UNIT 1 : EVIDENCE & ITERATION IN SCIENCE

v 1.0

SCIENTIFIC THINKING FOR ALL : A TOOLKIT

ACTIVITY 3

Scientific Advancement

CARD-BASED INVESTIGATION

ACTIVITY 3

Scientific Advancement

ACTIVITY SUMMARY

Students explore the development of scientific explanations over time. They investigate two timelines from the history of science. First, they organize the likely sequence of three events in one timeline. Then they place these events in a larger timeline containing multiple events in the development of the topic. Students discuss the role of evidence and advances in scientific tools and techniques in the development of scientific thinking.

ACTIVITY TYPE
CARD-BASED INVESTIGATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1–2

KEY CONCEPTS & PROCESS SKILLS

1. New scientific tools and techniques contribute to the advancement of science by providing new methods to gather and interpret data and can lead to new insights and questions. Technology can enhance the collection and analysis of data.

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

3. 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.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. *(Science and Engineering Practice: Engaging in Argument from Evidence)*

CONCEPTUAL TOOLS

SHARED REALITY

SENSES & INSTRUMENTATION

SCIENCE AS A HUMAN ENDEAVOUR

SCIENTIFIC ADVANCEMENT

VOCABULARY DEVELOPMENT

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

BACKGROUND INFORMATION

Scientific Advancement

The process of science is a way of building knowledge about the universe. Those ideas are initially tentative, but as they cycle through the process of science, they are tested and retested in different ways, resulting in increasing confidence in these ideas. Through this same iterative process, ideas are modified, expanded, and combined into more accurate explanations. For example, a few observations about inheritance patterns in garden peas can—through the work of many different scientists—be built into the broad understanding of genetics offered by science today. In this way, scientific knowledge is constructed, and there is scientific advancement in human understanding of the natural world.

MATERIALS & ADVANCE PREPARATION

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”
- STUDENT SHEET 1.4 “Unit Concepts and Skills” (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Discuss the graph in the introduction of the Student Book.**

- Have students carefully examine the graph in the activity's introduction, which shows outbreaks due to different sources of drinking water contamination over time. If needed, review how to examine the data provided in the graph to look for trends in the sources of drinking water contamination over time.
- First, have students make observations about patterns in the graph. They should notice that over time, the number of outbreaks with unidentified and parasitic causes decreased, while the number of outbreaks due to bacteria (including *Legionella*) and multiple causes increased, with bacteria (including *Legionella*) outbreaks trending up. The number of bacteria (non-*Legionella*) outbreaks appeared to stay steady over time. There was no discernible pattern in viral or chemical outbreaks.
- Ask, What do you think this graph might look like today? Based on the trends in the graph, current outbreaks due to bacteria (including *Legionella*) may be higher, while parasitic outbreaks may be less.
- Ask students to focus on the period of 1971–83 by covering the rest of the graph with their hands. Ask what trends they would have predicted solely on that data. Students should observe that there were consistently high levels of bacteria (non-*Legionella*) and increasing parasitic outbreaks. Predictions made for this time period lead to different predictions than ones based on more current information.
- Use the graph to point out that there are changes in data over time, and they can result in observations of different patterns. In a similar way, scientific ideas can change over time as new scientific tools and technology and new observations lead to more complete and revised explanations. In this activity, students will examine two timelines from the history of science to look for relationships between new observations as a result of advances in scientific tools and the development of scientific ideas.
- One of the timelines is on the topic of water on the planet Mars, and the other is on the imaging used to examine microscopic aspects of water. With the Mars timeline, emphasize the importance of water for life; scientists have used the presence of water as an indicator of possible life on other

planets. With the imaging timeline, highlight how understanding potential water contaminants is linked to the scientific tools and technology that allow for more detailed examination of components of water.

TEACHER'S NOTE: While these timelines further develop a unit focus on human senses and scientific tools and technology and are broadly related to water, they diverge from the primary focus on water quality. These timelines provide documented examples from the history of science that illustrate some of the key unit ideas.

2 Review the idea of a timeline by constructing a personal timeline.

- Explain that in this activity, students will organize events from the history of science into a timeline. If needed, use the following simple example to model how to construct a timeline by putting events in chronological order. Have students put the following (or similar) events in order:

  I ate solid foods.

