. Users can upload photos and provide additional information about observed blooms. Do you think information from such apps should be used to make government policy? Why or why not?

ACTIVITY 5

Iteration of Ideas

READING

5 : ITERATION OF IDEAS

GUIDING QUESTION

What is the role of evidence and iteration in developing scientific knowledge?

INTRODUCTION

Scientific explanations are those that best fit the known data at a particular time. Your thinking about Skipton's water quality likely changed with the availability of new evidence. New evidence from improved methods of data collection can support existing scientific explanations or cause scientists to adjust their ideas. For this reason, the process of science is iterative. Iteration is the revision of an idea or process. In this activity, you will learn about ways in which scientific processes such as iteration have contributed to issues related to water quality.

Scientists often collaborate on the iteration of scientific ideas.

CONCEPTUAL TOOLS

MULTIPLE LINES OF EVIDENCE

SENSES & INSTRUMENTATION

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

PROCEDURE

1 Follow the directions on Student Sheet 5.1, "Anticipation Guide: The Process of Science," to complete the "Before" reading tasks.

2 Your teacher will assign you one of the four case studies to read. As you read, follow the Read, Think, and Take Note strategy to help you understand the reading.

3 Work with others who read the same case study to complete your row of Student Sheet 5.2, "Case Study Summaries."

4 As a group, present your case study summary to the class.

5 Listen to other groups' summaries of the other three case studies. Use their presentations to complete Student Sheet 5.2.

MATERIALS LIST

FOR EACH STUDENT

- STUDENT SHEET 5.1 "Anticipation Guide: The Process of Science"
- STUDENT SHEET 5.2 "Case Study Summaries"
- 3–5 STICKY NOTES

READ, THINK, AND TAKE NOTE GUIDELINES

Stop at least three times during each section of the reading to mark on a sticky note your thoughts or questions about the reading.

As you read, use a sticky note from time to time to:

- explain a thought or reaction to something you read.
- note something in the reading that is confusing or unfamiliar.
- list a word from the reading that you do not know.
- describe a connection to something you've learned or read previously.
- make a statement about the reading.
- pose a question about the reading.
- draw a diagram or picture of an idea or connection.

After writing a thought or question on a sticky note, place it next to the word, phrase, sentence, diagram, drawing, or paragraph in the reading that prompted your note.

After reading, discuss with your partner the thoughts and questions you had while reading.

READING

CASE STUDY 1 MULTIPLE LINES OF EVIDENCE

In April 2014, under the direction of a state-appointed emergency manager, the city of Flint, Michigan, switched its water supply from its long-time provider the city of Detroit, which sourced water from Lake Huron over 100 miles away, to the nearby Flint River. The Flint River was meant to be a short-term and inexpensive water source while a new direct pipeline to Lake Huron was built to provide water to Flint and surrounding counties. That decision resulted in at least 12 deaths and hundreds of illnesses for Flint residents. Evidence from many different sources led to an understanding of what happened.

Immediately after the switch to the Flint River water, some residents started noticing changes in their tap water. It had a slightly brown-orange color, smelled funny, and had a metallic taste. One resident, Pastor R. Sherman McCathern, observed water coming out of a fire hydrant that was as dark as coffee. By October, a General Motors factory on the Flint River decided to stop using the river water because workers noticed corrosion on machine parts that were exposed to the water. Despite this evidence, the emergency manager for Flint, where a majority of residents are African American and about 40% of residents live in poverty, ignored residents' complaints and assured them that the water was safe.

Residents protest Flint water quality conditions outside the Michigan State Capitol in 2016.

Resident LeeAnne Walters' four children all exhibited signs of illness. She. along with other Flint residents, actively fought the city to have their water tested, and it was not until February 2015 that the city finally agreed. By then, one of Walters' children had developed a full body rash and was diagnosed with lead poisoning. The city's test revealed that her home's water had lead levels 89 parts per billion (ppb) higher than the EPA safety limit for lead of 0 ppb. Still, Flint's emergency manager decided to continue using the Flint River as a water source.

Walters and other residents, including Claire McClinton, Laura Sullivan, and Nayyirah Shariff, became community scientists. They reached out to others such as water quality expert Bob Bowcock, environmental activist Erin Brockovich, and Virginia Tech Professor Marc Edwards. Building on prior work done by scientists from the University of Michigan that had uncovered elevated lead levels in Flint's water, a Virginia Tech team tested hundreds of homes in Flint. Their laboratory analysis found extremely high lead levels in over 40% of the samples they collected. Additional lab experiments demonstrated that Flint River water was corrosive to lead piping, similar to the piping that has been used in Flint for over 100 years. The researchers concluded that corrosive water from the Flint River was reacting with the city's lead pipe system, causing lead to leach out of the pipes into drinking water.

Adding to these findings, Dr. Mona Hanna-Attisha, a pediatrician at Flint's Hurley Medical Center and Michigan State University (MSU), publicly reported an almost 2% increase in the number of children under 5–years-old who had elevated blood lead levels after the switch to the Flint River water. It took these multiple lines of evidence for the government to issue a city-wide lead advisory in September 2015. A month later, the city started providing free water filters and bottled water to residents. Soon after, a state of emergency was declared and, eventually, a plan was made to switch back to the city's original water source, replace all the lead pipes throughout the city, and provide safe drinking water to residents. Today, the work on the water systems of Flint is ongoing.

CASE STUDY 2 DATA FROM HUMAN SENSES AND SCIENTIFIC TECHNOLOGY

Growing up in a village in Guatemala, Africa Flores had to walk 3 kilometers (km) to her grandparents' house to get drinking water. On her trip, she passed three different rivers, but they were all too polluted for drinking. When her parents were young, they used to swim and fish in these rivers; however, by the time Flores was born, the levels of sewage and agricultural chemicals made the water unsafe for drinking. When she eventually moved to a different part of the country, she found the water there to be clean. Flores hoped that the rivers at home could one day be clean again, too.

Hoping to address this issue, Flores went to work for the Guatemalan government and realized that there was not much available environmental data. She started collecting data herself, hiking through the Guatemalan jungle to find out what was happening in local water bodies and forests. She soon discovered that lots of data were already being collected about the Guatemalan landscape, though not by Guatemala. The U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) had been collecting satellite images of all parts of Earth's surface since 1970. USGS and NASA were using this satellite data to monitor global environmental change. In 2008, this satellite data became free for anyone to use. It included millions of optical images of Earth that showed forests, water bodies, and soils.

Satellite data is often used to make models that can make predictions about a phenomenon, such as the path of a storm or the spread of an algal bloom. In Flores' case, she used satellite data to make a model to track the spread of a huge toxic algae bloom in Guatemala's Lake Atitlán in 2009. However, satellite data often needs to be compared to ground observations before it can be used in this way. In some satellite images, an area that looks like one thing (such as a forest) may be something different (such as a plantation). The only way for Flores to verify the accuracy of her satellite data was to collect measurements directly from Lake Atitlán. Flores used her on-the-ground measurements to revise and improve her original model. The new iteration of her model to predict algal blooms used evidence from both her direct measurements and satellite data.

Africa Flores at Lake Atitlán, Guatemala.

COURTESY OF SCIENCE FRIDAY.

Simulated natural-color image of Lake Atitlán.

Flores was able to use mapping software to input her data onto a map that showed Guatemala in the context of the countries around it. She could see how environmental change in one area was associated with change in neighboring areas. Combined with 50 years of satellite datasets, she could see how human activities had affected the environment over time. Finally, Guatemala had data on its environment that it could use to make better decisions about water and land use.

Today, Flores works for NASA and uses satellite data to track environmental changes, especially in countries such as Guatemala that don't have a lot of their own data resources. She is excited that more and more data is becoming freely available so others can utilize scientific technology as well as their senses to study the environment. When asked about the future, Flores said, "I don't think we have yet thought about all the questions we will need to answer and will be able to answer because of these technologies. For our life on Earth, we will depend more and more on [data from] satellites."

Africa Flores at the U.S. Space & Rocket Center in Huntsville, Alabama.

COURTESY OF SCIENCE FRIDAY.

