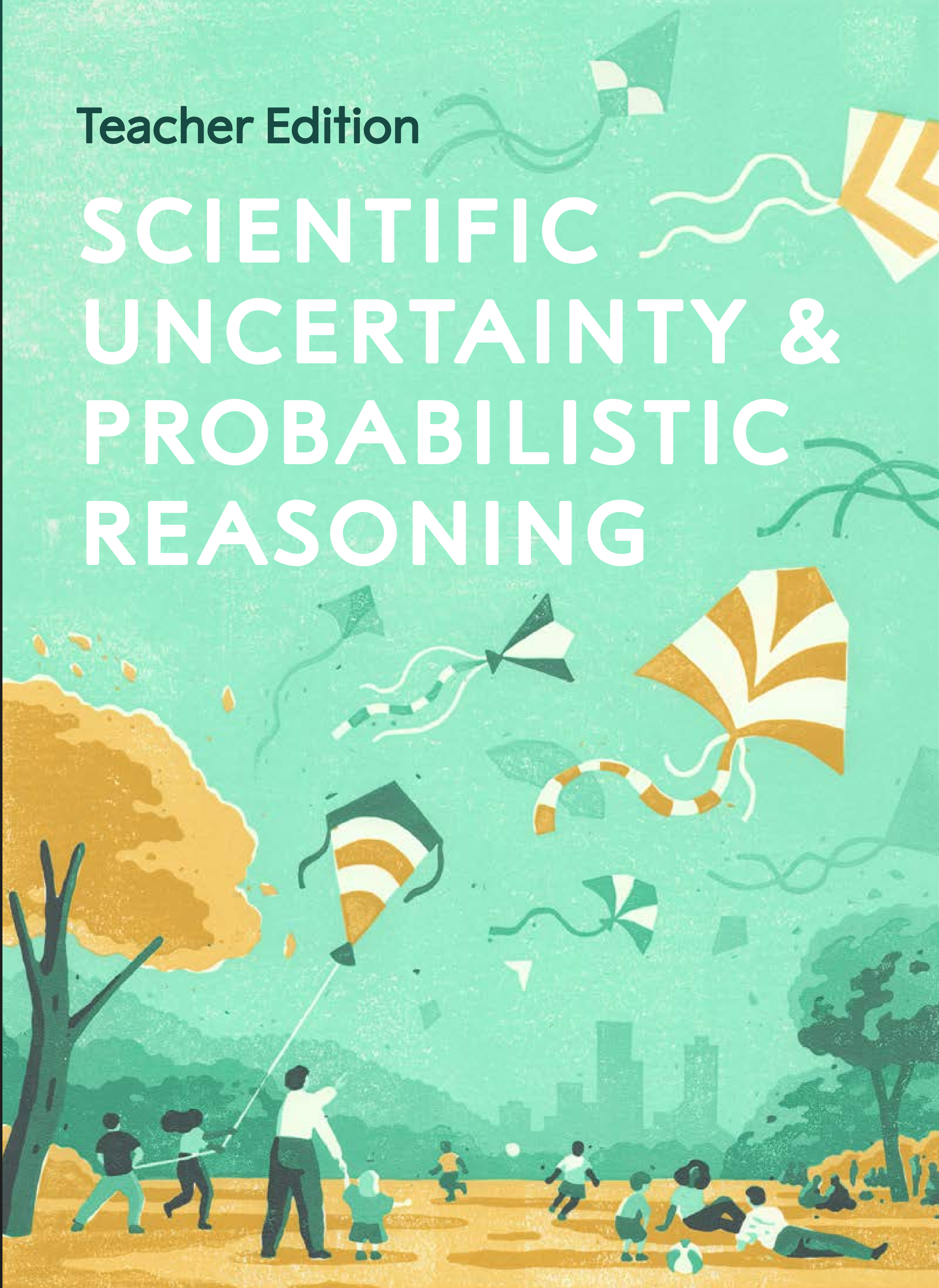
UNIT 3

v 1.0

Teacher Edition

SCIENTIFIC UNCERTAINTY & PROBABILISTIC REASONING



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://sensibility.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.

SCIENTIFIC THINKING FOR ALL TEAM

PRINCIPAL INVESTIGATOR
Saul Perlmutter

PROJECT DIRECTOR
Ben Koo

PROJECT LEAD
Janet Bellantoni

UNIT 3 AUTHORS
Manisha Hariani
Kristina Duncan
David House
Emlen Metz

OTHER CONTRIBUTORS
Janet Bellantoni
Maia Binding
Eric Greenwald
Kelly Grindstaff
Sara Kolar
Ben Koo

FIELD TEST COORDINATOR
Kelly Grindstaff

RESEARCH
Eric Greenwald
Kelly Grindstaff
Crystal Menzies

SCIENTIFIC REVIEW
Lynsey K. Parker
Master of Science in Civil and
Environmental Engineering
University of California, Berkeley

PRODUCTION

EDITING
Trudihope Schlomowitz

DESIGN
otherwise

TOOL ICONOGRAPHY
DOT Stockholm

COVER ILLUSTRATION
Merijn Jansen

THE LAWRENCE HALL OF SCIENCE
University of California, Berkeley
Berkeley, CA 94720-5200

DEAR TEACHER,

In a world flooded with information, we continually make choices about what information to believe, and human limitations and biases can make it easy to fool ourselves. Many people in the scientific community have worked to understand and counter these limitations, developing cognitive tools and techniques to minimize bias and avoid cognitive traps. Tools such as probabilistic reasoning, the use of multiple lines of evidence, and differentiating correlation from causation are essential to scientists' efforts to make sense of the world. For too long, these conceptual tools have been missing from much of high school education.

Scientific Thinking for All: A Toolkit is a curriculum designed to bring these ideas to students from all walks of life and cultural backgrounds. Our goal is to equip students with an everyday conceptual toolkit of some of the most powerful techniques from science. The curriculum situates the learning and practice of these techniques in real-world issue-based contexts of everyday importance that highlight the intersection of science and society. Your students will use these tools to ask questions, brainstorm ideas, interpret data, manage trade-offs, and develop solutions. The toolkit includes new and proven strategies to help students evaluate information, reflect on their thinking, and make more informed decisions. It is our hope that this science toolkit will empower your students to think more clearly about the things they care about, to provide them with strategies for addressing problems, and to help them achieve their personal goals.

As a teacher, you play a critical role in your students' lives and development. This work would not be possible without you. We invite you to work with us to help youth see the power and value of scientific thinking in their lives. Together, we can make scientific thinking more accessible, helping students to reimagine what science looks like and who gets to participate.

Sincerely,

Scientific Thinking for All Program Team

SCIENTIFIC THINKING FOR ALL

A TOOLKIT

COURSE DESCRIPTION

Scientific Thinking for All: A Toolkit is a high school curriculum designed to equip students with scientific tools and ideas for using and evaluating information. For example, conceptual scientific tools include modeling and strategies for probabilistic reasoning. Such conceptual tools can be used to interpret evidence, identify uncertainty, manage trade-offs, and develop iterative solutions. Students learn these ideas in the context of real issues at the intersection of science and society, ranging from medical treatments to land use.

The six-unit curriculum is divided into three major sections, each emphasizing different scientific tools. In Section 1, "Tools for Investigating the World," students are introduced to the nature of science as an iterative process based on observation and measurement and use modeling to represent and predict specific aspects of the world. In Section 2, "Tools for Evaluating Data," students evaluate different types of evidence for causation, discuss appropriate inferences and sources of uncertainty, and identify errors due to human bias. In Section 3, "Applying Science to Everyday Life," students use techniques that encourage effective decision-making and consider science as a lens through which to understand the world.

COURSE DRIVING QUESTION

How do scientific tools and scientific thinking help people address complex challenges?