  I went to middle school.

  I started kindergarten

  I was born.

  I started high school.

- Note that the events can first be ordered and then dates added to determine if the sequence is correct. Students will be doing something similar in this activity to investigate how scientific ideas develop over time.

PROCEDURE SUPPORT (30 MIN)

3 Pairs of students explore a timeline from the history of science.

- 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. Alternatively, you can place a set of cards in order for a class to model the process and then assign students to the other set (or work through ordering both sets together as a class). Cue students to look for words that may help determine sequence, such as first or the concept that a tool had to be invented before it was used.

- Provide each pair of students with the three cards from either Timeline cards Set 1 or Timeline cards Set 2 as identified in the following table. Students are asked to place the cards in the correct sequence and to describe their reasoning. A sample response is provided.
- Guide students to see the connections between events in the timelines. Ask students to examine the three cards in their timeline to identify an example of a technological innovation, an observation made using the technical innovation, and an explanation derived from the observation. A sample response for each timeline is provided in the following table.
- Provide students with the remaining cards in their sets for them to sequence. Some students may find it helpful to have a set of cards that can be annotated to show how one idea leads to another or to use highlighters to annotate the student sheet to differentiate among an example of a technological innovation, an observation made using the technical innovation, and an explanation derived from the observation. Point out that the cards highlight only certain events in the history of science and are not comprehensive in terms of all the work that has led to scientific thinking on these topics.

	SET 1: WATER ON MARS	SET 2: IMAGING
PROVIDE STUDENTS:	CARDS B, G, AND I	CARDS C, K, AND B
Correct sequence (oldest to youngest)	CARD B *Scientists Gustav Kirchhoff and Robert Bunsen invented the spectroscope, an instrument for observing light spectra. It can be used to determine the composition of an object.* CARD I *Astronomers William Huggins and Pierre Janssen pointed a spectroscope at Mars and observed absorption lines (light spectra) consistent with water on Mars. They inferred that there was water on Mars.* CARD G *New scientific models by planetary scientists indicate that between 30%–99% of water on Mars is incorporated as ice into minerals in the planet's crust, while the remaining fraction of water evaporates into space.*	CARD C *Italian physicist Giovanni Amici invented the oil-immersion microscope, which could magnify objects 6,000 times.* CARD K *German scientist Robert Koch used an oil-immersion lens and a condenser to see bacteria cells. He was able to prove that infectious diseases such as tuberculosis, typhoid, and anthrax are each caused by specific microbes.* CARD B *Molecular biologist Elizabeth English and her team used live-cell imaging (a way of seeing living cells by using time-lapse microscopy) to update knowledge of the life cycle of Cryptosporidium.*
Reasoning	*The spectroscope had to be invented before it could be used to observe Mars. New models of water on Mars had to occur after older ones.*	*The first observations had to happen before later ones. Then, each improvement in the microscope allowed people to see smaller and smaller things.*

- After students have ordered the cards, discussed their thinking with their partners, and recorded their ideas in their science notebooks, hand out Student Sheet 3.1a or 3.1b, "Timeline Dates" (depending on which card set students examined). Students can use this student sheet to correct their sequence, as required. Students may find it helpful to annotate the timeline with notes or highlights to compare their proposed order with the sequence of historical events.

	TIMELINE 1: MARS	TIMELINE 2: IMAGING
Technological innovation	*invention of spectroscope*	*microscope*
Observations made, using the technical innovation	*spectra indicating water on Mars*	*observations of bacteria and protozoa*

- In Procedure Part B, students are asked to think through the logic of how each event built on previous events and to develop their sense of the iterative and cumulative advancement of science through new tools, new observations, and revised explanations. You may wish to have pairs of students with the same Timeline sets work together if they are finding Procedure Part B challenging.

- Hand out Student Sheet 3.2, "Timeline Analysis." Ways in which students may identify the different events as contributing to scientific advancements are described in the sample responses to Student Sheet 3.2 found at the end of the activity.