CASE STUDY 3 ADDRESSING WATER QUALITY THROUGH ITERATION

Julius Lucks and Sera Young, husband and wife, are both professors at Northwestern University in Chicago, Illinois. Young, an anthropologist, studies how women cope with water insecurity in Kenya. Many people do not live close to a safe water source and must decide between hauling water miles from a well or using more convenient surface water, which is more likely to be contaminated. Water quality tests exist, but they are often expensive, slow, and not widely available.

Julius Lucks (left) and two of his field researchers, Khalid Alam (below top) and Kirsten Jung (below bottom), conduct water sample testing on-site.

At the same time, bioengineer Lucks, along with his students Khalid Alam and Kirsten Jung, had been studying how microorganisms like bacteria use proteins to detect toxins in their environment. What is toxic to microorganisms also tends to be toxic to humans. Talking with his wife, Lucks realized he could use his research on microorganisms to help people. Some microorganisms fluoresce, or light up, under certain conditions. Lucks' team wanted to use this response to create a water quality test that would fluoresce when exposed to a toxin.

The problem was that the microbial cells are fragile and can die if it gets too hot. Lucks' team found out that other scientists had recently worked out how to make RNA detect chemicals and create fluorescence outside cells. Using this technique, Lucks, Alam, and Jung created an RNA-based nanotechnology that lights up only in contaminated water. It works on all kinds of contaminants, from metals to antibiotics. Since it is cell-free, it can be freeze-dried and shipped anywhere. They named this system ROSALIND (RNA Output Sensors Activated by Ligand Induction).

The Lucks Lab's water-test kits contain tubes with molecules from bacteria that will turn fluorescent green when contaminants such as copper or zinc are present.

Lucks' team used their system to test water samples in Paradise, California, after the town had been destroyed by wildfires. However, the desiccant—a substance for keeping materials dry—leaked into the test kits and ruined half of them. The other half of the kits worked. The team adjusted the packaging and shipped test kits back to Paradise to test them on copper-contaminated water. The copper-contaminated water samples glowed, while the clean water samples did not. Lucks and Young teamed up to ship additional kits to Kenya. This time, *all* the water samples glowed. This implied that all the water samples tested in Kenya were contaminated, which didn't seem right. It took six months for the team to determine what went wrong and revise their interpretation. The kits had been shipped through the United Arab Emirates during a time when temperatures exceeded 38°C (100°F). The intense heat ruined the kits, invalidating the test results from Kenya. The team then knew that it was important to store the kits within a certain temperature range.

The team also recognized that the test did not provide data about *how much* toxin was in a sample that tested positive. Some chemicals, such as fluoride, are healthy in small amounts but unhealthy in larger amounts. The team iterated on their design until their device could show how much toxin was present. Hoping to try out the kits in a different context, the team went door-to-door in Evanston, Illinois, offering to test people's tap water for lead. Some people refused. The next challenge facing the team is to not only get the kits to people who may need them, but to help people understand why the kits are useful.

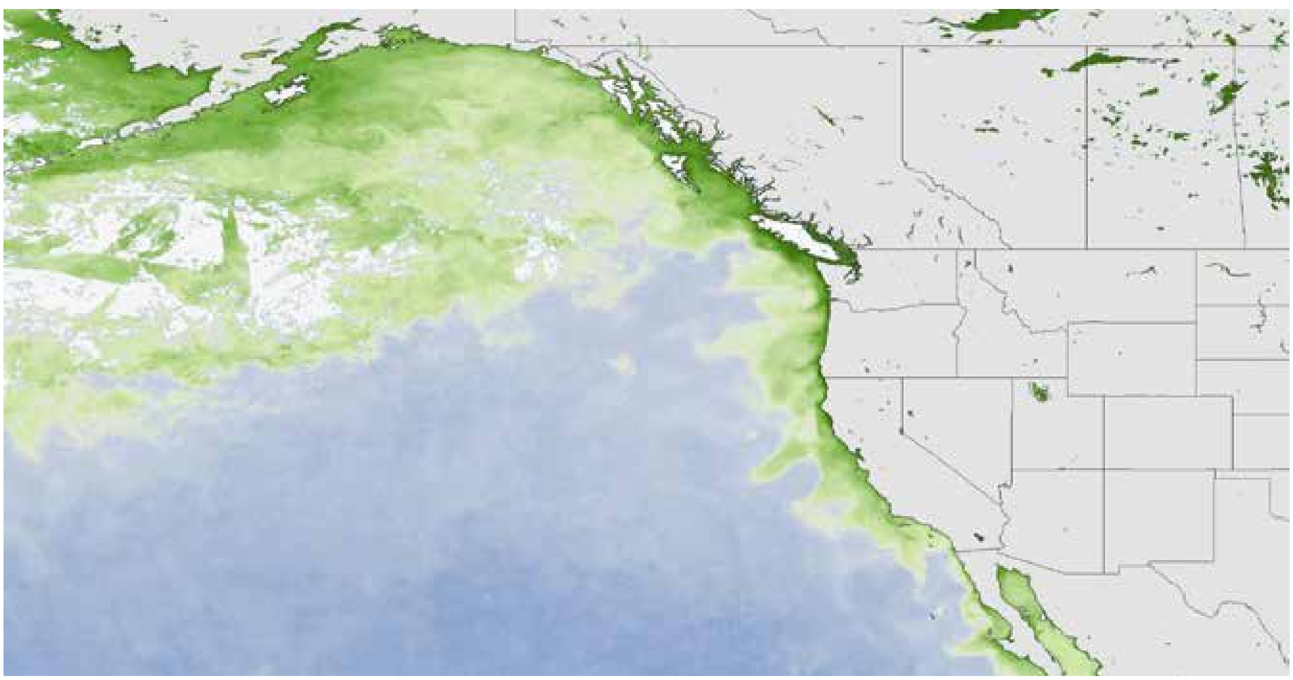
Despite the setbacks in the process, Lucks and Young's team made several iterations and developed this nanotechnology quickly. When asked how they did it, Lucks said his motto is "Fail fast." In other words, go as fast as you can, fail, and learn from your failures.

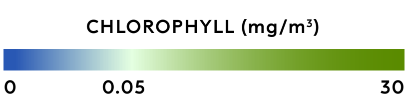
CASE STUDY 4 SCIENTIFIC ADVANCEMENT

In 1987, a serious outbreak of food poisoning occurred on Prince Edward Island, Canada. Three people died, and over 100 were sickened. Most people experienced diarrhea and vomiting, while some individuals developed nervous system symptoms, including memory loss. The food poisoning was traced to cooked mussels, but the contaminant in the mussels could not be immediately identified with any known toxins. It took several weeks of laboratory research to determine that the contaminant was domoic acid, a neurotoxin produced by the marine algae *Pseudo-nitzschia.*

Additional research led to an understanding of the environmental conditions—such as warm water temperatures, sunlight, increased nutrient levels, and stable wind conditions—that result in large-scale algal blooms. An algal bloom occurs when tiny aquatic plant-like organisms grow in large quantities in a body of water. Not all algal blooms are harmful. However, toxic algal blooms are a concern for drinking water quality. High levels of exposure to the toxins from such blooms can cause diarrhea, vomiting, skin irritation, organ damage, and even death. While domoic acid was identified as the cause of what is now known as amnesic shellfish poisoning, it was still not known how the toxin was produced or what triggered its production.

FIGURE 5.1
Algal bloom in Pacific Ocean
July 2015



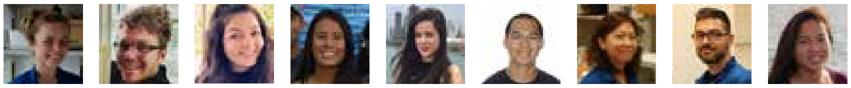


Chlorophyll is a photosynthesizing pigment found in green algae. In the 2015 algal bloom in the Pacific Ocean, chlorophyll concentrations measured by satellites were used to determine the spread of the bloom.

