UNIT 1

v 1.0

Teacher Edition

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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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.

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