4 Have students work in groups of four to compare different timelines.

- Have pairs join another pair who investigated a different timeline. Students share the most important aspects of their timelines by sharing their responses to Student Sheet 3.2. They should be able to explain where in their timeline:
  - a new scientific tool or experiment led to a new observation.
  - an observation led to a new idea.
  - an explanation was revised based on new evidence.
  - an idea was later rejected or updated.

- With the class, revisit the concept of a shared external reality by pointing out that 200 years ago, some of the images described in the timeline could not be seen because the technology had not yet been invented. Ask, Does that mean that these aspects of the physical world did not exist? Review the idea that the planets and microbes existed before they were observed and described.

SYNTHESIS OF IDEAS (20 MIN)

5 **Class discusses what the timelines reveal about scientific advancement**

- The term **scientific advancement** is formally defined in Build Understanding item 3. You can use Build Understanding item 3 to formatively assess students' understanding of scientific advancement.

- Support students in their understanding of scientific advancement as needed by asking questions such as:

  - Did anyone find cases in which scientists got something wrong? How do you know they got it wrong? Students may identify different events. For example, some people thought there were artificial canals constructed on Mars by intelligent beings. Later, scientists revealed that the pattern of artificial canals was an optical illusion from flaws in the telescope lenses.

  - How did the scientists realize they had gotten something wrong? In some cases, new tools and techniques, such as space rovers, provided evidence in the form of new observations, such as images of Mars' surface.

  - Does scientific advancement occur when ideas are later shown to be incorrect? Emphasize that the advancement of scientific knowledge occurs through continual re-evaluation and revision of ideas that are informed by new evidence, improved methods of data collection and experimentation, collaboration with others, and trial and error. This means that errors and mistakes are a part of the process of science, and scientific processes are intended to eventually identify those errors through new lines of evidence.

- Summarize elements of scientific advancement—how new scientific tools and technology make new observations possible beyond those from earlier instruments or human senses; how these new observations inform the revision of ideas; how additional evidence can help evaluate explanations that have gone awry and enable scientists to revise and improve their ideas to be accurate, reliable, and complete.

- Note that some students may raise issues about how unethical, immoral, or even illegal actions have been taken in the name of scientific progress. Support students in sharing their knowledge of such issues. Validate students' points of view by eliciting students' observations, experiences, and knowledge as assets to building understanding.

- You may wish to have students revisit Student Sheet 1.4, "Unit Concepts and Skills," and add information about the concept of scientific advancement.

SAMPLE STUDENT RESPONSES

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.

   Student responses will vary based on the assigned timeline.

   In the Mars timeline, new evidence was collected when Cassini observed pale spots with his telescope, improved methods of data collection occurred when the rover Curiosity landed on Mars, and collaboration occurred when two scientists worked together to invent the spectroscope.

   In the imaging timeline, new evidence was collected when Leeuwenhoek described organisms he observed with his microscope, improved methods of data collection occurred as microscopes improved, and scientists collaborated on the development of the Mesolens.

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

   New scientific tools and techniques can provide new data about things that might be unknown, such as cells or microbes. The data can challenge previously held ideas or raise new questions. Making sense of new data can lead to providing more evidence for existing explanations or create new ideas to investigate.

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.**

   Student responses will vary based on the assigned timeline.

   The Mars timeline represented scientific advancement because there has been more evidence and understanding about water on Mars. Data from telescopes, spectroscopes, and rovers all provided evidence that there is water on Mars. This data was collected over hundreds of years.

   The imaging timeline represented scientific advancements because both the technology and the scientific ideas built on each other over time. The first microscopes provided evidence of living things unseen by human senses, and later improvements in microscopes helped identify the role of microbes in disease. Today, modern scientific technology is providing information about microbes inside host organisms.

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.**

I think it has increased the speed of discovery and innovation. People from different parts of the world can work together online to share observations and ideas.