A heatwave in the Pacific Ocean resulted in a record-setting algal bloom in 2013–2015, as shown in Figure 5.1. It was caused by *Pseudo-nitzschia* and forced the closure of recreational, commercial, and tribal shellfish harvesting. Marilou Sison-Mangus, an ocean sciences professor at the University of California, Santa Cruz, and her team became concerned about the impact of toxic algal blooms on people. They investigated the role of bacteria in the production of domoic acid. Their experiments showed that bacteria-free cultures of *Pseudo-nitzschia* are not able to produce domoic acid, while adding bacteria to the cultures restores toxin production. She explained, “There are blooms of *Pseudo-nitzschia* every spring and summer along the California coast, but the toxicity varies a lot. We know . . . bacteria are associated with toxic blooms in the ocean, and we know they cause toxicity to spike in the lab, but we don’t know the mechanisms of toxin production.”

New insights into this question appeared in 2022. Scientists from the Scripps Institution of Oceanography at the University of California, San Diego; the University of São Paulo, Brazil; and University of California, Santa Cruz collaborated to discover and validate the enzymes responsible for the production of another toxin called guanitoxin, which is associated with harmful algal blooms in freshwater lakes and ponds. Their research is likely to inform the ongoing research on the marine algae *Pseudo-nitzschia*.

While advances in the scientific understanding of algal blooms continue, in 2016 Ohio became the first state in the United States to require that the public water supply be tested for toxins from algae.



University of California, Santa Cruz professor Marilou Sison-Mangus studies the connections between bacteria and their aquatic hosts, like the *Pseudo-nitzschia* algae, with scanning electron microscopes and other scientific techniques. (Sison-Mangus Lab members from the left to right): Marilou Sison-Mangus, Monica Appiano, Stephan Bitterwolf, Destiny Gomez, Sami Chen, Lauren Kallan, Jiunn Nicholas Fong, Leni Dejeto-Yap, Sanjin Mehic, and Anina Baker.

BUILD UNDERSTANDING

1. Complete the Anticipation Guide on Student Sheet 5.1. Be sure to think about information from all four of the case studies, not just the one you read.

2. The development of scientific knowledge is iterative and occurs through continual re-evaluation and iteration of ideas that are informed by:

   - new evidence
   - improved methods of data collection and experimentation
   - collaboration with others
   - trial and error

   Which of these were represented in the case study you read? Clearly describe how these elements were represented in your case study.

3. Think about your work over the course of this unit so far. What are the advantages and disadvantages of relying solely on scientific technology for data?

4. In this activity, you learned about the role of science in the accumulation of scientific knowledge about algal blooms. Explain how scientific research about algal blooms built on previous ideas and led to new questions.

5. Each case study emphasized one of the key ideas listed here. Reflect on your case study and explain how it modeled another idea from the following list.

   - multiple lines of evidence
   - data from human senses and scientific tools and technology
   - iteration
   - scientific advancement

CONNECTIONS TO EVERYDAY LIFE

6. Think about how you use technology in your everyday life. Describe an instance when you used your senses to validate the information you received from your technology.

KEY SCIENTIFIC TERMS

iteration

ACTIVITY 6

Claims and Evidence

COMPUTER SIMULATION

6: CLAIMS AND EVIDENCE

GUIDING QUESTION

How can evidence be used to support or refute a claim?

INTRODUCTION

Scientists often make claims about a phenomenon based on data that already exists or from data that they gather. Data becomes evidence when it has been interpreted and is used to support or refute a scientific idea. Gathering enough evidence that is relevant, accurate, and reliable helps support or refute scientific ideas. In this activity, you will investigate the role of evidence from different scientific tools and techniques in supporting or refuting claims about the quality of Skipton's water. A claim is a statement that asserts something is true.

CONCEPTUAL TOOLS

Sampling water from lake.

PROCEDURE

PART A: FINDING AND EVALUATING EVIDENCE ABOUT A CLAIM

1 Read the following scenario.

The Skipton city council has decided to move forward with sourcing water directly from Lake Timtim. As they gather more data to support this decision, individual members of the city council have made the following four claims about water in Lake Timtim:

CLAIM 1: The algae in Lake Timtim is harmless.

CLAIM 2: Lake Timtim will likely have water for another 100 years.

CLAIM 3: The amount of suspended solids in Lake Timtim is decreasing.

CLAIM 4: Lake Timtim does not contain levels of the chemical tributyltin (TBT) high enough to pose a health concern.

Based on their prior experience, many residents would like to further investigate these claims. The city council has asked scientists at the nearby Skipton University to collect data about Lake Timtim and the surrounding areas. You will determine whether the data supports or refutes these claims.

2 Your teacher will assign you and your partner a claim to investigate. Read your assigned claim and the background information provided.

MATERIALS LIST

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 6.1 “Assessing My Evidence”
- STUDENT SHEET 6.2 “Writing Frame: Claims, Evidence, and Reasoning”
- STUDENT SHEET 6.3 “Sharing Claims and Evidence”

CLAIM 1

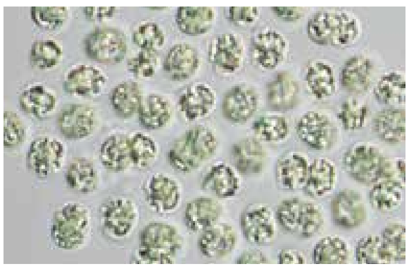
THE ALGAE IN LAKE TIMTIM IS HARMLESS.

Background Information

There are many types of algae that grow in aquatic environments: brown algae, red algae, green algae, and blue-green algae (also known as cyanobacteria). Some algae are beneficial to a healthy ecosystem, while others are harmful. Some species of blue-green algae produce toxins such as microcystin. When people are exposed to contaminated water or eat contaminated shellfish such as mussels or clams, these toxins are poisonous and cause short-term memory loss and even death. These toxins can also cause the death of fish, birds, and mammals. Algal growth is associated with increased nutrient levels (such as nitrogen and phosphorus) in the water, high light levels, and warm water temperatures. Microscope images can be used to distinguish between toxic and nontoxic species of algae since some species are too small to identify with the human eye.

Water quality Limits

The U.S. Environmental Protection Agency (EPA) recommends water for recreational use to have microcystin levels below 8 micrograms per liter (μg/L). Drinking water should have less than 0.3 μg/L for infants and preschool-age children and less than 1.6 μg/L for all other age groups.



Some blue-green algae species such as *Microcystis* produce toxins (left), while other blue-green algae species, such as *Arthrosprira* (right), are used as a food supplement.

CLAIM 2

LAKE TIMTIM WILL LIKELY HAVE WATER FOR ANOTHER 100 YEARS.

Background Information

Some residents of Skipton have raised concerns about the long-term reliability of water from Lake Timtim. Factors such as rainfall, temperature, drought conditions, water capacity, and water level can all contribute to the potential longevity of a water source. Residents point to how some of these factors have caused long-term change at nearby Wazi Lake, which has a similar climate and geography. They are concerned that something similar could happen to Lake Timtim.

Satellite images are digital pictures of Earth's surface compiled from data collected by satellites that orbit Earth.

CLAIM 3

THE AMOUNT OF SUSPENDED SOLIDS IN LAKE TIMTIM IS DECREASING.

Background Information

Turbidity is a water quality indicator that refers to the clarity of the water. The greater the amount of suspended solids, the cloudier the water appears, and the higher the measured turbidity. Clay, silt, sand from soils, phytoplankton, bits of decaying vegetation, industrial wastes, and sewage are examples of suspended solids. In general, lower turbidity is associated with cleaner water. This is not always the case, though. For example, a clean lake may have a large amount of suspended sediments after a heavy rainfall, resulting in high turbidity. Turbidity measurements can vary across different types of environments, so they are especially useful when comparing similar environments or the same water body through time.

Water quality Limits

Turbidity readings using a turbidity meter are recommended to be below 0.3 NTUs for drinking water sources and below 5 NTUs for recreation.

The water in this river has high turbidity.

CLAIM 4

LAKE TIMTIM DOES NOT CONTAIN LEVELS OF TRIBUTYLTIN (TBT) HIGH ENOUGH TO POSE A HEALTH CONCERN.