TABLE OF CONTENTS

UNIT 3

SCIENTIFIC UNCERTAINTY & PROBABILISTIC REASONING

UNIT SUMMARY

INTRODUCTION

Scientific investigations try to answer questions about the natural world, such as identifying components of Earth's atmosphere and how air quality affects health. This can involve a certain amount of **scientific uncertainty**. Uncertainty in science can come from incomplete information or **scientific errors**. In this unit, students will explore air quality data to learn how to identify uncertainty and errors in science. By recognizing these uncertainties and errors, they will learn how to reduce them and become more sure of their findings. They will use **probabilistic reasoning** to make predictions, such as the likelihood of wildfire spread. Students will also look for meaningful **signals** in data and understand how **false positives** and **false negatives** can influence decisions. Throughout the unit, students will apply these conceptual tools to air quality issues at both the local and global levels.

UNIT DRIVING QUESTION

How do you address scientific uncertainty when investigating claims about air quality?

PRIMARY CONCEPTUAL TOOL

Probabilistic Reasoning

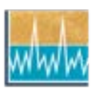
UNIT 3

SCIENTIFIC UNCERTAINTY & PROBABILISTIC REASONING

KEY CONCEPTS & PROCESS SKILLS

PROBABILISTIC REASONING & UNCERTAINTY

- When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.



- Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal.

ADDRESSING UNCERTAINTY

- Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

- Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).
- Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.

While each activity focuses primarily on one or two of these concepts outlined in the following table, the concepts are addressed in multiple places throughout the unit. In the table, you can see where in the unit each of these Key Concepts & Process Skills is addressed.

KEY CONCEPTS & PROCESS SKILLS	ACTIVITY 1	2	3	4	5	6	7	8	9	10
When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.	■	■	■				■	■	■	■
Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal.		■				■	■	■		
Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.			■	■	■	■	■	■	■	■
Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).				■	■	■	■	■		
Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.					■	■	■		■	■

UNIT 3

SCIENTIFIC UNCERTAINTY & PROBABILISTIC REASONING

UNIT OVERVIEW

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
1. Investigating Probabilistic Reasoning CARD-BASED INVESTIGATION In the context of air quality and its potential health effects, students use probabilistic reasoning to determine the most likely causes of various respiratory illnesses. Students compare the symptoms of four fictional students to a respiratory symptom chart. They explain their reasoning and begin to identify the limits of the data. Additional information allows students to reassess their findings. The concept of scientific uncertainty as well as false positives and false negatives is introduced.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.	**How do you make predictions with incomplete information?**
2. Signal and Noise DATA ANALYSIS Graphs from real-world studies provide students with the opportunity to evaluate the accuracy of a claim in an article. Students look for the signal in the noise as they investigate indoor vs. outdoor air quality during a wildfire.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal. • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.	**How do you identify the meaningful data in a data set?**

UNIT OVERVIEW

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
3. Scientific Uncertainty in Data COMPUTER INVESTIGATION The concept of scientific uncertainty is further developed with the introduction of scientific error and true value. Students explore regional air quality data from online sources and begin to identify possible sources of scientific uncertainty in data. They compare data from crowdsourced applications to data from higher-quality sensors provided by government sites. Students are asked to analyze data, draw conclusions, and discuss the role of probabilistic reasoning in making determinations about air quality.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • NGSS Connection: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**What are some sources of scientific uncertainty in data?**
4. Reducing Error in Experimental Design LABORATORY Students investigate local air quality by designing a lab to collect particulate matter data. They work to identify sources of scientific uncertainty in their experiment as they are formally introduced to random error and systematic error. By identifying errors, students consider how to reduce them and increase the certainty of their findings.	• Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*). • NGSS Connection: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**How do you design a study to reduce scientific error?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
5. Addressing Uncertainty in Science READING Students read about the Harvard Six Cities Study, one of the first large studies on the health effects of poor air quality, and synthesize ideas previously introduced in the unit, including scientific uncertainty and sources of error. Students learn how scientists plan for and reduce errors in experimental design and data collection. They learn that confidence intervals and confidence levels are methods scientists use to communicate uncertainty in their work.	• Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*). • Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate. • NGSS Connection: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**How do scientists reduce uncertainty in science?**
6. Quantifying Scientific Uncertainty COMPUTER SIMULATION Students use a computer simulation to gather data from an air quality sensor under different conditions. By analyzing the data generated by the simulation, students further explore random errors and systematic errors. They learn how collecting more data and averaging can affect the accuracy of random errors but not systematic errors. Students consider how error bars can communicate scientific uncertainty in data. They use this information to consider a decision between two air sensors.	• Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*). • Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate. • Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal. • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • NGSS Connection: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**How can you reduce random errors and systematic errors in data?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
7. Reducing Scientific Uncertainty INVESTIGATION Students map air quality sensor data for a fictional town before and after work begins at a construction site. They consider the sources of uncertainty in the data and brainstorm ways to reduce that uncertainty. They calculate how the mean varies from the range and its implications for air quality. Limitations of the data include small sample size and systematic error. Students discuss how addressing limitations of the data can lead to new conclusions.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal. • Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*). • Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate. • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • NGSS Connection: Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.	**What are ways to collect and analyze data to reduce scientific uncertainty?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
8. Collecting Experimental Data for Predictions LABORATORY One increasingly challenging source of particulate matter is wildfire smoke, which can travel hundreds or even thousands of miles and affect air quality far from the fire. Students apply their knowledge of scientific uncertainty and probabilistic reasoning to collect experimental data to make predictions about the real world. They conduct an experiment to measure the ignition time and the heat of combustion of different vegetation to model wildfire fuel sources. Students use their laboratory results to make predictions about how fuel sources affect wildfire spread.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal. • Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*). • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • NGSS Connection: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**How can you use experimental results to make predictions about the real world?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
9. Probabilistic Modeling MODELING Students use a probabilistic model of a fictional wildfire to make predictions about its spread through a community and calculate the probability of its spread based on the model. Students practice using probabilistic reasoning to make recommendations about water drops and controlled burns in order to reduce the spread and risk of the fire.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate. • NGSS Connection: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • NGSS Connection: Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.	**How can probabilistic reasoning be used to predict an outcome?**
10. Applying Probabilistic Reasoning CARD-BASED INVESTIGATION Using a fictional scenario, students investigate different risk factors related to wildfire ignitions from electric power lines. Students analyze various data and use probabilistic reasoning to recommend where and when a power shut off is necessary.	• When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision. • Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct. • Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate. • NGSS Connection: Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.	**How can you use probabilistic reasoning to reduce risk?**

ACTIVITY 1

Investigating Probabilistic Reasoning

CARD-BASED INVESTIGATION

ACTIVITY 1

Investigating Probabilistic Reasoning

ACTIVITY SUMMARY

In the context of air quality and its potential health effects, students use probabilistic reasoning to determine the most likely causes of various respiratory illnesses. Students compare the symptoms of four fictional students to the information in a respiratory symptom chart. They explain their reasoning and begin to identify the limits of the data. Additional information allows students to reassess their findings. The concept of scientific uncertainty as well as false positives and false negatives is introduced.