REFERENCES

Andrews, R. G. (2021, March 16). Where did Mars's liquid water go? A new theory holds fresh clues. *National Geographic*. Retrieved from https://www.nationalgeographic.com/science/article/where-did-mars-liquid-water-go-new-theory-holds-fresh-clues

Arizona Memory Project. (2004). Black and white drawing of Mars by Percival Lowell, 1901. Lowell Observatory Archives. Retrieved from https://azmemory.azlibrary.gov/nodes/view/92745

Blevins, S. M., & Bronze, M. S. (2010, September). Robert Koch and the 'golden age' of bacteriology. *International Journal of Infectious Diseases*, 14(9), e744–e751. doi.org/10.1016/j.ijid.2009.12.003. Retrieved from https://www.sciencedirect.com/science/article/pii/S1201971210023143

Case, Anna. (2018, July 3) 'Nothing to worry about. The water is fine': how Flint poisoned its people. *The Guardian*. Retrieved from https://www.theguardian.com/news/2018/jul/03/nothing-to-worry-about-the-water-is-fine-how-flint-michigan-poisoned-its-people

English, E. D., Guérin, A., Tandel, J., Striepen, B. (2022). Live imaging of the *Cryptosporidium parvum* life cycle reveals direct development of male and female gametes from type I meronts. *PLoS Biology*. 20(4): e3001604. Retrieved from https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.3001604

Kennedy, M. (2016, April 20) Lead-Laced water in Flint: A step-by-step look at the makings of a crisis. National Public Radio (NPR). Retrieved from https://www.npr.org/sections/thetwo-way/2016/04/20/465545378/lead-laced-water-in-flint-a-step-by-step-look-at-the-makings-of-a-crisis

National Aeronautics and Space Administration (NASA) Education. (2009, April). The 'Canali' and the first Martians: Schiaparelli drawing. Retrieved from https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Canali_and_First_Martians.html

O'Leary, J. K., Sleator, R. D., Lucey, B. (2021, August 20). *Cryptosporidium* spp. diagnosis and research in the 21st century. *Food Waterborne Parasitol*. 24, e00131. doi: 10.1016/j.fawpar.2021.e00131. PMID: 34471706; PMCID: PMC8390533. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8390533/

Schimpf, C., & Cude, C. (2020, February). A Systematic literature review on water insecurity from an Oregon public health perspective: Etiology of drinking water-–associated outbreaks by year—United States, 1971–2014. *International Journal of Environmental Research and Public Health 17(3)*, 1122. doi: 10.3390/ijerph17031122 Retrieved from https://www.mdpi.com/1660-4601/17/3/1122

Tzipori, S., & Widmer, G. (2008). A hundred-year retrospective on *Cryptosporidiosis*. *Trends Parasitol.* 24(4),184–9. doi: 10.1016/j.pt.2008.01.002. Epub 2008 Mar 7. PMID: 18329342; PMCID: PMC2716703. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2716703/

SET 1: CARD A

The former Soviet Union successfully launched the first spacecraft, *Sputnik 1*, in orbit around Earth.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD B

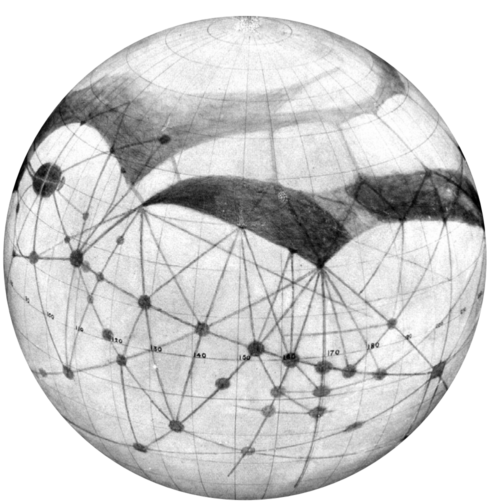
Scientists Gustav Kirchhoff and Robert Bunsen invented the spectroscope, an instrument for observing light spectra. It can be used to determine the composition of an object.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD C

American amateur astronomer Percival Lowell studied Mars for 15 years, making intricate drawings of the planet's surface. He concluded that there were multiple nonnatural features on the surface, including artificial canals.

