ACTIVITY 7

Evidence and Explanations

CARD-BASED INVESTIGATION

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ACTIVITY SUMMARY

Students further investigate the use of multiple lines of evidence to support or refute a scientific explanation, using the context of cholera outbreaks in 19th-century London. They compare their thinking about cholera transmission to three widely held explanations of the time. Students receive Evidence cards and evaluate which explanation is most substantiated by the evidence. They brainstorm investigations that could provide additional evidence.

ACTIVITY TYPE
CARD-BASED INVESTIGATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1–2

KEY CONCEPTS & PROCESS SKILLS

1 The development of scientific knowledge is iterative; it occurs through the continual reevaluation and revision of ideas that are informed by new evidence, improved methods of data collection and experimentation, collaboration with others, and trial and error.

2 Through science, humans seek to improve their understanding and explanations of the natural world. Individuals and teams from many nations and cultures have contributed to the field of science.

CONCEPTUAL TOOLS

TEACHER BACKGROUND INFORMATION

History of Water Treatment and Waterborne Disease

The recognition of the importance of clean water began in prehistoric times. Recorded knowledge of water treatment is found in Sanskrit medical texts and in Egyptian inscriptions dating back to the 15th century B.C. Boiling of water, the use of wick siphons, filtration through porous vessels, and even filtration with sand and gravel as a means to purify water are methods that have been prescribed for thousands of years. The first widely referenced evidence of waterborne disease were the studies of cholera done by Dr. John Snow in 1854. During the 17th to the early 19th centuries, a number of improvements in water supply were made, primarily new filtration techniques that improved water turbidity. During this same period, the germ theory of disease became established as a result of research by Louis Pasteur, Robert Koch, and others. In 1884, Koch isolated the cause of cholera—the bacteria *Vibrio cholera*.

John Snow and Evidence for Cholera Transmission

This activity is based on a historical case study. Initially, most scientists believed cholera was transmitted via miasma, or bad air that rose from contaminated rotting material in the ground. But in the 1850s, John Snow collected evidence that made him believe that contrary to the miasma theory, cholera was transmitted through contaminated water. At first he had difficulty convincing people, so he collected more evidence. Still, most people were not convinced. Snow believed cholera was spreading because the neighborhood well, the Broad Street pump, was contaminated with feces from the open sewers. He tried removing the handle from the Broad Street pump, making it impossible for people in the neighborhood to get water from that well. The spread of cholera stopped. This evidence convinced most people of the contaminated water explanation. Because of this work, John Snow is often called the father of modern epidemiology.

Cholera in Modern Times

Cholera is an acute illness caused by infection of the intestine by the bacterium *Vibrio cholerae*. It is primarily spread through drinking water or food contaminated with the bacteria and is most prevalent in places with untreated drinking water or poor sanitation. Events that interfere with safe drinking water systems, including weather disasters, human conflict, and poverty, can contribute to outbreaks. An estimated 1.3–4 million people around the world get cholera each year, and 21,000–143,000 people die as a result. The majority of people who get cholera have mild symptoms or no symptoms. Approximately 10% of infected people develop severe symptoms such as diarrhea, vomiting, and cramps. In these cases, the rapid loss of body fluids can lead to dehydration and sometimes death; rehydration and antibiotics are used to treat the disease. A cholera vaccine is available, though it is effective for relatively short periods (6 months for children aged 2–5 and 2 years for adults), becoming less effective over that time.

MATERIALS & ADVANCE PREPARATION

FOR EACH GROUP OF FOUR STUDENTS

- 15 EVIDENCE CARDS
- 3 EXPLANATION CARDS

FOR EACH STUDENT

- STUDENT SHEET 7.1 "Evaluating Evidence"

You may find it helpful to reproduce the Evidence cards in a different color than the Explanation cards for easy reference and sorting.

TEACHER'S NOTE: Other curriculum produced by SEPUP utilizes the story of John Snow to teach scientific concepts. This activity, while utilizing the same historical event, is a different activity than those found in other SEPUP materials.

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Elicit students' experience of being ill.**

- Invite students to describe a time they felt sick, but they did not know why, and what evidence they used to guess at the cause of their sickness.
- Ask, Why did you want to know what made you sick? Students are likely to respond that if they knew the cause, they could better treat their illness and avoid that source of illness in the future (and, thus, avoid getting sick again).
- Some questions in this activity may require sensitivity, depending on students' individual experiences. Questions about serious illness can require particular care. Some students or their family members may have been seriously ill (or died) due to the COVID–19 pandemic, an example raised in Build Understanding item 3. Modify the Introduction and questions in this activity as needed.