ACTIVITY TYPE
CARD-BASED INVESTIGATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1 When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS

VOCABULARY DEVELOPMENT

false negative
a type of error when something is incorrectly identified as absent but is actually present

false positive
a type of error when something is incorrectly identified as present

particulate matter (PM)
microscopic particles suspended in the air that are so small that they can be inhaled

PM2.5
particulate matter in the air that has a diameter of 2.5 micrometers (μm) or less, also known as fine particles

probabilistic reasoning
a way of making predictions or drawing conclusions based on how likely something is to happen, especially when there is not enough clear data

scientific uncertainty
an understanding that there are limits to data and conclusions about the natural world, and additional data and/or investigations can lead to increased surety or new questions

trade-off
a desirable outcome given up to gain another desirable outcome

TEACHER BACKGROUND INFORMATION

Probabilistic Reasoning

Probabilistic reasoning is a method of scientific inference that uses probability theory to analyze and interpret data, particularly when dealing with uncertainty or incomplete information. Unlike traditional deductive logic, which assumes absolute truth, probabilistic reasoning acknowledges that many scientific observations are subject to variability and randomness. Scientists can make informed conclusions based on the likelihood of different outcomes rather than absolute certainty. One key aspect of probabilistic reasoning is that prior knowledge can be combined with new data to calculate the probability of a hypothesis, enabling scientists to continuously refine their understanding as more evidence becomes available.

Probabilistic reasoning is commonly used in everyday situations. People intuitively consider the available evidence, think about uncertainties, and estimate the chance that something is true. Science is based on the very same process but requires the use of rigorous, established methods before a conclusion can be reached. Although there are more, three of these methods are described in this unit: (1) reducing the scientific uncertainty of data, (2) quantifying the remaining uncertainty afterward, and (3) using confidence levels when analyzing data. Together, these methods are designed to increase one's certainty in the accuracy of data from scientific studies and the conclusions that can be drawn from that data. Probabilistic reasoning is widely used in scientific fields such as genetics, medicine (diagnostic testing), climate science (predicting weather patterns), particle physics (interpreting experimental results), and ecology (modeling species distributions).

Air Quality

Air pollution occurs in many forms but generally refers to gas and particulate contaminants in the atmosphere. The most common air pollutants are particulate matter (PM), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants can harm health and the environment and cause property damage. Primary pollutants are released directly into the air, while secondary pollutants result from primary pollutants reacting with other substances in the air. Ozone and acid rain are examples of secondary pollutants. Particulate matter can be both a primary and a secondary pollutant.

Ground-level ozone can cause health problems (such as lung irritation) in contrast to ozone high in the stratosphere, where it is protective of health since it blocks incoming solar UV radiation. (The hole in the ozone layer was an environmental issue discovered in the 1980s—by banning human-emitted chlorofluorocarbons (CFCs), the hole recovered and is one of the most successful global environmental efforts.)

In the United States, the Clean Air Act, first enacted in 1963, is the federal law that regulates air emissions. It also authorizes the Environmental Protection Agency (EPA) to regulate outdoor air pollutants by developing criteria based on human and environmental health. The EPA also raises awareness of indoor air pollution, which involves exposures to particulates, carbon oxides, and other pollutants carried by indoor air or dust. Examples include household products and chemicals, off-gassing of building materials, allergens (mouse droppings, mold, pollen), and tobacco smoke.

PM2.5 and Human Health

Health studies reveal a strong association between particle pollution exposure and health risks. Health effects include cardiovascular effects, such as cardiac arrhythmias and heart attacks, and respiratory effects, such as asthma attacks and bronchitis. Exposure to particle pollution can result in increased hospital admissions, emergency room visits, absences from school or work, and restricted activity days, especially for those with preexisting heart or lung disease, older people, and children. The health effects of wildfire smoke can range from eye and respiratory-tract irritation to more serious disorders, including reduced lung function, exacerbation of asthma and heart failure, and premature death.

The size of particles is directly linked to their potential for causing health problems. Fine particles (PM2.5) pose the greatest health risk. These fine particles can get deep into lungs, and some may even get into the bloodstream. Exposure to these particles can affect a person's lungs and heart. PM10 particles have diameters that are generally 10 micrometers (μm) and smaller and, therefore, include PM2.5 particles but also include some larger particles such as dust.

Risk levels vary throughout a lifetime, generally being higher in early childhood, lower in healthy adolescents and younger adults, and increasing in middle age through old age as the incidences of heart and lung disease and diabetes increases. Factors that increase the risk of heart attacks, such as high blood pressure or elevated cholesterol levels, may also increase the risk from particle exposure.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 1.1 "Developing Communication Skills"
- VISUAL AID 1.2 "Understanding Conceptual Tools"
- VISUAL AID 1.3 "Complete Symptom Chart" (OPTIONAL)
- VISUAL AID 1.4 "PM2.5 and Human Health" (OPTIONAL)

FOR EACH GROUP OF FOUR STUDENTS

- SET OF STUDENT HEALTH CARDS (4 CARDS)
- SET OF STUDENT FOLLOW-UP CARDS (4 CARDS)

FOR EACH PAIR OF STUDENTS

- SET OF COLORED PENCILS (2 DIFFERENT COLORS)

FOR EACH STUDENT

- 2 STUDENT SHEETS 1.1 "Analyzing Symptoms"
- STUDENT SHEET 1.2 "Symptom Chart"
- STUDENT SHEET 1.3 "Unit Concepts and Skills" (OPTIONAL)
- STUDENT SHEET 1.4 "Writing Frame: Evidence and Trade-Offs" (OPTIONAL)

Prepare a class set of Student Health cards and Student Follow-Up cards. Note that students will not receive both sets of cards at the same time. You may wish to create stacks of Student Follow-Up cards for each fictional student so pairs can independently collect the appropriate Student Follow-Up card during Procedure Step 7.

Preview an approximately 9-minute video titled *Probabilistic Thinking* produced for the college course Sense and Sensibility and Science, from which this high school course is adapted. Note that the script was written and narrated by 2011 Nobel Prize in Physics winner Dr. Saul Perlmutter.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (5–10 MIN)

1 **Elicit students' prior knowledge about air quality.**

- One approach to eliciting students' prior knowledge is to create a class list of words and phrases that students associate with air quality. Students may have personal experience with and prior knowledge of issues related to air quality. Engaging students about their experiences can create a stronger foundation for learning. Support students, particularly those with varied life experiences, in sharing their prior knowledge of and personal experiences with this issue. Specifically validate funds of knowledge—not just textbook knowledge but also family or cultural insights, practices, and personal histories—by eliciting students' observations and experiences as assets to building understanding. Throughout this unit, encourage students to respond to any topics or questions that arise to which they feel a personal connection—during small-group or class discussions, when students respond to relevant Build Understanding items, and/or when they write reflections in their science notebooks.

TEACHER'S NOTE: Some topics in this unit may require particular care and sensitivity, depending on students' individual experiences. For example, some students may have severe asthma or have experienced loss due to wildfires (a topic raised multiple times in the unit).

2 **Read the Introduction and the Guiding Question (*How do you make predictions with incomplete information?*), either as a class or individually.**

- Connect students' prior knowledge and ideas about air quality to the information provided in the Student Book Introduction. Student ideas most likely will include a greater breadth of topics related to air quality than is addressed in the Introduction. You may want to ask, What are you most interested in learning? Student responses will vary but may include wanting to know the exact effect of air pollutants on health, an assessment of their local air quality (which will be further investigated in Activities 3 and 4), or what causes poor air quality. Point out that the Introduction sets the stage for the general focus of this unit.
- Review the highlighted terms provided in the Introduction, as well as the relative size of the particulate matter of 2.5 micrometers (μm), as needed. These terms are defined at the start of the activity but are developed conceptually over the course of this and the following activities. It is

not necessary to spend significant time reviewing the meaning of these terms at the start of the activity; instead, support students to develop meaning during the activity procedure and synthesis of ideas.

- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by reviewing the terms in this activity and supporting the construction of a word wall. At the start of this activity, record the terms *particulate matter (PM), PM2.5*, and *probabilistic reasoning*. For more information on a Word Wall, see Appendix 1: Literacy Strategies.

PROCEDURE SUPPORT (40 MIN)

3 **Present the factual article found in Procedure Step 1.**

- This activity explores the relationship between wildfires and indoor air quality. The article presented in Step 1 can be shared with the class in multiple ways. Read the article 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 the article 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 article independently.