Background Information

Tributyltin (TBT) is a chemical that used to be found in boat and marine paints. It has been banned in marine paints worldwide since 2008 because it has been shown to have toxic effects on organisms. At concentrations of 1,500,000 parts per trillion (ppt), TBT affects the development of shellfish such as mussels and clams. TBT accumulates in organisms higher up the food chain and can have negative impacts on human health. Though it may no longer be present in the water column, it can persist in aquatic sediments for many decades. Gas chromatography-mass spectrometry is a scientific technology that can be used in a laboratory to isolate and identify chemical compounds in a sample, including chemicals such as TBT.

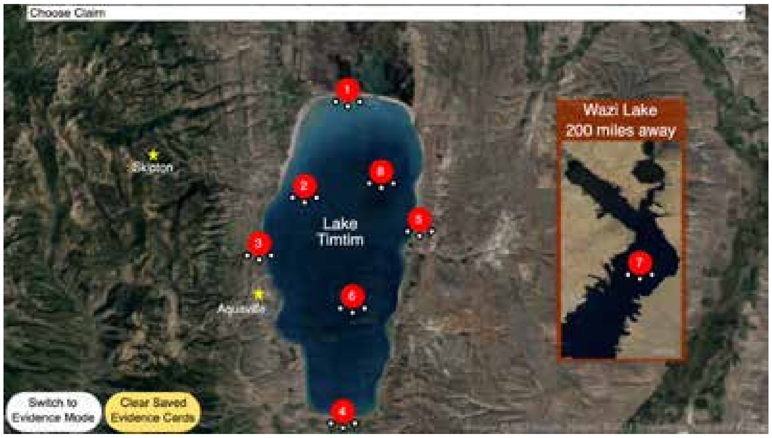
Water quality Limits

TBT levels are required to be lower than 460,000 ppt in drinking water sources.

These workers are cleaning the side of a large ship. TBT was used to prevent algae, molluscs, and other organisms from attaching to boats and other marine equipment.

3 You will use a computer simulation to gather evidence related to your claim. Follow your teacher's instructions for accessing the Lake Timtim Evidence Simulation, found at https://sepup.lawrencehallofscience.org/lake-timtim-evidence-simulation/.

4 The **Map mode** shows multiple sites where data has been collected. You can explore the locations in any order. The small circles under the site number change colors, helping you track whether you viewed all the evidence at that site, as well as whether or not you saved the evidence for use with your claim. (White: unviewed data; gray: viewed data; green: saved evidence)



a If you determine that the data is relevant to the claim you are investigating, save it by selecting the **Save Evidence** button. You will be able to save up to eight (8) evidence statements.

b Each site contains more than one piece of evidence. Decide with your partner whether you'd like to gather more evidence at a particular location.

c Continue to visit sites until you have looked at evidence from each location.

5 Select the button to switch to **Evidence mode**. Evidence mode shows you all the pieces of evidence that you saved from the map. You can then sort it based on whether it supports or refutes your claim (or is not relevant).

- **a** Select your claim at the top of the page.
- **b** Select the title of one of the Evidence cards that you saved (on the left side of the screen).
- **c** With your partner, discuss the evidence to determine how it is related to the claim.
- **d** Select a button to place the evidence into a category:
  - Evidence Supports the Claim
  - Evidence Refutes the Claim
  - Evidence Unrelated to the Claim

6 Complete Student Sheet 6.1, “Assessing My Evidence,” by:

- **a** evaluating the relevance of a particular piece of evidence.
- **b** determining if a particular piece of evidence supports or refutes your claim.
- **c** explaining any limitations of your data, questions you may have, and anything else.
- **d** deciding if your claim has been supported or refuted by considering all the evidence.

7 Based on your conclusion, discuss with your partner whether you think Lake Timtim would make a good source of drinking water for Skipton. Record your ideas in your science notebook.

PART B: SHARING CLAIMS AND EVIDENCE ABOUT LAKE TIMTIM

8 Your teacher will pair you with another pair of students who investigated the same claim. As a group, compare the evidence you found and your conclusions about your claim.

Remember to listen to and consider the ideas of other members of your group. If you disagree with others in your group, explain why you disagree.

9 Work with your group to prepare to present your claim to the class. Use Student Sheet 6.2, " Writing Frame: Claims, Evidence, and Reasoning," to help you organize your ideas. To help you prepare, summarize the following points:

a your claim

b whether your claim was supported or refuted by the evidence

c evidence relevant to your claim

10 Present your claim and evidence to the class. As your classmates share their findings, record notes on Student Sheet 6.3, "Sharing Claims and Evidence."

11 With your group, revisit your decision about whether you think Lake Timtim would make a good source of drinking water for Skipton.

BUILD UNDERSTANDING

1. What is your recommendation to the Skipton City Council about the use of Lake Timtim as a drinking water source? Write a letter to the Skipton City Council supporting your answer with multiple lines of evidence and identifying the trade-offs of your decision.

2. In the simulation, each location provided different evidence, such as observations from human senses, results of lab tests, or data from scientific technology.
   a. Select one site and describe all the evidence found at that location.
   b. How could you improve the reliability of this data?

CONNECTIONS TO EVERYDAY LIFE

3. Your teacher just told the class that soccer is the most popular sport in the world. What evidence could you collect (without using an Internet search) to evaluate this claim? Explain how this evidence would support or refute this claim.

4. In your everyday life, how do you decide if you have enough evidence to support a decision? Explain your thinking by describing an everyday example, such as when you go to sleep or how you spend money.

EXTENSION

Consider the range of water quality tests—such as pH, turbidity, and water sampling—for bioindicators such as algae. Multiple lines of evidence from these various tests are used to determine overall water quality. Select one water quality indicator and describe what information it does and does not provide about water quality. Explain why its use is important in determining water quality as well as its limitations.

KEY SCIENTIFIC TERMS

claim

ACTIVITY 7

Evidence and Explanations

CARD-BASED INVESTIGATION

7: EVIDENCE AND EXPLANATIONS

GUIDING QUESTION

What is the role of evidence in evaluating scientific explanations?

INTRODUCTION

The Skipton scenario is built on a modern understanding of how contaminants can be transmitted from the environment to people. It was not until the 1830s and 1840s that the use of data collection and analysis began to show that there was a direct link between poor living conditions, disease, and life expectancy. Around the same time, Dr. John Snow was studying cholera outbreaks in London in an attempt to find out how it was being transmitted. Cholera is an infectious disease that can cause severe diarrhea and vomiting, sometimes resulting in death by dehydration. Some cases are mild or without symptoms. Today, there are an estimated 2.9 million cases and 95,000 deaths globally due to cholera. In this activity, you will take on the role of scientists investigating the cause of cholera transmission by looking at the available evidence, as John Snow did in the 1800s. You will consider how the evidence does or does not support each of the three main explanations of transmission considered possible by scientists at the time.

CONCEPTUAL TOOLS

MULTIPLE LINES OF EVIDENCE

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

A boy receives the oral cholera vaccine from a public health worker in Haiti, where cholera outbreaks are a significant health concern today.

PROCEDURE

1 Read the following scenario, which describes a cholera outbreak in London in the 1800s.

For most of August 1854, there were few cholera deaths in Soho, London. However, during the night of August 31st, 56 new cases were reported. The next day, there were 143 new cases and on September 2nd, 116 cases. Many of those infected died: 70 people on September 1st and 127 on September 2nd. Imagine you are a doctor during this cholera outbreak in London. Some people come to you asking for your help. They want to prevent the spread of the disease but they do not know how it is being transmitted.

A busy London street in the 1800s.

2 In your group, generate at least two possible explanations for how this sickness might be spreading in 19th-century London.

3 Your group will receive three Explanation cards. Compare these three explanations to your own two explanations and then discuss what evidence you would need to decide which explanation of cholera transmission is correct.

4 Your group will receive Evidence cards 1–4. Work with your group to read each card and determine whether the evidence supports one or more of the three explanations or is not relevant evidence. Record your responses on Student Sheet 7.1, “Evaluating Evidence.”