Percival Lowells' drawing of canals on Mars



SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD D

The U.S. National Aeronautics and Space Administration (NASA) spacecraft *Mariner 4* took pictures as it passed by Mars, showing ice caps but no canals. Scientists became more confident that Mars had polar ice caps but no canals.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD E

NASA landed *Sojourner*, the first robotic rover, on the surface of Mars. It gathered and sent back data on the planet's surface.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD F

French astronomer Camille Flammarion researched the Martian canals and argued that they were constructed to transport water over the entire planet. He suggested the presence of the canals indicated a form of life on Mars that might be more advanced than humans.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD G

New scientific models by planetary scientists indicate that between 30%–99% of water on Mars is incorporated as ice into minerals in the planet's crust, while the remaining fraction of water evaporates into space.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD H

Dutch eyeglass maker Hans Lipperhey built the first telescope.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD I

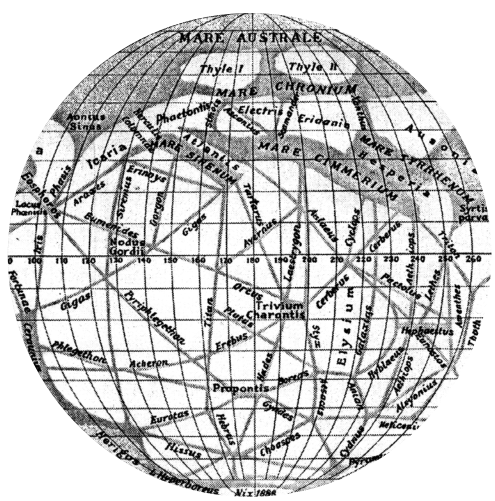
Astronomers William Huggins and Pierre Janssen pointed a spectroscope at Mars and observed absorption lines (light spectra) consistent with water on Mars. They inferred that there was water on Mars.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD J

Italian astronomer Giovanni Schiaparelli used a 22-centimeter telescope to create the first detailed map of Mars, including linear features he called *canali*, which is Italian for *channels*. Later observers of his maps mistranslated *canali* as *canals*, instead of *channels*.

Giovanni Schiaparelli's map of canals on Mars



SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD K

Italian mathematician Giovanni Domenico Cassini observed pale spots on the poles of Mars through his telescope. He inferred that Mars has polar ice caps made of frozen water.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD L

English astronomers Joseph Edward Evans and Edward Maunder conducted visual experiments with telescopes. They demonstrated that with a poor-quality telescope, certain features, such as craters, appear to connect to form lines. They argued that the observations of Martian canals were due to an optical illusion.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 1: CARD M

Curiosity, a fourth U.S. rover, landed on Mars. It used a laser spectrometer to gather data on the chemical and mineral composition of the surface and found gravel deposits like those found in streambeds on Earth. NASA scientists concluded that there had been an ancient streambed with a vigorous flow of water on Mars.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD A

American physician Dr. Ernest Edward Tyzzer used a light microscope to observe and describe *Cryptosporidium* in the intestinal tissue of mice.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD B

Molecular biologist Elizabeth English and her team used live-cell imaging (a way of seeing living cells by using time-lapse microscopy) to update knowledge of the life cycle of *Cryptosporidium*.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD C

Italian physicist Giovanni Amici invented the oil-immersion microscope, which could magnify objects 6,000 times.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD D

After its original identification in animals, the first human cases of *Cryptosporidium* were not reported until almost 70 years later.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD E

Electron microscopy was used to determine that *Cryptosporidium* parasites live inside the cells of host organisms, such as humans.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD F

Dutch scientist Antonie van Leeuwenhoek wrote to the Royal Society of London reporting his discovery of little animals (bacteria and protozoa). English scientist Robert Hooke was asked by the Society to confirm Leeuwenhoek's findings. He did so, leading to wide acceptance of Leeuwenhoek's discoveries.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD G

Dutch opticians Hans Janssen and his son Zacharias are credited with inventing the first compound microscope—a microscope that uses more than one lens. This microscope could magnify objects 20–30 times its original size. This was not enough magnification to observe the tiny microbes that can cause disease.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD H

Genome sequencing (a way of determining an organism's DNA sequence) was used to determine that *Cryptosporidium* obtains all its nutrients from its host.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD I

English scientist Robert Hooke improved the design of the existing compound microscope by adding a light and using three lenses. This illuminated and enlarged the specimens. He observed many things, including cork (which has a regular shape he called cells).