4 **Distribute a set of 4 Student Health cards to each group of 4.**

- It may be helpful to preread the cards with emerging multilingual learners before diving into the procedure.
- Explain that first, partners will read and analyze the symptoms of one fictional student and work through the activity together. Then, they will examine the symptoms of a second fictional student. The other pair in the group will complete the same process for the other two fictional students. In Procedure Step 12, both pairs will share their findings as a group.

TEACHER'S NOTE: Do *not* provide students with the Student Follow-Up cards at the start of the activity. Students will receive those cards in Procedure Step 7.

- In Procedure Step 3, provide each student with two copies of Student Sheet 1.1, "Analyzing Symptoms," (one copy for each fictional student) and one copy of Student Sheet 1.2, "Symptom Chart." Also provide each pair with a set of two different-colored pencils. Mention to students that they will use one color pencil on Student Sheet 1.2 for one fictional student and a different color pencil for a second fictional student. They can make a key on the student sheet for the color they use for each fictional student. After pairs discuss their thinking, each student can record their own ideas on Student Sheet 1.1 and 1.2. Partners do not need to agree.

- Sample student responses for all four fictional students are located at the end of this activity.
- Have student groups work together to share their ideas. To support students' discussion, you may wish to use optional Visual Aid 1.1, "Developing Communication Skills," to help guide student interactions. Visual Aid 1.1 is a tool to help students effectively participate in class discussions by providing sentence starters that students can use to initiate a conversation and express their ideas. You may want to address student discomfort with navigating disagreement with peers and provide additional guidance, for example, by modeling a conversation in which two individuals disagree respectfully. For more information about Developing Communication Skills, see Appendix 1: Literacy Strategies.

5 **When students are ready for Procedure Step 7, have them collect the appropriate Student Follow-Up card for their fictional student.**

- Students record updated recommendations (even if it remains the same) and reasoning.
- In Procedure Step 10, students are asked to assess how sure they are of their diagnoses, using a scale of 0–100%, where:

0% = there is no chance their diagnosis is correct
50% = their diagnosis is just as likely to be wrong as it is to be correct
100% = they are absolutely sure that their diagnosis is correct

You may need to support students to understand that they are making an estimate based on the available evidence. Their estimates will vary, though estimates should likely be above 50% (they have enough evidence that they are not simply guessing) but below 100% (there is not enough evidence to make a definitive diagnosis).

SYNTHESIS OF IDEAS (20 MIN)

6 **Highlight the idea that students made determinations about student health despite uncertainty in the data.**

- Use Student Sheet 1.1 to discuss comments and questions that students had about the evidence. Ask students to share some of the questions they had for the fictional students. Highlight these questions as an example of identifying uncertainty in the data.
- Review the concept of scientific uncertainty by having students think of a time when they were uncertain about a decision they had to make. Then ask, What did you do to deal with the uncertainty? Students' responses may vary but should include information about what was uncertain, how it was managed, and what affected the decision. Contrast the usage of uncertainty in examples from everyday life, as mentioned here, with the concept of scientific uncertainty used throughout the unit. Remind students that the term *uncertainty* has a more specific meaning in science. Scientific uncertainty is not about being unsure, but about an understanding that there are limits to data

and conclusions about the natural world, and additional data and/or investigations can lead to increased surety or new questions. This is an essential part of scientific work and includes reasoning about the probability that conclusions drawn from limited unclear data are likely to be true.

- Ask, Do you have enough information to diagnose a student and feel 100% sure of your diagnosis? Point out that students were able to make diagnoses with some level of surety despite the limited data. In some cases, this could lead to an incorrect conclusion; communicate that it is okay to be wrong in their conclusions. In science, confidence in an explanation grows with increasing amounts of relevant, accurate, and reliable evidence.

- Discuss which factors, such as additional symptoms or information about a student's environment, can reduce uncertainty in their diagnoses. In the case of medicine, doctors have access to additional data—including medical knowledge, access to many medical tests and test results, and awareness of the frequency of different illnesses in the community. Use Build Understanding item 2 to introduce false positives and false negatives—even in the process of gathering additional data, errors can be introduced.

- You may wish to share optional Visual Aid 1.3, "Complete Symptom Chart," which provides additional symptoms for the respiratory illnesses that were investigated in the activity, as well as Respiratory Syncytial VIrus (RSV). You may wish to discuss how common certain symptoms are for a particular illness and/or how variable illness can be. For example, many of the symptoms are common in cases of COVID-19, yet many people have few or no symptoms. Nonetheless, it is possible to make diagnoses with some level of certainty.

- Students may want to talk about their own experiences by responding to questions such as, How similar were the student's actions to your own when you had similar symptoms? What do you think the follow-up should be for each patient after their symptoms went away or were treated? Allow students to share their experiences as appropriate. Engaging students about their experiences can create a stronger foundation for learning. Specifically validate funds of knowledge (not just textbook knowledge, but also family or cultural insights, practices, and personal histories) by eliciting students' observations and experiences as assets to building understanding.

7 Revisit the article presented in Step 1.

- Have students share their growing understanding of the relationship between air quality and human health. Ask, Did the student health data support the title of the article: "Increase in Wildfires May Affect Respiratory Health?" Why or why not? Have students support their responses with evidence. For example, a student may agree with the headline because it was possible that Student 4: Ali had asthma that was triggered by poor air quality. Students may also note that taking a patient's history can provide insight into illness, such as when Student 3: Tara appeared to have an allergic reaction to flowers. Other students may disagree because there was limited data provided in the activity with regard to the specific role of air quality in illness. You may wish to ask students to describe the type of evidence that could be gathered to address this question and brainstorm the type of studies that might be conducted.

- Highlight opportunities for metacognition—thinking about and understanding one's own thought processes—here and throughout the unit. Research has found that students show greater improvements in their learning when they are given opportunities to determine and evaluate their own learning. Ask, In what ways could knowing about your thinking process influence your decision-making skills? Encourage students to share their ideas. Some students may note that being more aware of their own thinking may make them more likely to expand their own ideas or make them more likely to change their minds. It may also help to enhance their skills at communicating their ideas.

8 **Use optional Visual Aid 1.4, "PM2.5 and Human Health," to review air quality and its potential impacts on human health.**

- You may wish to use Visual Aid 1.4 to review how this size of particulate matter can interact with the human respiratory system.
- You may also wish to provide additional context or information regarding air quality and other air pollutants. This unit will focus solely on PM2.5.

9 **Introduce the concept of trade-offs and how it applies to health-care decisions associated with air quality.**

- Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs. In Build Understanding item 3, students make a decision about the construction of an urgent care asthma center. Decision-making in the context of trade-offs includes the following key ideas:
  - Decisions often involve trade-offs.
  - Identifying trade-offs involves analyzing evidence.

  The concept of trade-offs is used throughout the units in this curriculum, especially as part of the decision-making focus.

- A trade-off is a desirable outcome given up to gain another desirable outcome. In a decision involving trade-offs, something positive (or desirable) is given up to gain another positive (or desirable) outcome. Since many decisions involve trade-offs, students should understand that a perfect choice that maximizes all goals is often not possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision.
- Provide an example of a trade-off. For example, when choosing to purchase a disposable or reusable water bottle, there are several benefits and trade-offs to consider. A consumer who chooses the disposable water bottle may want a cheap option that doesn't need to be cleaned or maintained. Disposable bottles are also easily shared with others, since they are not expected to be returned. However, in choosing the disposable water bottle, the consumer is contributing to environmental problems, such as increased energy use and higher amounts of solid waste in landfills if the bottle is not recycled. A consumer choosing to purchase a reusable water bottle may do so to save money over time, to save bottles from ending up in a landfill, and—by their example—to encourage others to purchase reusable bottles. However, this option has trade-offs as well, such

as the increased upfront cost of the reusable bottle and the need to clean and maintain the bottle. Neither choice is ideal, and both choices have positives and negatives. Identifying the trade-offs helps clarify the reasoning that is being applied to make a decision.