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- 15 EVIDENCE CARDS
- 3 EXPLANATION CARDS

FOR EACH STUDENT

- STUDENT SHEET 7.1 “Evaluating Evidence”

5 Discuss with your group which explanation is most consistent with the evidence and why.

6 Additional evidence becomes available. Your group will receive more Evidence cards representing this evidence. Read each card, determine which explanation(s) the evidence supports, and add your responses to Student Sheet 7.1.

7 Discuss with your group which explanation is most consistent with the fuller set of evidence and why.

8 Based on your current explanation for how cholera spreads, work with your group to identify steps that could reduce the spread of cholera.

9 Consider what other evidence you would like to have. Work with your group to brainstorm questions and investigations that would help you answer them.

10 In your science notebook, record one investigation that you think would be most helpful in testing your explanation. Record how your investigation could provide evidence supporting your explanation and how your investigation might provide evidence refuting your explanation.

HINT: If exactly the same thing would happen whether your explanation is supported or not, it is likely not a good test of your explanation.

BUILD UNDERSTANDING

1. Cholera outbreaks in the 19th century occurred before many modern scientific tools were developed. What is one modern scientific tool that might have helped doctors of the time figure out the transmission of cholera more quickly? How could this tool have been used to investigate cholera?

2. The development of scientific knowledge is iterative and occurs through continual re-evaluation and iteration of ideas that are informed by:

   - new evidence
   - improved methods of data collection and experimentation
   - collaboration with others
   - trial and error

   Which of these were relevant to Dr. Snow's investigation of cholera? Provide examples that describe how these elements were represented in his work.

3. How was the cholera outbreak in 1800s London similar to the Skipton scenario? How was it different?

CONNECTIONS TO EVERYDAY LIFE

4. Evidence can be useful in making everyday decisions. Imagine that your family decides they want to eat more fruit and less cereal at breakfast. Your dad says he heard that having smaller package sizes of foods in the house reduces the amount people eat. He buys more fruit and smaller boxes of cereal and then claims that the family has met their goal.

   a. Did he support his claim?

   b. Identify the relevant evidence and explain your reasoning.

   c. Explain what additional evidence could support his claim.

5. How do you think scientists know when they have enough information to construct a scientific explanation?

ACTIVITY 8

Science is a Human Endeavor

VIDEO

8: SCIENCE IS A HUMAN ENDEAVOR

Activity 8 is still under development and will be available in future downloads

CONCEPTUAL TOOLS

SENSES & INSTRUMENTATION

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

SCIENTIFIC OPTIMISM

ACTIVITY 9

Water Quality Design Challenge

LABORATORY

9: WATER QUALITY DESIGN CHALLENGE

GUIDING QUESTION

How can you utilize the processes of iteration and collaboration to construct a device to improve water quality?

INTRODUCTION

People are developing relatively low-cost and effective technologies for testing and treating local water sources, which can increase the amount of water available for people to use. In 2017, 12-year-old Gitanjali Rao (pictured on the following page) heard about the water issues in Flint, Michigan, and created a prototype device to detect lead in water. Her prototype included a 3-D-printed frame, a carbon nanotube sensor, and an internal processor. If lead was present, it would bind to the nanotube, create resistance, and send the data to a smartphone app. In 2022, a team of researchers from the Massachusetts Institute of Technology (MIT) in Boston, Massachusetts (pictured on the following page), developed a water desalination unit that removes salts from saltwater quickly and cheaply. In about half an hour, the device produces a cupful of clean drinking water. The unit requires less power to operate than a phone charger, weighs less than 10 kg (22 lbs), and costs around $50. MIT researcher Jongyoon Han said, “This is really the culmination of a 10-year journey that I and my group have been on. We worked for years on the physics behind individual desalination processes, but pushing all those advances into a box, building a system, and demonstrating it in the ocean, that was a really meaningful and rewarding experience for me.” In this activity, you will work in teams to design and revise a simple water-filtration device.

CONCEPTUAL TOOLS

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

SCIENTIFIC OPTIMISM

Gitanjali Rao working in the lab.

MIT desalination research team in 2022.

MATERIALS LIST

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
- ACTIVATED CHARCOAL
- BAKING SODA
- COARSE SAND
- FINE SAND
- GRAVEL
- RULER (cm)
- 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

FOR EACH STUDENT

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

PROCEDURE

PART A: INITIAL DESIGN

1 Read the following scenario.

Now that you have experience testing for water quality, Skipton's city council has reached out to you to work with someone on the Water Resources Control Board to educate local elementary students on how water treatment works.

Your goal is to create an efficient, cheap water-filtration device that:

1. reduces the turbidity of water.

2. adjusts the water to a safe pH level.

3. simulates the removal of harmful contaminants. The red dye in your contaminated water sample represents contaminants such as harmful metals or toxins that can affect living organisms.

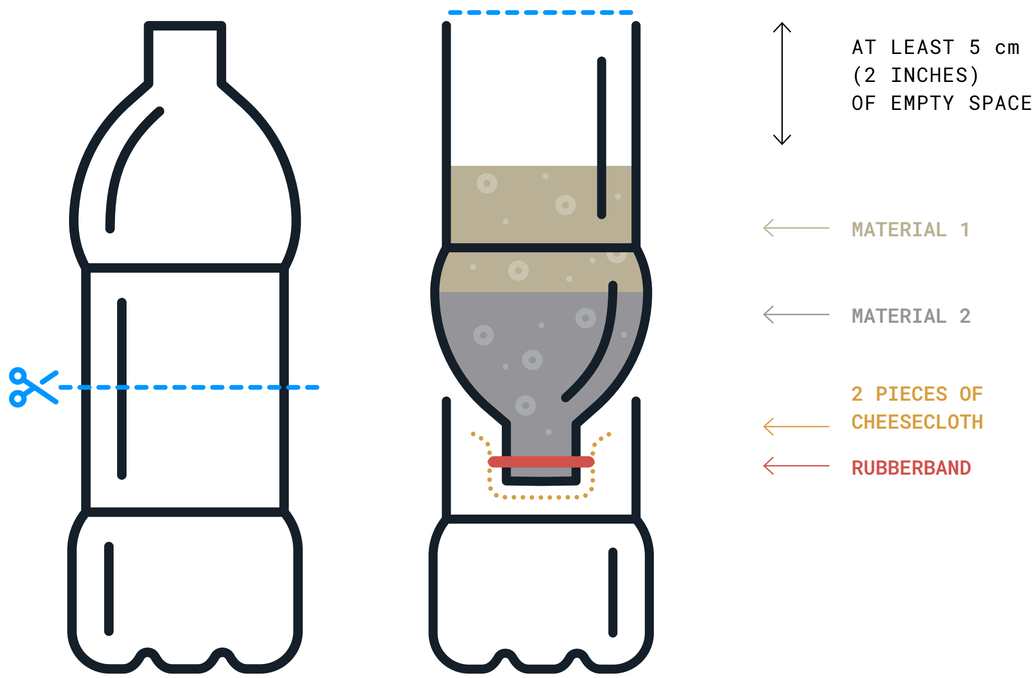
You will choose among various materials that can be used to filter the contaminated water sample that needs to be treated. Your design must use a plastic water bottle that is cut in half, cheesecloth, and a rubber band.

SAFETY NOTE

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

2 Look at Figure 9.1, which shows the basic design of your filtration device. Brainstorm with your group about which two of the following materials—activated charcoal, baking soda, coarse sand, fine sand, gravel—you would like to use to treat the water and why. Record in your science notebook the material you think will best treat the water's pH, turbidity, and contaminants.