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD J

English biologist Brad Amos led a team of researchers in designing the Mesolens, a giant microscope objective lens—about the length and width of a human arm—for use by computers. It is used to produce new images of microscopic parasites.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD K

German scientist Robert Koch used an oil-immersion lens and a condenser to see bacteria cells. He was able to prove that infectious diseases such as tuberculosis, typhoid, and anthrax are each caused by specific microbes.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD L

Dutch scientist Antonie van Leeuwenhoek invented a microscope that could enlarge an image 400 times. He made the first observations of protozoa and bacteria, helping to disprove the idea of spontaneous generation.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

SET 2: CARD M

Greek philosopher Aristotle described spontaneous generation as the idea that living organisms can form from nonliving things.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 1: Evidence & Iteration in Science, Activity 3

TIMELINE DATES: WATER ON MARS (SET 1)

NAME

CARD H	1608	Dutch eyeglass maker Hans Lipperhey built the first telescope.
CARD K	1666	Italian mathematician Giovanni Domenico Cassini observed pale spots on the poles of Mars through his telescope. He inferred that Mars has polar ice caps made of frozen water.
CARD B	1860	Scientists Gustav Kirchhoff and Robert Bunsen invented the spectroscope, an instrument for observing light spectra. It can be used to determine the composition of an object.
CARD I	1867	Astronomers William Huggins and Pierre Janssen pointed a spectroscope at Mars and observed absorption lines (light spectra) consistent with water on Mars. They inferred that there was water on Mars.
CARD J	1877	Italian astronomer Giovanni Schiaparelli used a 22-centimeter telescope to create the first detailed map of Mars, including linear features he called *canali*, which is Italian for *channels*. Later observers of his maps mistranslated *canali* as *canals*, instead of *channels*.
CARD F	1892	French astronomer Camille Flammarion researched the Martian canals and argued that they were constructed to transport water over the entire planet. He suggested the presence of the canals indicated a form of life on Mars that might be more advanced than humans.
CARD C	1895	American amateur astronomer Percival Lowell studied Mars for 15 years, making intricate drawings of the planet's surface. He concluded that there were multiple nonnatural features on the surface, including artificial canals.
CARD L	1903	English astronomers Joseph Edward Evans and Edward Maunder conducted visual experiments with telescopes. They demonstrated that with a poor-quality telescope, certain features, such as craters, appear to connect to form lines. They argued that the observations of Martian canals were due to an optical illusion.
CARD A	1957	The former Soviet Union successfully launched the first spacecraft, *Sputnik 1*, in orbit around Earth.
CARD D	1965	The U.S. National Aeronautics and Space Administration (NASA) spacecraft *Mariner 4* took pictures as it passed by Mars, showing ice caps but no canals. Scientists became more confident that Mars had polar ice caps but no canals.
CARD E	1997	NASA landed *Sojourner*, the first robotic rover, on the surface of Mars. It gathered and sent back data on the planet's surface.
CARD M	2012	*Curiosity*, a fourth U.S. rover, landed on Mars. It used a laser spectrometer to gather data on the chemical and mineral composition of the surface and found gravel deposits like those found in streambeds on Earth. NASA scientists concluded that there had been an ancient streambed with a vigorous flow of water on Mars.
CARD G	2021	New scientific models by planetary scientists indicate that between 30%–99% of water on Mars is incorporated as ice into minerals in the planet's crust, while the remaining fraction of water evaporates into space.

TIMELINE DATES: IMAGING (SET 2)