- Develop some examples of trade-offs in students' lives by brainstorming with the class a list of decisions they make every day that involve trade-offs. Choose one and talk through the associated trade-offs of deciding one way or another. This practice will familiarize students with ways to identify and consider trade-offs in this and subsequent activities.

- Optional Student Sheet 1.4, "Writing Frame: Evidence and Trade-Offs," provides additional support for students responding to Build Understanding item 3b in which they apply the concepts of evidence and trade-offs. A Writing Frame can support learners, particularly emerging multilingual learners, in decoding scientific ideas, constructing meaning, sensemaking, and language acquisition. This strategy, which has been deemed effective for emerging multilingual learners, was built on and adapted from strategies for English-proficient learners. You may wish to provide students with the Writing Frame to compose their responses or simply as a reference or checklist to help them organize how they will respond. Consider posting an enlarged version of the writing frame on a classroom wall for students to refer to now and in future assessments. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.

TEACHER'S NOTE: The Writing Frame for this unit is identical in all activities, despite different issues being addressed. The sample student response is specific to the issue raised within an activity.

10 Discuss the conceptual tool of probabilistic reasoning.

- Discuss the role of probabilistic reasoning as a tool in a student's scientific toolkit. The scientific toolkit is intended to be a set of conceptual tools that can be applied to everyday life. With each new unit, students will add conceptual tools to their toolkits. Depending on your student population, you may wish to use optional Visual Aid 1.2, "Understanding Conceptual Tools," to review the use of the word *tool*, which is defined as an implement used to carry out a particular function. The word is commonly used to refer to construction tools such as hammers, levels, and tape measures. In a science classroom, examples of scientific tools include beakers, graduated cylinders, and microscopes. In this unit, scientific tools and technology are used to gather evidence—students consider conceptual tools, such as probabilistic reasoning, as a way of exploring the application of science to everyday life.
- You may want to help students distinguish the meaning of the term *probabilistic reasoning* from the term *probability*. The meaning of *probability* is a mathematical measure of the likelihood that a specific event will happen. A basic review of the concept of probability is found in the Science Review at the end of the Student Book activity.
- Use Connections to Everyday Life items 4 and 5 to review when it is useful to use probabilistic reasoning. You would not use probabilistic reasoning when you have complete confidence about the outcome of a situation. When dealing with well-defined, deterministic scenarios in which every piece of information is known and leads to a single, definite conclusion, there is no need to calculate probabilities as the outcome is already fully predictable.

- As students build understanding about the importance of probabilistic reasoning, they will build a conceptual tool about this idea in their minds and develop skills to utilize it at various points in the unit. You may wish to use optional Student Sheet 1.3, "Unit Concepts and Skills," to help students organize their learning. This organizer is designed to help students reflect on their understanding of the conceptual tool, consider how they have used it to analyze problems throughout the unit, and how it may influence their decisions about unit topics.
- While a completed sample unit organizer is provided in this activity, students will not be able to complete it at this time; the ideas in the sample student response will be built over the course of the unit. At the end of this activity, students can add initial ideas about probabilistic reasoning.

EXTENSION (10 MIN)

11 **Use the Extension as an opportunity for advanced learning.**

In this extension, students review how scientists manage uncertainty and use probabilistic reasoning by watching the video *Probabilistic Thinking* narrated by Nobel Laureate Saul Perlmutter. After showing the video, hold a class discussion on the advantages and disadvantages of using probabilistic reasoning in everyday life.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

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

1. **Doctors, like other scientists, try to identify and reduce sources of uncertainty in science.**

   a **What factors caused you to be uncertain about your diagnoses?**

   Limited information about a student, their symptoms, and the disease, as well as not being able to get additional test results.

   b **What factors caused you to reduce uncertainty in your diagnoses?**

   Information about a disease's symptoms, having more information about a student's symptoms, and knowing about other factors that could be affecting a student's health.

2. **Examine the data in the following table.**

TABLE 1.1
Evaluation of Over-the-Counter COVID-19 Tests, 2021

BRAND	PERCENT OF POSITIVE COVID-19 CASES CORRECTLY IDENTIFIED	PERCENT OF NEGATIVE COVID-19 CASES CORRECTLY IDENTIFIED
1	49.4%	100%
2	44.6%	100%
3	45.8%	97%
4	54.9%	100%

   a **A false positive is a type of error when something is incorrectly identified as present—for example, a positive COVID-19 test result when someone does not have COVID-19. A false negative is a type of error when something is incorrectly identified as absent but is actually present—for example, a negative COVID-19 test result when someone does have COVID-19. Based on Table 1.1, are over-the-counter COVID-19 tests more likely to result in a false positive or a false negative? Explain your reasoning.**

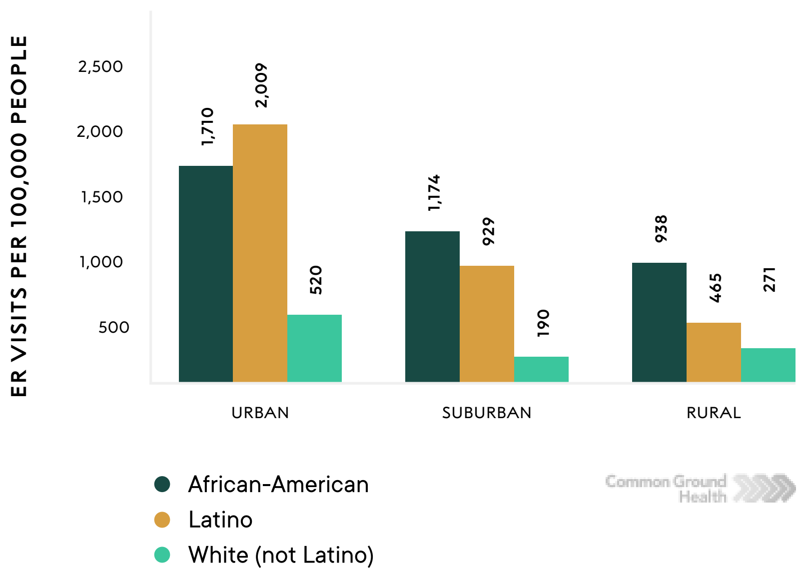
A false negative is more likely because COVID-19 is incorrectly identified as being absent when it is actually present. The range of correctly identified COVID-19 tests are from 44.6% to 54.9%. This means that about half of the people with COVID-19 would have a positive test result, while the other half would have a negative test result, even though they had COVID-19.

b Imagine that you were feeling unwell and had symptoms similar to those of COVID-19. You take an over-the-counter COVID-19 test, and the test result is negative. Use probabilistic reasoning to explain whether or not you should go to a friend's birthday party.

I should go to my friend's birthday party because it is extremely likely that I do not have COVID-19. Based on the data, over-the-counter COVID-19 tests are 97%–100% reliable if a person does not have COVID-19.

③ Examine the graph in Figure 1.2, which provides data about emergency room visits for a three-year period.

FIGURE 1.2
Emergency Room (ER) Visits for Asthma
in New York Finger Lakes Region, 2014–2016



a What can you conclude about the likelihood of emergency room visits for asthma?

From 2014–2016, people in urban areas are more likely to have emergency room visits for asthma than those living in suburban and rural areas. In every region, African-American and Latino populations are more likely to have emergency room visits for asthma than white populations.

b Imagine your state has the funds to build one urgent care asthma center. Would you recommend they build it in an urban, suburban, or rural area? Support your answer with evidence and identify the trade-offs of your decision. A trade-off is a desirable outcome given up to gain another desirable outcome.