FIGURE 9.1
Water-bottle setup for testing filtration materials



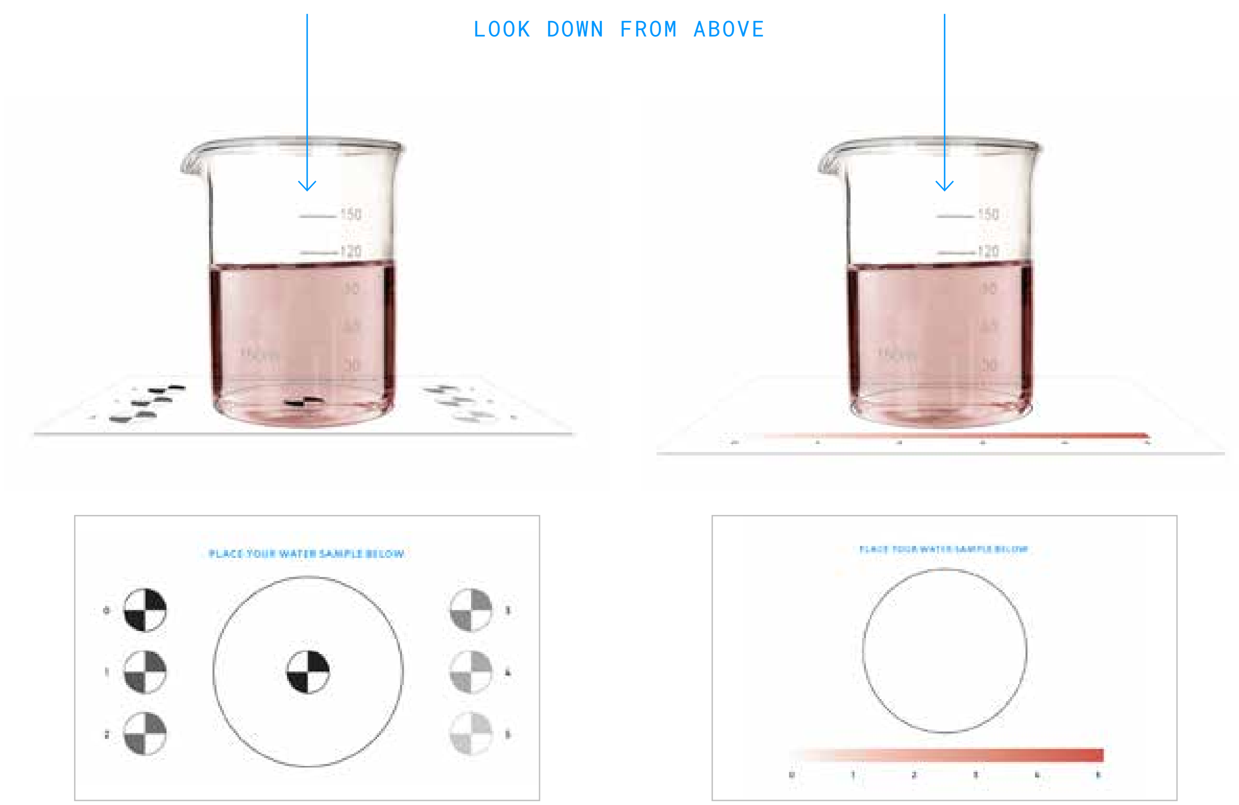
3 Before you build your device, test the turbidity, contaminant level, and pH of your water sample by pouring 100 mL into the empty beaker and completing the following steps.

a Measure turbidity by stirring the sample and placing the beaker in the middle of the Turbidity Rating Model card, as shown in Figure 9.2. The turbidity rating can be measured by looking straight down through your sample and choosing the Secchi disk (numbered 0–5) that most closely matches the one below your sample. Record your results on Student Sheet 9.1, "Filtration Design Challenge."

b Measure the contaminant level by placing the beaker with the sample in the white space above the colored scale of the Contaminant Level Rating card. The contaminant rating can be measured by looking straight down through your sample and choosing the color on the measurement card that most closely matches your sample (0–5). Record your results on Student Sheet 9.1.

c Test pH by dipping a piece of pH paper into your sample and comparing it to the pH scale for your pH paper. Record your results on Student Sheet 9.1.

FIGURE 9.2
Estimating turbidity and contaminant level using the measurement cards.



4 Plan the design of your filtration device by deciding on the order of placement of the two materials in your device and the thickness of each layer (in centimeters). Record your choices in Table 9.1 on Student Sheet 9.1. Then rinse out your testing beaker and follow your teacher's instructions for gathering your materials.

5 Attach 2 pieces of the cheesecloth across the neck of the bottle with a rubber band, as shown in the diagram of the water-bottle setup in Step 2. Add your 2 filtration materials to the inside of the bottle while keeping it over the second piece of the cut bottle. Note: You must leave at least 4 cm of empty space between the uppermost layer of filtration material and the very top of the bottle for the water sample.

6 Pour 150 mL of the water sample into the top of your filtration device. You may wish to note the time in order to record the amount of time it takes for the water to filter through your device. You can also measure the total amount of water recovered.

7 After the water has been filtered through, pour it into an empty beaker similar to the one used for your control. Compare the filtered water sample to that of clear tap water.

8 Test your filtered solution for turbidity, contaminant level, and pH as described in Step 3. Record your results in the second row of Table 9.2 on Student Sheet 9.1 and compare your test results to your initial ideas.

PART B: COLLABORATION WITH OTHER GROUPS

9 As a group, visit at least two other teams to:
   a share the results of your filtration device.
   b learn about their use of materials and their results.

10 Based on these findings, record in your science notebook at least two ideas for improving your filtration device.

PART C: ITERATION OF YOUR DESIGN

Filtration device

11 As a group, work together to decide how you will improve the design of your filtration device. For your second iteration, you may choose up to 3 filtration materials but must still leave at least 4 cm of empty space at the top. Record in your science notebook how you think these materials will affect turbidity, contaminant level, and pH. Note: You may use different materials or some of the same materials used in your first iteration. Rinse out your testing beaker and follow your teacher's instructions for gathering your materials.

12 Build your second filtration device with your three chosen materials, once again recording the order and thickness of your layers in Table 9.1 of Student Sheet 9.1.

13 Pour 150 mL of the water sample into the top of your filtration device. You may wish to note the time in order to record the amount of time it takes for the water to filter through your device. You can also measure the total amount of water recovered. If you saved a sample of filtered water from your first iteration, you can also compare the water samples.

14 Test the filtered solution for turbidity, contaminant level, and pH as described in Step 3. Record your results in the third row of Table 9.2 on Student Sheet 9.1.

15 Re-evaluate the ideas for your second design based on your new results.

  a As a group, compare your findings to at least two other teams and record in your science notebook two or more new or revised ideas.

  b Based on your findings and those from other teams, evaluate which parts of your design were a success and which still need to be improved upon. Record your ideas in your science notebook.

  c Work together to propose a design for a third iteration of your filtration device. As before, you may choose up to 3 filtration materials but must still leave at least 4 cm of empty space at the top. Record your ideas in the last column of Table 9.1 on Student Sheet 9.1.

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.

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.

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

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.

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.

EXTENSION

Revision of scientific ideas can sometimes occur quickly. The Internet started as a way for government researchers to share information quickly and easily. Find out how the invention of the Internet was a result of iteration, collaboration, and scientific advancement by doing research online.

KEY SCIENTIFIC TERMS

desalination

ACTIVITY 10

Solutions Through Scientific Optimism

PRESENTATION

10: SOLUTIONS THROUGH SCIENTIFIC OPTIMISM

GUIDING QUESTION

How are key scientific ideas reflected in modern solutions to regional water issues?

INTRODUCTION

Over the years, many individuals and teams from different nations and cultures have contributed to fields of science such as water quality. In 2016, microbiologist Joan Rose received the Stockholm Water Prize, a prestigious global award that recognizes outstanding achievements in water-related activities. She is considered one of the world's authorities on the parasite *Cryptosporidium*. She was recognized for her research and her ability to clearly communicate her scientific findings to others, such as governmental policy makers. In 2012, the entire International Water Management Institute of Colombo, Sri Lanka, was awarded the prize for their research in improving agricultural water management, helping reduce poverty in developing countries.

The Skipton scenario was based on a 1993 outbreak of *Cryptosporidium* in Milwaukee, Wisconsin, that affected more than 400,000 people, 69 of whom died. In this activity, you will brainstorm solutions, gather information, and construct a plan for addressing water needs for a specific region by using currently available tools and techniques. You will then construct a *public service announcement* (PSA), an educational message created to raise awareness and change people's attitudes or behavior.

