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.

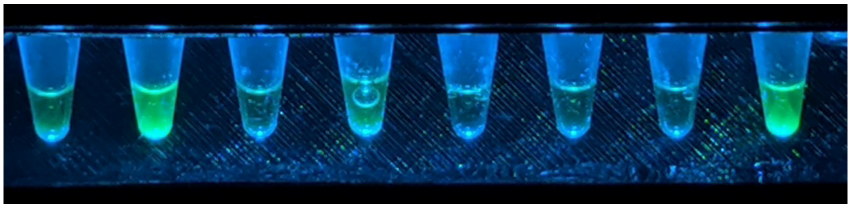
CASE STUDY 3 ADDRESSING WATER QUALITY THROUGH ITERATION

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.

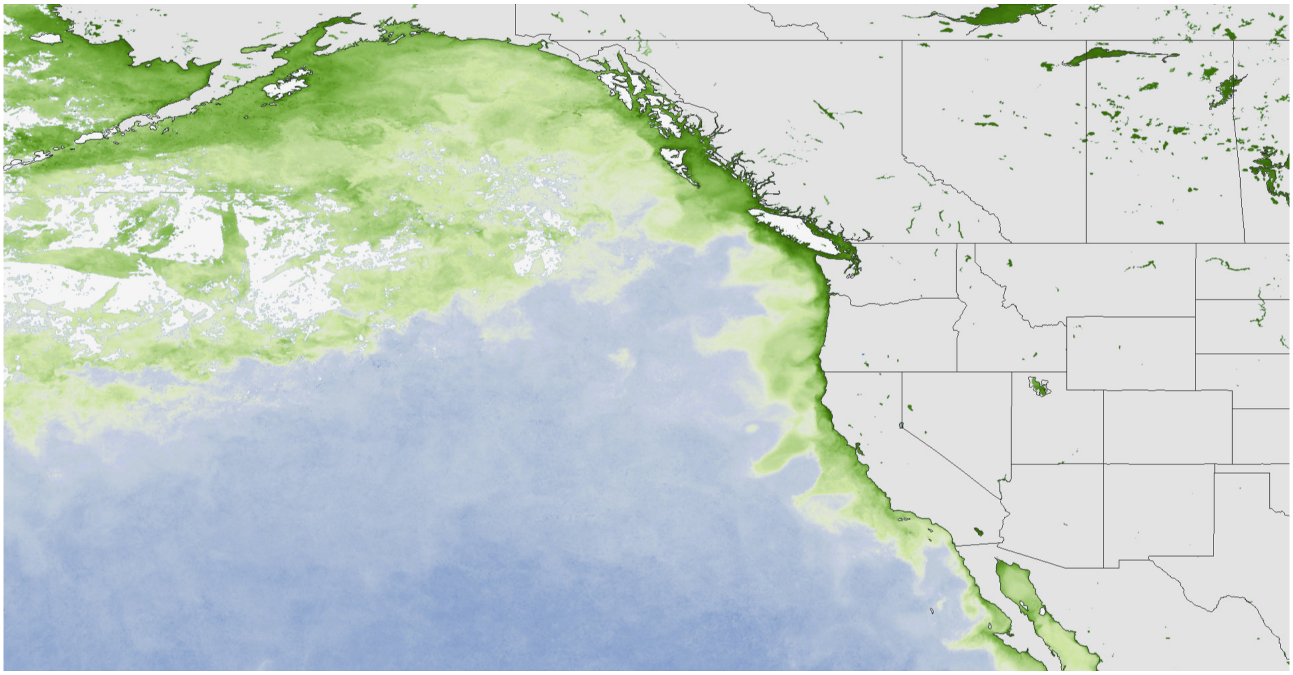
Despite the setbacks in the process, Lucks and Young's team made several iterations and developed this nanotechnology quickly. When asked how they did it, Lucks said his motto is "Fail fast." In other words, go as fast as you can, fail, and learn from your failures.

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



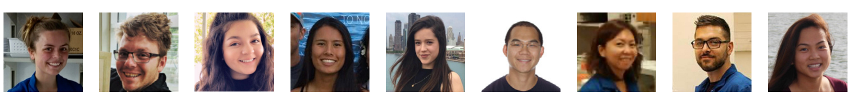
CHLOROPHYLL (mg/m³)
0 0.05 30

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