I would recommend they build it in an urban area because the number of ER visits for asthma there is the highest. Since asthma interferes with breathing, it is important to have immediate care. My evidence is that the combined number of visits in the urban area was 4,239 compared to 2,293 in the suburban area and 1,674 in the rural area. Since more people live in an urban area, more people would have access to immediate care. The trade-off is that people in rural areas may be farther from any medical care and may experience more severe effects without immediate treatment.

CONNECTIONS TO EVERYDAY LIFE

④ **Which of the following are examples of probabilistic reasoning? Explain.**

- a estimating the chance of getting stuck in a traffic jam based on the time of day
- b deciding on where to have dinner based on your favorite food and the cost of the meal
- c a basketball player calculating the odds of making a shot based on their past performance and the current situation on the court
- d a doctor considering the likelihood of a specific disease based on a patient's symptoms and test results
- e selecting a concert to attend based on which concert venue is the closest to where you live
- f figuring out your chances of getting a job offer based on your qualifications and the competition for the position

The following are examples of probabilistic reasoning: a, c, d, and f.

a estimating the chance of getting stuck in a traffic jam based on the time of day

If a traffic jam has not yet happened, you can't know how much of a traffic slowdown might occur. You are making a prediction based on past events or experience.

c a basketball player calculating the odds of making a shot based on their past performance and the current situation on the court

A basketball player can't guarantee they will make the shot, so they have to make a prediction of how likely the shot is to be successful.

d a doctor considering the likelihood of a specific disease based on a patient's symptoms and test results

A doctor relies on information to assess and determine whether the disease is the most likely cause of illness, though there is a possibility of error based on how much or little information is available for the diagnosis.

f figuring out your chances of getting a job offer based on your qualifications and the competition for the position

You cannot know in advance if you will receive a job offer, but you can determine how well you match the requirements for the position. You can also determine the potential number of other qualified applicants to figure out if you are likely to be offered the job.

5. **Choose one example of probabilistic reasoning from item 4 and describe one action you could take to reduce scientific uncertainty in that example.**

You could reduce uncertainty in determining the likelihood of getting stuck in a traffic jam by gathering data about traffic patterns over a long period of time, such as a week or a month (or by checking traffic reports for any recent accidents).

REFERENCES

Asthma and Allergy Foundation of America, World Health Organization, Centers for Disease Control and Prevention. (2024). Chart: "How Can I Tell the Difference Between Asthma, COVID-19, the Flu, a Cold, or Seasonal Allergies?"

https://community.aafa.org/blog/coronavirus-2019-ncov-flu-what-people-with-asthma-need-to-know

Common Ground Health. (2016). Asthma-driven ED visit rate by race/ethnicity and geography, New York Finger Lakes Region (2014–2016). New York State Department of Health SPARCS.

https://www.commongroundhealth.org/insights/library/asthma-driven-ed-visit-rate-by-raceethnicity-and-geography

Olearo, F., Nörz, D., Heinrich, F., Sutter, J. P., Roedl, K., Schultze, A., Wiesch, J. S. Z., Braun, P., Oestereich, L., Kreuels, B., Wichmann, D., Aepfelbacher, M., Pfefferle, S., & Lütgehetmann, M. (2021). Handling and accuracy of four rapid antigen tests for the diagnosis of SARS-CoV-2 compared to RT-qPCR. *Journal of Clinical Virology*. *137*(104782). doi:10.1016/j.jcv.2021.104782.

Perlmutter, Saul. (2024). *Probabilistic Thinking* (video). University of California, Berkeley. https://www.youtube.com/watch?v=ydgLEE0dRrQ

STUDENT SHEET 1.1 | ANALYZING SYMPTOMS | NAME

	STUDENT NUMBER AND NAME:	
Symptoms		
Most probable diagnoses	1	2
Reasoning	1	2
Two questions you'd like to ask the student		
Recommended course(s) of action		
What happened (based on Student Follow-Up card)?		
Course of action supported or not?		
Revisited diagnoses, reasoning, and level of sureness	1	2

 SAMPLE STUDENT RESPONSE FOR STUDENT 1

	STUDENT NUMBER AND NAME: *Student 1: Serena*	
Symptoms	• *coughing for 2 weeks and after laughing hard or running* • *short of breath sometimes* • *feels fine otherwise*	
Most probable diagnoses	1 *Asthma*	2 *COVID*
Reasoning	1 *Coughing and shortness of breath are symptoms of asthma. Otherwise, feels fine.*	2 *Coughing and shortness of breath are symptoms of COVID, but no other symptoms of illness.*
Two questions you'd like to ask the student	*How long have you had these symptoms (from childhood or are they recent)?* *Have you taken an at-home COVID test?*	
Recommended course(s) of action	• *Avoid strenuous outdoor activities such as sports.* • *Take an at-home COVID test.* • *Wear a face mask when with others.* • *Consider seeing a doctor for a prescribed inhaler.*	
What happened (based on Student Follow-Up card)?	*Negative for COVID*	
Course of action supported or not?	*Yes*	
Revisited diagnoses, reasoning, and level of sureness	1 *Asthma because the COVID test was negative, and other symptoms suggest asthma. 80% likely it was asthma.*	2 *Might be good to check for allergies since they can trigger asthma. 15% likely it was COVID.*

	STUDENT NUMBER AND NAME: *Student 2: Marcus*	
Symptoms	• *fever* • *runny nose* • *chills*	
Most probable diagnoses	1 *COVID*	2 *Flu*
Reasoning	1 *Fever, runny nose, and chills are all common symptoms of COVID; no other illness on the chart has all these symptoms as common.*	2 *Fever, runny nose, and chills are all possible symptoms of the flu, but chills only occur in some cases.*
Two questions you'd like to ask the student	*How long have you been feeling sick?* *Have you taken an at-home COVID test?*	
Recommended course(s) of action	• *Take an at-home COVID test.* • *Isolate from other people as much as possible.* • *Wear a face mask when with others.*	
What happened (based on Student Follow-Up card)?	*Stayed home and symptoms eventually went away.*	
Course of action supported or not?	*Yes*	
Revisited diagnoses, reasoning, and level of sureness	1 *COVID still possible but no COVID test results and a quick recovery, so 50% likely it was COVID.*	2 *Equally likely that it was flu, so 50% flu.*

	STUDENT NUMBER AND NAME: *Student 3: Tara*	
Symptoms	• *sneezing* • *runny nose* • *headaches*	
Most probable diagnoses	1 *Allergies*	2 *COVID*
Reasoning	1 *Sneezing, runny nose, and headaches are all possible symptoms of allergies; she also recently received flowers.*	2 *Runny nose and headaches are symptoms of COVID, although sneezing is rare.*
Two questions you'd like to ask the student	*Do you have any other symptoms, like shortness of breath?* *How long have you had these symptoms (did they start after receiving flowers)?*	
Recommended course(s) of action	• *Ignore the symptoms and maintain routine activities.* • *Take an over-the-counter allergy medicine.* • *Take an over-the-counter headache medicine.*	
What happened (based on Student Follow-Up card)?	*Symptoms disappeared when flowers were thrown away.*	
Course of action supported or not?	*Yes*	
Revisited diagnoses, reasoning, and level of sureness	1 *Symptoms went away when flowers were tossed, 99% likely it was allergies.*	2 *Symptoms of illness quickly disappeared after flowers were thrown away; 1% likelihood of COVID.*