CONCEPTUAL TOOLS

MULTIPLE LINES OF EVIDENCE

SENSES & INSTRUMENTATION

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

SCIENTIFIC OPTIMISM

CREDIBLE SOURCES

MATERIALS LIST

FOR EACH PAIR OF STUDENTS

— COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

— STUDENT SHEET 10.1 "Water Solutions and Key Concepts"

— STUDENT SHEET 10.2 "Research Notes for a PSA"

— MATERIALS REQUIRED FOR PSA

PROCEDURE

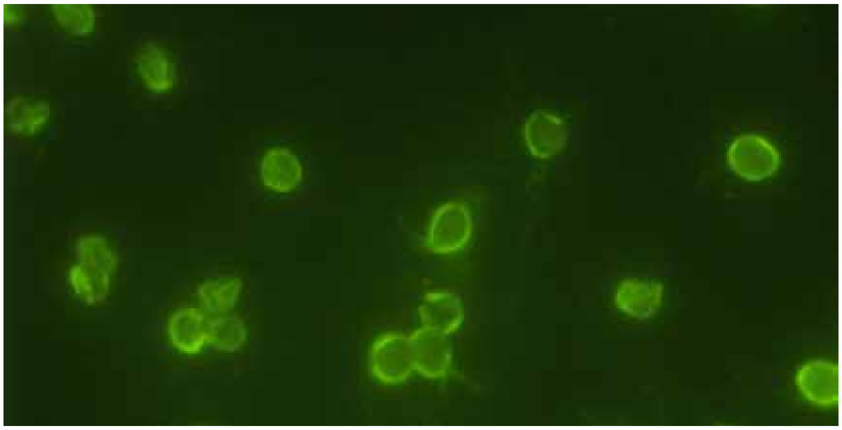
PART A: SOLVING THE FRESHWATER PROBLEM

1 As a class, brainstorm a list of the water issues raised in this unit. Add any additional issues related to water that are relevant to your local community.

2 With your group, select one of the water issues you identified. Brainstorm solutions to addressing this issue and record your responses in your science notebooks.

3 Discuss the following questions with your group:

- Do the scientific tools and technologies required to implement your solution exist today? If not, explain how you think they could be created.
- Based on your discussion, do you feel optimistic about the future of water? Explain why or why not.



One stage of *Cryptosporidium's* life cycle can be seen under a light microscope with the use of a fluorescent dye.

PART B: CURRENTLY PROPOSED WATER SOLUTIONS

4 You learned in this unit that there are many scientific tools, techniques, and ways of thinking that can be useful for solving complicated problems. Student Sheet 10.1, "Water Solutions and Key Concepts," contains a list of some of the key concepts that you have learned. Take a moment to read through these concepts and discuss with your partner about the many places in the unit where you encountered these ideas.

5 Many people are working together to solve global water needs. Eight proposed solutions (A–H) are described here. Read a summary of one of these solutions, as directed by your teacher.

6 Discuss with your partner how your paragraph about the water solution is connected to the unit concepts listed on Student Sheet 10.1.

   a Identify and mark the concepts you think are relevant to your water solution.

   b Work with another pair of students who read the same paragraph to create a short summary of your water solution, in your own words.

   c Present your summary to the class.

   d As you listen to other group's summaries, mark which concept(s) are most relevant to the described solution.

A. WATER CONSERVATION

Water conservation is the practice of using water efficiently to reduce unnecessary water usage. Individuals can reduce water use by turning off water when brushing teeth, shaving, taking shorter showers, and using dishwashers and washing machines with full loads only. Communities can use low-water plants in public spaces and install water-efficient faucets and toilets in city buildings. The city of Cape Town, South Africa, reduced its overall water consumption even as the city's population increased over a 15-year period. They used technology to detect leaks in piping, adjust water pressure, and improve water meters. They also educated the community on how to consume less water.

Cape Town, South Africa's capital city, has focused on water conservation as it has struggled to meet the water needs of its growing population.

B. WATER STORAGE

Water storage refers to holding water in a contained area for a period of time. Manufactured types of water storage range in size from rain barrels and household water tanks to city water towers, industrial holding ponds, and large dam reservoirs such as Lake Kariba. Located between Zambia and Zimbabwe in Central Africa, Lake Kariba is the largest artificial lake in the world and was formed by damming the Zambezi River. It extends for 217 kilometers (135 miles) and holds up to 180 cubic kilometers of freshwater. On a smaller scale, local people in India's Alwar district turned to traditional *johads*, earthen dams that capture rainwater and recharge reserves of groundwater under the surface. After local people built more than 3,000 johads, groundwater tables rose nearly 18 feet, and adjacent forest cover increased by a third.

Large-scale dam projects, such as the Kariba Dam, create large reservoirs for water storage.

Smaller-scale water-storage projects, such as this johad in the village of Thathawata in Rajasthan, India, can have more direct benefits for locals.

C. WATER TRANSPORTATION

Humans have been transporting water from place to place for thousands of years, with the earliest evidence coming from text describing irrigation networks in Mesopotamia during 2475–2315 B.C.E. *Water transportation* is the intentional movement of water over large distances, usually via canals or long-distance pipelines. Unless it has the assistance of gravity, water transportation requires pumping stations at regular intervals and can be very expensive due to the weight of water. China is implementing a water project that will redirect over 44 billion cubic meters of water per year from its southern rivers to its drier north. First proposed in 1952 and planned for completion in 2050, the project will link China's four main rivers—the Yangtze River, Yellow River, Huaihe River, and Haihe River—and is expected to cost about $62 billion.

Water from the Danjiangkou Reservoir (seen in the distance) will travel north via a canal system. This is one of the starting points of China's South-North water transfer project.

D. WATER RECYCLING

Water recycling (also known as water reuse or water reclamation) collects water from a variety of sources before treating it for reuse. Sources of water can include household wastewater, industrial wastewater, stormwater, and agricultural runoff. Water must then be treated to meet specific requirements for a particular reuse. For example, recycled water for crop irrigation would need to meet standards that would prevent harm to plants and soils, maintain food safety, and protect the health of farmworkers. The process of osmosis (materials passing through a membrane) was first described by French physicist Jean-Antoine Nollet in 1748. In 1959, Srinivasa Sourirajan and Sidney Loeb invented reverse osmosis, a pressure-driven membrane separation system that removes 99% of water contaminants such as dissolved solids and bacteria. Places using recycled wastewater for drinking water include Australia, Singapore, Namibia, South Africa, Kuwait, the United States, and the United Kingdom.

Recycled wastewater is treated and then used to water plants.

E. DESALINATION

Desalination is the removal of salt from saltwater and is a process that has been around for thousands of years. Greek sailors used to boil water to evaporate freshwater away from the salt and then condense the vapor into drinkable water, and Romans used clay filters to trap the salt. Today, the most common methods utilize distillation or filtration. As described in the introduction of Activity 9, new scientific desalination technology continues to be developed because desalination is both energy intensive and expensive. There are about 15,000 desalination plants around the world, with the biggest plants in the desert countries of the United Arab Emirates, Saudi Arabia, and Israel. These countries utilize solar energy and other emerging technologies to make desalination more sustainable.

Desalination plant in Ras Al Khaimah, United Arab Emirates.

F. NATURE-BASED SOLUTIONS

As cities have expanded, people have paved over wetlands and floodplains and diverted waterways such as creeks. This has resulted in less rainwater seeping into the ground to refill underground aquifers. Some cities are now investing in nature-based solutions by restoring watersheds—such as creeks, wetlands, marshes, and floodplains—that naturally absorb and filter surface water before filling underground aquifers. In 2000, Chinese landscape architect Kongjian Yu proposed "sponge cities" in which there is more green space for plants, the use of native vegetation that requires less water, green roofs that have a layer of plant material that absorbs water, and the construction of large dirt pits that capture rainwater instead of letting it wash away. Auckland, New Zealand; Nairobi, Kenya; Singapore; Mumbai, India; New York, New York; and Shanghai, China, are cities in which about 1/3 of the city is considered "spongy."

Nature-based water solutions such as restoring natural wetland habitats can help reduce flood risk while helping recharge groundwater reserves.