2 **Read the Introduction in the Student Book to set the context for the activity.**

- Point out that cholera is an illness that has been identified and diagnosed since the 1800s. Do not focus on the cause or transmission of the disease at this point in the activity—that is the focus of the activity itself.
- Let students know that in this activity, they will use what they have learned thus far—namely that science knowledge is based on multiple lines of relevant, accurate, and reliable evidence—to identify how cholera is transmitted.

PROCEDURE SUPPORT (25–30 MIN)

3 Present the scenario of the cholera outbreak during 1850s London found in Procedure Step 1.

- The procedure takes students through the experience of the scientists in England in 1850 who initially had incomplete evidence, which made the incorrect explanations seem more likely than the correct explanation.
- The scenario presented in Step 1 can be shared with the class in multiple ways. Read the scenario aloud to the class or have individual students read it aloud while others follow along with the text (either as a whole class or in small groups).
- Reading aloud can better support comprehension for many students, including neurodiverse students and emerging multilingual learners, who often have more highly developed listening and oral skills than reading comprehension skills. Alternatively, students can read the scenario independently.

4 Students brainstorm possible modes of cholera transmission and compare their ideas to three Explanation cards.

- Based on their prior knowledge and the information in the scenario, students are likely to conclude that the disease is infectious (vs. genetic or some other type of disorder). Students may hypothesize that the disease is spread through direct contact, such as touching; is airborne; or is transmitted through contaminated food or water.
- The three Explanation cards represent ideas popular at the time, including miasma (bad air), effluvia (airborne), and foul water (contaminated water).
- Students may consider that evidence of a contaminated food source could provide evidence for contaminated food. Respiratory symptoms such as coughing might provide evidence for an airborne illness, while finding evidence of a parasite could provide evidence for spreading through direct contact.
- Most students will not propose evidence for miasma (bad air) since that explanation appears unbelievable through modern eyes; it was, however, the most popular theory at the time. You may want to ask students what aspects of the miasma explanation are similar to or different from modern scientific knowledge about disease transmission.

5 Groups examine Evidence cards 1–4.

- Groups work together to determine whether each Evidence card supports one or more of the three explanations or is not relevant evidence.
- Students should record their responses on Student Sheet 7.1, "Evaluating Evidence." A sample response to Student Sheet 7.1 is found at the end of this activity.

- Facilitate the engagement of students with learning disabilities and neurodiverse learners by providing targeted support. Consider how to best adapt the activity to the needs of your particular student population. Students who need more time processing language (such as students with dyslexia) can be provided with a set of the cards in advance of the day's activity.

- While groups work, walk around and ask students to share their thinking about the Evidence cards and the cards' relationship to one or more of the explanations. For example, students may note that people got sick in the same family within a few days of each other, supporting the airborne explanation because families breathe the same air. This explanation could also be supported by the fact that people were regularly interacting with one another (and breathing the same air).

- Encourage students to reflect on their own thinking processes in terms of evaluating the evidence and considering how it might support one or more of the three explanations. If students disagree about the relevance of a piece of evidence to a particular explanation, encourage them to explain their thinking to the group and to consider what might convince their group members to change their minds about their conclusion.

6 Hand out Evidence cards 5–15 to each group.

- The remaining Evidence cards provide more support for the three explanations. Encourage students to discuss the additional evidence with their groups and evaluate how it supports each of the explanations.

- Procedure Steps 6 and 8 provide opportunities for metacognitive thinking. Reflecting on one's confidence level can help reduce overconfidence by reminding students to consider potential sources of uncertainty or error. Point out this opportunity for student self-reflection and have students share their confidence levels, as well as what factors contributed to these levels, at these two different points of the activity.

7 Students evaluate the evidence supporting the three explanations.

- Students are likely to conclude that foul water (contaminated water) is the source of cholera transmission. Much of the evidence, such as the proximity of smelly (potentially leaking) sewers to the well, support this explanation.

- Suggestions for stopping the spread of cholera through contaminated water may include getting drinking water from another well, treating the contaminated water by filtration or boiling, repairing or moving potentially leaking sewers to stop the likely source of contamination, or digging a drinking water well at another location.

- Discuss students' ideas from Procedure Step 9 by asking, What other evidence would help you be more confident in your conclusion? Students may want to know whether cholera could be detected in the water, whether the water could be analyzed in some other way, or if boiling drinking water

helped people avoid getting sick. Finding out that there was no evidence of cholera in the water or that treating the water did not reduce disease transmission might change students' minds about the source of the spread.