NAME

CARD M	4th c.	Greek philosopher Aristotle described spontaneous generation as the idea that living organisms can form from nonliving things.
CARD G	1595	Dutch opticians Hans Janssen and his son Zacharias are credited with inventing the first compound microscope—a microscope that uses more than one lens. This microscope could magnify objects 20–30 times its original size. This was not enough magnification to observe the tiny microbes that can cause disease.
CARD I	1665	English scientist Robert Hooke improved the design of the existing compound microscope by adding a light and using three lenses. This illuminated and enlarged the specimens. He observed many things, including cork (which has a regular shape he called cells).
CARD L	1673	Dutch scientist Antonie van Leeuwenhoek invented a microscope that could enlarge an image 400 times. He made the first observations of protozoa and bacteria, helping to disprove the idea of spontaneous generation.
CARD F	1678	Dutch scientist Antonie van Leeuwenhoek wrote to the Royal Society of London reporting his discovery of little animals (bacteria and protozoa). English scientist Robert Hooke was asked by the Society to confirm Leeuwenhoek's findings. He did so, leading to wide acceptance of Leeuwenhoek's discoveries.
CARD C	1840	Italian physicist Giovanni Amici invented the oil-immersion microscope, which could magnify objects 6,000 times.
CARD K	1877	German scientist Robert Koch used an oil-immersion lens and a condenser to see bacteria cells. He was able to prove that infectious diseases such as tuberculosis, typhoid, and anthrax are each caused by specific microbes.
CARD A	1907	American physician Dr. Ernest Edward Tyzzer used a light microscope to observe and describe *Cryptosporidium* in the intestinal tissue of mice.
CARD D	1976	After its original identification in animals, the first human cases of *Cryptosporidium* were not reported until almost 70 years later.
CARD E	1986	Electron microscopy was used to determine that *Cryptosporidium* parasites live inside the cells of host organisms, such as humans.
CARD H	2004	Genome sequencing (a way of determining an organism's DNA sequence) was used to determine that *Cryptosporidium* obtains all its nutrients from its host.
CARD J	2016	English biologist Brad Amos led a team of researchers in designing the Mesolens, a giant microscope objective lens—about the length and width of a human arm—for use by computers. It is used to produce new images of microscopic parasites.
CARD B	2022	Molecular biologist Elizabeth English and her team used live-cell imaging (a way of seeing living cells by using time-lapse microscopy) to update knowledge of the life cycle of *Cryptosporidium.*

STUDENT SHEET 3.2	TIMELINE ANALYSIS	NAME

	TIMELINE :
A new scientific tool or experiment that led to a new observation	
An observation that led to a new idea	
An explanation was revised based on new evidence	
An idea that was later rejected or updated	

STUDENT SHEET 3.2	TIMELINE ANALYSIS	NAME	SAMPLE STUDENT RESPONSE

Students are expected to provide only a single response in each row.
This table provides more than one correct sample response.

	TIMELINE: *Mars*
A new scientific tool or experiment that led to a new observation	• *Lipperhey built the first telescope, which allowed Cassini to observe pale spots on Mars through his telescope* • *invention of the spectroscope led astronomers to observe absorption lines that indicated water on Mars* • *development of first spacecraft eventually led to pictures of Mars showing ice caps but no canals*
An observation that led to a new idea	• *Cassini's observations of pale spots on the poles of Mars led to the idea that Mars has polar ice caps made of frozen water* • *astronomers' observations of absorption lines of Mars led to the idea that there was water on Mars* • *telescope observations produced detailed map of Mars, which led to the (false) idea that there was a network of canals built by life on Mars* • *rover landed on Mars and found gravel deposits, leading to idea of ancient streambeds on Mars*
An explanation was revised based on new evidence	• *idea of Martian canals was revised based on astronomers' experiments showing that the canals were an optical illusion* • *idea of water on Mars was revised as more evidence about the planet's surface, including photos and samples, revealed that water is present as ice in minerals in the planet's crust*
An idea that was later rejected or updated	• *Flammarion's idea that there was a network of water canals built by life on Mars*

STUDENT SHEET 3.2	TIMELINE ANALYSIS	NAME	SAMPLE STUDENT RESPONSE

Students are expected to provide only a single response in each row.
This table provides more than one correct sample response.

	TIMELINE : *Imaging*
A new scientific tool or experiment that led to a new observation	• *invention and improvement of microscope led to identifying first cork cells* • *microscope that could enlarge 400x led to first observations of protozoa and bacteria* • *microscope led to describing Cryptosporidium in mice* • *electron microscopy led to idea that Cryptosporidium parasites live inside cells of hosts*
An observation that led to a new idea	• *observation of little animals led to idea of microscopic organisms such as bacteria and protozoa* • *observations of bacteria cells led to idea that infectious diseases are each caused by specific microbes*
An explanation was revised based on new evidence	• *idea about how Cryptosporidium lives in hosts was revised based on new imaging* • *idea about how Cryptosporidium gets its food was revised based on electron microscopy*
An idea that was later rejected or updated	• *idea of spontaneous generation* • *updated knowledge of the life cycle of Cryptosporidium*