Adding more green spaces with native vegetation to urban areas can help reduce flood risk while helping recharge groundwater reserves.

G. RAINWATER CAPTURE

Rainwater capture is the practice of collecting and storing rain for reuse, rather than letting water run into urban storm drains or natural water bodies. Techniques to capture rainwater include permeable pavement, bioswales, and rain catchment. Permeable pavement typically involves using gravel and paving stones instead of a solid piece of concrete for driveways, sidewalks, and patios. These materials allow water to seep into the ground below, while still being strong enough to support cars and people. Bioswales are long ditches planted with vegetation, allowing more water to sink into the ground instead of running off into storm drains and creeks. Rain catchment systems can be as simple as placing a large rain barrel at the downspouts of a building's gutter system. In Mexico City, Mexico, water activist Enrique Lomnitz and others collaborated with geographer Elizabeth Tellman to identify the parts of the city that would benefit most from rain catchment. In 2019, 10,000 systems were installed.

Rainwater capturing techniques: rainwater catchment system

Rainwater capturing techniques: permeable pavement

Rainwater capturing techniques: bioswale

H. GEOLOGICAL PALEO VALLEYS

University of California, Davis, professor Graham Fogg first suggested using paleo valleys for water management almost 40 years ago. Paleo valleys are prehistoric riverbeds that formed thousands of years ago in the last ice age as rivers flowed from melting glaciers. It took Fogg and his students nearly 25 years to identify just three paleo valleys, using thousands of soil samples from wells. More recently, Stanford University geophysicist Rosemary Knight collaborated with Fogg to use specialized electromagnetic imaging cameras mounted on helicopters to study California's Central Valley. They have discovered several ancient paleo valleys that could be part of a solution to the state's water crisis. While the ancient riverbeds are currently just below the surface, they are highly permeable due to the type of sediment (layers of coarse sand and large gravel) they contain. Scientists hypothesize that if rainwater could be directed to these areas, water could flow more quickly to the underground aquifers that supply local towns and agriculture with freshwater. More research is needed to find more efficient ways of identifying more of these paleo valleys, both in California and in other places around the world.

Helicopter carrying an electromagnetic imaging camera to survey the geology in California's Central Valley.

PART C: DEVELOPING A REGIONAL SOLUTION

7 Your teacher will guide you on selecting a community or country to investigate. Research and record the following information about this region on Student Sheet 10.2, "Research Notes for a PSA":

- general geographic location
- primary source of drinking water
- most pressing water issues facing this region
- currently utilized solutions to water issues facing this region

8 Share your research with your group. Discuss similarities and differences in your region's water issues.

9 Consider what you learned from your research and in Procedure Parts A and B. Discuss with a partner what you think is the best approach to addressing your region's drinking water issues over the next few decades.

10 Develop a plan for addressing your region's drinking water issues over the next few decades by doing the following:

a identifying and listing the solutions most relevant to your region.

b prioritizing these solutions from the most to least important for your region.

c describing how these solutions will help address drinking water issues in this region.

PART D: COMMUNITY PUBLIC SERVICE ANNOUNCEMENT (PSA)

11 One commonly recognized element of addressing global water issues is education. Public service announcements (PSAs) are intended to provide useful and important information to the public; they are not selling a specific brand or service. People who create PSAs are responsible for making sure that the information is correct and helpful. This means that claims should be supported by relevant, accurate, and reliable evidence.

Create a PSA to communicate one or more aspects of your regional solution to the local community.

a Decide on your format
(video, poster, comic strip, song, etc.)

b Decide on your audience
(elementary school children, general public, etc.)

c Brainstorm ideas.

d Create your PSA, making sure that it:
- contains scientific information.
- is accurate.
- addresses other class requirements.

12 Share your PSA with your class.

BUILD UNDERSTANDING

1. Consider which characteristics of your region informed your choice of water solutions.
   a. What is one characteristic in this region that may change in the future due to climate or economic changes?
   b. If this change occurs, how would it affect your proposed solution?
   c. How could you modify your proposal to address this change?

2. You began this unit by making decisions about Skipton's water supply.
   a. Based on what you know now, would you change your decision? Why or why not?
   b. Are there other decisions you made during this unit that you would change? Explain.

3. How do you think global water issues, such as water quality and water availability, should be addressed? Support your answer with multiple lines of evidence from this unit and identify the trade-offs of your decision.

CONNECTIONS TO EVERYDAY LIFE

4. Many people think that advances in science and technology will eventually result in solutions to most global problems. Do you agree or disagree? Explain your ideas.

5. How can the concepts you learned in this unit be applied to your own life?

EXTENSION

Historically, constructing dams and levees to contain water have been one approach to addressing water scarcity. Today, new approaches—some of which are based on the traditional knowledge of local communities—are being considered. Search online to discover the most recent research and latest innovations in addressing global water issues.

STUDENT GLOSSARY

accuracy
closeness of a measured value to a standard or true value

claim
a statement that asserts something is true

collaborate
work jointly with others, often to accomplish a common task.

contaminant
any physical, chemical, biological, or radiological substance in water (as defined by the U.S. Safe Water Drinking Act)

control
standard of comparison for checking or verifying the results of an experiment; results of the experiment are compared with the control in order to see if the variable changed in the experiment caused any effect

credible source
one with relevant expertise which provides accurate information that is free from bias

data
information gathered from an experiment or observations

desalination
removal of salt from saltwater

evidence
information that helps support or refute a claim or leads to the development of a new claim

genome sequencing
a way of determining an organism's DNA sequence

hypothesis
possible explanation for observations, facts, or events that may be tested by further investigation

indicator
any visible sign that shows the condition of the system being studied; in chemistry, a chemical that indicates the presence, absence, or concentration of a particular substance

iteration
the revision of an idea or process

iterative
repeating a process or action, usually to improve it

johad
traditional earthen dam in India that captures rainwater and recharges reserves of groundwater under the surface

live-cell imaging
a way of seeing living cells, using time-lapse microscopy

multiple lines of evidence
data from two or more investigations that support a claim

paleo valleys
prehistoric riverbeds that formed thousands of years ago in the last ice age as rivers flowed from melting glaciers

pH
a measure of how acidic or basic a solution is; the pH scale measures the relative concentration of hydrogen ions (H+), utilizing a scale where 1–6 is classified as acidic, 7 as neutral (neither acidic nor basic), and 8–14 is classified as basic

precision
how close measurements of the same item are to each other

public service announcement
an educational message created to raise awareness and change people's attitudes or behavior

rainwater capture
practice of collecting and storing rain for reuse, rather than letting water run into urban storm drains or natural water bodies

refute
prove an idea or statement to be wrong; disprove

relevant
closely connected to or related to the idea or question being considered

reliable/reliability
able to be reproduced consistently

shared external reality
the physical world is observed by many people in similar ways

science as a human endeavor
people from many nations and cultures seek to improve their understanding of the natural world

scientific advancement
the progress of science toward more accurate, reliable, and complete explanations of phenomena

scientific law
well-supported explanation of the natural world that has been repeatedly tested using observations, measurement, experimentation, and evaluation of results

scientific optimism
the belief that persistence and iteration on a scientific problem will eventually lead to insights

senses and instrumentation
data gathered by human senses and/or scientific tools and techniques

solubility
ability of a substance to dissolve in another substance

theory
a well-supported explanation of the natural world that has been repeatedly tested using observations, measurement, experimentation, and evaluation of results and may incorporate scientific facts, hypotheses, and scientific laws

toxicity
quality of being very harmful or poisonous

trade-off
an exchange of one valued outcome for another by giving up something that is a benefit or advantage in exchange for another benefit that may be more desirable

turbidity
a water quality indicator that refers to how clear the water is and indicates the presence of suspended particles such as soil or algae

validation
process of determining the accuracy of a measurement

water conservation
practice of using water efficiently to reduce unnecessary water usage

water recycling
collection of water from a variety of sources before treating it for reuse; also known as water reuse or water reclamation

water storage
holding water in a contained area for a period of time

water transportation
intentional movement of water over large distances, usually via canals or long-distance pipelines

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