- Possible investigations include preventing the use of the Broad Street pump for drinking water and determining if this action stops the spread (as was done by John Snow) or by testing the water by having a few animals drink the water and observing if they also get sick. Students may also suggest investigations using modern scientific tools and techniques that were not available or well established at the time.

SYNTHESIS OF IDEAS (10 MIN)

8 Discuss the quantity and quality of evidence supporting the explanations.

- Evaluate if your students are able to identify the essential ideas of the activity related to the key concepts and process skills by asking the Guiding Question, *What is the role of evidence in evaluating scientific explanations?* Highlight the roles of both quality and quantity of evidence in constructing a scientific explanation. Ask, What was more important in making your decision about cholera transmission: the quantity or quality of evidence? There was some evidence supporting each explanation, but the evidence supporting foul water was more accurate and reliable, and there was the most evidence for it. Discuss the importance of evaluating the quality of evidence as well as the quantity. For example, having large quantities of biased, inaccurate, or unreliable evidence would lead to suspect explanations.

- Ask, Did you revise your initial explanation based on evidence? Explain your reasoning. Some students may have initially hypothesized that the spread of the disease would be airborne, like COVID–19. Have them identify what evidence was most convincing in changing their thinking.

- Connections to Everyday Life item 4 can be used to formatively or summatively assess students' ability to support or refute a claim.

9 Highlight common misconceptions about science that can influence decision-making.

- Highlight how this activity addresses two opposing common misconceptions of science by asking students to describe how making decisions about cholera transmission might reinforce one of the following misconceptions. Have students consider how they might address these misconceptions, either with their own thinking or with the thinking of others. The two common misconceptions are summarized here:

  - Sometimes people believe that science is always right or always progresses linearly toward greater accuracy with no false directions. This is untrue; science is a human enterprise, and people

make mistakes. In addition, limitations of human senses and scientific tools mean that data may not be available or may not have been gathered to make accurate and reliable conclusions.

- Sometimes when people learn that scientists make mistakes and their resulting claims may be uncertain, they conclude that people can believe anything and that there is no method for making conclusions reliably. However, the practices of science are designed deliberately to iteratively approach increasingly accurate descriptions of the world. They do this by (1) grounding claims in observations—evidence, and (2) continuing to be open to new observations that may reveal errors or limitations of earlier ideas based on more limited observations. By considering both previously collected evidence and new evidence, the full amount of information available to scientists to make sense of the world can keep on growing. More complete evidence makes it easier to form better explanations and theories.

- Highlight the connection between better scientific understanding and better solutions. For example, the germ theory of disease is not just more accurate, but it has led to interventions and treatments that are more likely to produce desirable outcomes.

- Connections to Everyday Life item 5 provides an opportunity for metacognitive thinking about the nature of science. Point out this opportunity for student reflection.

- Complete the activity by evaluating if your students are able to identify the essential ideas of the activity related to the key concepts and process skills by asking the Guiding Question, What is the role of evidence in evaluating scientific explanations?

SAMPLE STUDENT RESPONSES

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?**

Microscopes could have been useful to figure out the transmission sources more quickly. Scientists could have collected water samples and looked for evidence of microbial transmission.

② **The development of scientific knowledge is iterative and occurs through continual reevaluation 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.

Dr. Snow gathered new evidence by collecting, analyzing, and interpreting the cases of cholera. He improved the method of data collection by asking questions and mapping cases to observe patterns.

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

It was similar to the Skipton scenario because people became sick from a microbe in their drinking water. In both cases, it took time to gather evidence to prove that the contamination was in the water and not another source. It was different from Skipton because John Snow analyzed the data more methodically, looking for patterns between illness and the source of water. Also, people had a common water source vs. today when people have water piped directly into their homes. This means that there are more potential points of contamination in the water, and it can be difficult to make conclusions without lots of data.

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.

He was wrong—he did not support his claim. The only evidence he had was something he heard and what he shopped for. He did not explain who provided the information that he quoted, so it is difficult to determine if it is accurate. Also, he did not provide information about whether the family was eating less cereal, or if he was buying smaller boxes of cereal more often. To support his claim, he could provide evidence about how much cereal the family was eating before and how much they are eating now.

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

I think scientists know if they have enough information to construct a scientific explanation if they have multiple lines of reliable, accurate, and precise data that is validated through the scientific community. Scientists work with others in person and in the literature, and these people provide feedback on the scientific ideas that are presented.