	STUDENT NUMBER AND NAME: *Student 4: Ali*	
Symptoms	• *short of breath* • *headaches* • *watery eyes*	
Most probable diagnoses	1 *Asthma*	2 *COVID*
Reasoning	1 *Abrupt onset of symptoms with shortness of breath common for asthma, with headaches a possible symptom.*	2 *Shortness of breath and headaches are both common symptoms, but abrupt onset makes it less likely.*
Two questions you'd like to ask the student	*Have you been spending a lot of time outside?* *Do you wear a mask when outside?*	
Recommended course(s) of action	• *Stay indoors.* • *Avoid strenuous outdoor activities such as sports.* • *Wear a face mask when outdoors.*	
What happened (based on Student Follow-Up card)?	*Ali felt fine after the wildfire ended.*	
Course of action supported or not?	*Yes*	
Revisited diagnoses, reasoning, and level of sureness	1 *Symptoms went away but asthma is still possible, and symptoms could reappear; 75% likely it was asthma.*	2 *Symptoms of illness quickly disappeared after wildfire ended; 15% likely it was COVID.*

STUDENT SHEET 1.2 | SYMPTOM CHART | NAME

SYMPTOMS	ASTHMA	SEASONAL ALLERGIES	COLD	COVID-19	FLU
Onset of symptoms	gradual or abrupt onset of symptoms	abrupt onset of symptoms	gradual onset of symptoms	symptoms range from mild to severe	abrupt onset of symptoms
Length of symptoms	can start quickly or last for hours or longer	several weeks	less than 14 days	7–25 days	7–14 days
Cough	common	rare	common	common	common
Shortness of breath or trouble breathing	common	no*	no*	common	no*
Sneezing	no*	common	common	rare	no
Runny or stuffy nose	no*	common	common	common	sometimes
Sore throat	no*	sometimes (usually mild)	common	common	sometimes
Fever	no	no	short fever period	common	common
Headaches	rare	sometimes (related to sinus pain)	rare	common	common
Chills	no	no	no	common	sometimes

* Allergies, cold, flu, and some strains of COVID-19 can all trigger asthma, which can lead to shortness of breath. People with both allergies and asthma may have a runny nose, sore throat, and sneezing.

STUDENT SHEET 1.3 | UNIT CONCEPTS AND SKILLS | NAME

UNDERSTAND		ANALYZE
CONCEPT	DESCRIPTION	UNIT EXAMPLE(S)

WHAT DECISION(S) WERE MADE OR ACTION(S) TAKEN?

STUDENT SHEET 1.3 | UNIT CONCEPTS AND SKILLS | NAME *SAMPLE STUDENT RESPONSE*

UNDERSTAND		ANALYZE
CONCEPT	**DESCRIPTION**	**UNIT EXAMPLE(S)**
Probabilistic Reasoning	*When data is unclear, it is useful to have an approach to determine the likelihood of different outcomes based on available evidence.*	*Predicting illness, determining air quality (outdoor vs. indoor, local air quality data, construction site scenario), making predictions about wildfires (fuel lab, probabilistic modeling, power line scenario)*
Scientific Uncertainty	*Uncertainty in data is often a result of scientific error. Scientific methods can reduce uncertainty.*	*PM2.5 air quality data from websites, PM2.5 air quality lab, power shut-off activity*
False Positive, False Negative	*These two types of errors can lead to incorrect decisions based on inaccurate results.*	*Questions about COVID tests, air quality sensors, smoke alarms, probabilistic wildfire models, power line sensors*
Signal and Noise	*Probabilistic reasoning can help identify the signal being investigated.*	*Outdoor vs. indoor air quality activity, computer app, ER visits graph, regional PM2.5 graph*
Systematic Error	*Can be reduced by calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (confounds).*	*PM2.5 air quality lab, Harvard Six Cities Study, computer simulation, construction site scenario, power line scenario*
Random Error	*Can be reduced by taking repeated measurements and averaging across many samples*	*PM2.5 air quality lab, Harvard Six Cities Study, computer simulation, fuel lab, power line scenario*
Confidence Level, Confidence Interval, Error Bar	*Scientists communicate scientific uncertainty, using statistics to describe levels of surety and likelihood of a range of data containing a true value.*	*Harvard Six Cities Study, computer simulation, construction site scenario, probabilistic modeling*

WHAT DECISION(S) WERE MADE OR ACTION(S) TAKEN?

Evaluation of claims in articles and computer simulation, decision about power shut-offs

STUDENT SHEET 1.4 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

STUDENT SHEET 1.4 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME *SAMPLE STUDENT RESPONSE*

There is a lot of discussion about the issue of

where to build an urgent care asthma center.

My decision is that

it should be built in an urban area.

My decision is based on the following evidence:

First,

since asthma interferes with breathing, it is important to have immediate care.

Second,

the combined number of visits in the urban area was 4,239, compared to 2,293 in the suburban area and 1,674 in the rural area.

Third,

because more people live in an urban area, more people would have access to immediate care.

The trade-off(s)

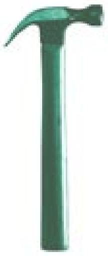
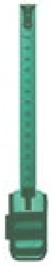
is that people in rural areas may be farther from any medical care.

People who disagree with my decision might say that

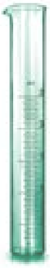
people who live in rural areas may experience more severe effects without immediate treatment if there is no nearby medical care in the area.

COMMUNICATION	SENTENCE STARTERS
to better understand	One point that was not clear to me was... What if we tried...? I have an idea. We could try...
to disagree	I see your point, but what about...? Another way of looking at this is... I'm still not convinced that...
to challenge	How do you reach the conclusion that...? What makes you think that...? How does it explain...?
to look for feedback	What would help me improve is... Does it make sense, what I said about...?
to provide positive feedback	One strength of your idea is... Your idea is good because...
to provide constructive feedback	The argument would be stronger if... Another way to do it would be... What if you said it like this...?