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EVIDENCE	SUPPORTS EFFLUVIA (AIRBORNE) EXPLANATION	SUPPORTS FOUL WATER EXPLANATION	SUPPORTS MIASMA (BAD AIR) EXPLANATION	NOT RELEVANT TO ANY EXPLANATION
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

EVIDENCE	SUPPORTS EFFLUVIA (AIRBORNE) EXPLANATION	SUPPORTS FOUL WATER EXPLANATION	SUPPORTS MIASMA (BAD AIR) EXPLANATION	NOT RELEVANT TO ANY EXPLANATION
1	X		X	
2	X			
3	X		X	
4			X	
5		X	X	
6		X	X	
7		X		
8				X
9		X	X	
10		X		
11				X
12	X	X	X	
13		X		
14		X		
15		X		

EXPLANATION A
MIASMA (BAD AIR)

Cholera is caused by the transmission of poisonous vapors from foul smells due to poor sanitation.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 7

EXPLANATION B
EFFLUVIUM (AIRBORNE)

People who are ill with cholera give off effluvia in their breath, releasing contagious particles into the air, which can be inhaled into the lungs by others nearby.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 7

EXPLANATION C
FOUL WATER
(CONTAMINATED WATER)

Cholera comes from water that people drink that is contaminated by particles from the feces of other people who are infected with cholera.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 7

EVIDENCE 1

Hot weather caused the smell of untreated human waste in the River Thames to be so strong it was known as "The Great Stink." It occurred one summer in central London during a period of cholera transmission.

EVIDENCE 2

Residents of the area interacted with one another, though mostly outside. People who lived closer together interacted more often, especially those who lived in nearby houses. They often went in and out of one another's homes.

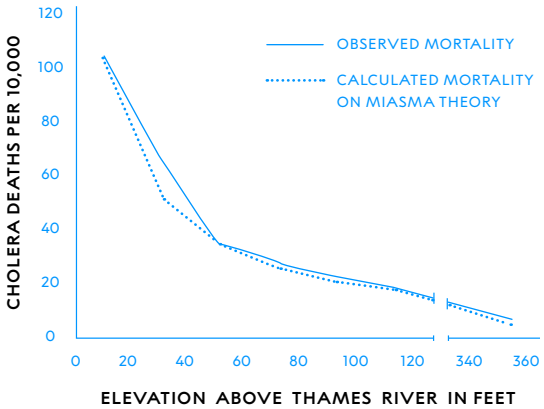
EVIDENCE 3

A number of people got sick with cholera a day or two after someone else in the same family became sick.

EVIDENCE 4

Dr. William Farr reasoned that soil at low elevations, especially near the banks of the River Thames, contained a lot of organic matter, which contributes to miasma (bad air). The concentration would be greater at lower elevations than in communities in the surrounding hills. He supported his reasoning with the following data.

Cholera Mortality, London 1849



EVIDENCE 5

Some of the patients who caught cholera had no contact with any previous victims.

EVIDENCE 6

There was a well below the Broad Street water pump that was 28 feet deep. At 22 feet down, near the well, there was a sewer. A few people reported that the water had smelled offensive or that it was a bit "off" near the time of the cholera outbreak.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
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EVIDENCE 7

Dr. John Snow mapped the cases of cholera during the 1849 outbreak and observed a pattern showing that the majority of cases surrounded the Broad Street water pump.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
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EVIDENCE 8

Patients with severe cholera were injected with a weak saline solution, causing them to look and feel much healthier for a short time.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
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EVIDENCE 9

A widow who had not lived near the Broad Street water pump died of cholera on September 2nd. Dr. Snow interviewed the widow's son and discovered that the widow had once lived on Broad Street. She had liked the taste of the well water there so much that she had sent her servant to bring back a large bottle of it every day.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
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EVIDENCE 10

The men who worked in a brewery on Broad Street did not get cholera. The men drank the beer they made or water from the brewery's own well and not the water from the Broad Street pump.

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EVIDENCE 11

There were four major cholera outbreaks in London between 1832 and 1866.

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EVIDENCE 12

In houses much nearer another water pump (not the Broad Street pump), there had only been 10 deaths.

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EVIDENCE 13

A factory at 37 Broad Street kept two tubs of water from the Broad Street water pump on hand for employees to drink; 16 of the workers died from cholera.

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EVIDENCE 14

Two water companies provided water pumps and supplied most of the water to London residents. Dr. Snow noted that the S&V Water Company supplied water directly from the River Thames in London, while the Lambeth Water Company had moved its water intake on the Thames upstream, outside of London.

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EVIDENCE 15

A prison nearby had 535 inmates but almost no cases of cholera. Dr. Snow discovered that the prison had its own well and bought water from a different water company, the Grand Junction Water Work.

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