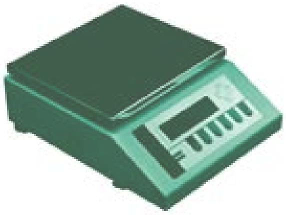
CONSTRUCTION TOOLS

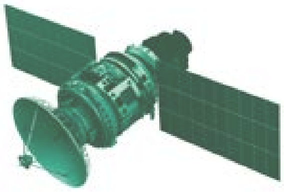




SCIENTIFIC TOOLS




SCIENTIFIC TOOLS + TECHNOLOGY





CONCEPTUAL TOOLS

VISUAL AID 1.3 | COMPLETE SYMPTOM CHART

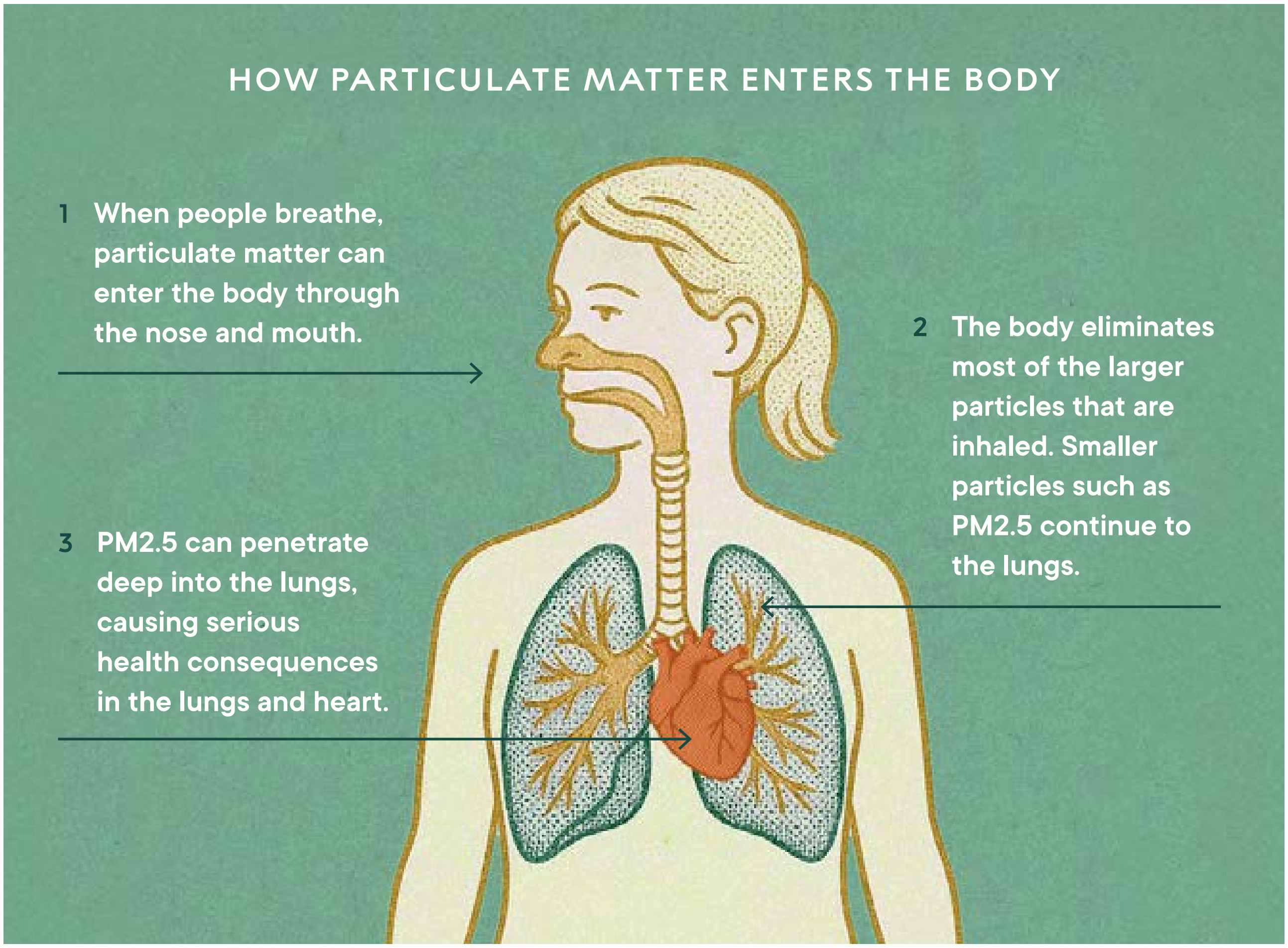
Symptoms	Asthma Gradual or abrupt onset of symptoms	Seasonal Allergies Abrupt onset of symptoms	Cold Gradual onset of symptoms	Coronavirus[†] (COVID-19) Symptoms range from mild to severe	Flu Abrupt onset of symptoms	Respiratory Syncytial Virus (RSV) Gradual onset of symptoms
Length of symptoms	Can start quickly or last for hours or longer*	Several weeks	Less than 14 days	7-25 days	7-14 days	7-10 days
Cough	Common (can be dry or wet/productive)	Rare (usually dry unless it triggers asthma)	Common (mild)	Common (usually dry)	Common (usually dry)	Common
Wheezing	Common	No**	No**	No**	No**	Common
Shortness of breath or trouble breathing	Common	No**	No**	Sometimes	No**	No*** (sometimes in infants)
Chest tightness/ pain	Common	No**	No**	Sometimes	No**	No**
Rapid breathing	Common	No**	No**	Rare	No**	No*** (sometimes in infants)
Sneezing	No**	Common	Common	Rare	No	Common
Runny or stuffy nose	No**	Common	Common	Common	Sometimes	Common
Sore throat	No**	Sometimes (usually mild)	Common	Common	Sometimes	Rare
Fever	No	No	Short fever period	Common	Common	Common
Feeling tired and weak	Sometimes	Sometimes	Sometimes	Common	Common	Rare
Headaches	Rare	Sometimes (related to sinus pain)	Rare	Common	Common	No
Body aches and pains	No	No	Common	Common	Common	Rare
Diarrhea, nausea, and vomiting	No	No	Rare	Common	Sometimes	No
Chills	No	No	No	Common	Sometimes	Sometimes
Loss of taste or smell	No	Sometimes	Rare	Common	Rare	No

Your symptoms may vary. If you have any cold, COVID-19, or flu-like symptoms, talk with your doctor, get tested, and stay home.

*If you are having trouble breathing and your quick-relief medicine is not helping your asthma symptoms, call your health care provider or seek medical attention immediately. **Allergies, colds, flu, and some newer strains of COVID-19 can all trigger asthma which can lead to shortness of breath, chest tightness/pain, and rapid breathing. People with both allergies and asthma may have runny nose, sore throat, and sneezing. ***This is not common but may be seen in babies 6 months or younger. †Information about COVID-19 is still evolving. Many people may not have symptoms.

Sources: *Asthma and Allergy Foundation of America, World Health Organization, Centers for Disease Control and Prevention.* Edited with medical review: 1/18/24 • aafa.org/rti

VISUAL AID 1.4 | PM2.5 AND HUMAN HEALTH



STUDENT 1: SERENA

Serena has been coughing for two weeks. She usually starts coughing after laughing really hard or running to catch the bus. She sometimes feels short of breath. Most of the rest of the time, she feels fine.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 1: FOLLOW UP

Serena took a COVID-19 test and tested negative for COVID-19.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 2: MARCUS

Marcus has missed two days of school so far. He has a fever, runny nose, and chills.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 2: FOLLOW UP

Marcus stayed home for three more days and began to feel better at the end of that time. His symptoms went away, and he went back to school after a week of being sick.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 3: TARA

Tara has been sneezing and had a runny nose for the last week. She also has occasional headaches. Tara turned 18 a week ago, and her friends and family surprised her with several bouquets of flowers.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 3: FOLLOW UP

Tara ignored her symptoms since they did not interfere with her everyday activities. The flowers wilted, and she threw them away. Her symptoms went away.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 4: ALI

Ali was feeling fine. A large wildfire in the area resulted in high levels of particulate matter in the air. Since then, he's been feeling short of breath, had headaches, and his eyes have been watering.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

STUDENT 4: FOLLOW UP

Ali stayed indoors and avoided strenuous activities such as sports. Heavy rainfall in the area helped extinguish the wildfire. Ali has been feeling fine since then.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 3: Scientific Uncertainty & Probabilistic Reasoning, Activity 1

ACTIVITY 2

Signal and Noise

DATA ANALYSIS

ACTIVITY 2

Signal and Noise

ACTIVITY SUMMARY

Graphs from real-world studies provide students with the opportunity to evaluate the accuracy of a claim in an article. Students look for the signal in the noise as they investigate indoor vs. outdoor air quality during a wildfire.

ACTIVITY TYPE
DATA ANALYSIS

NUMBER OF
40–50 MINUTE
CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1 When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

2 Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS

SIGNAL & NOISE

VOCABULARY DEVELOPMENT

noise
information that hides, distracts from, or falsely resembles the meaningful information that is being investigated

signal
meaningful information about the phenomenon that is being investigated

TEACHER BACKGROUND INFORMATION

Signal and Noise in Science

In science, the term *signal* refers to the meaningful information or pattern you are trying to detect; the term *noise* represents the random, unwanted fluctuations or variations that obscure the signal, making it difficult to accurately interpret the data. Essentially, the signal is the important information you want to measure, and the noise is everything else that interferes with that measurement. A signal can be a specific trend, correlation, or change in a variable within the data. For example, consider an experiment to measure the effect of a new drug on blood pressure. The signal would be a change in blood pressure specifically due to the drug. The noise would be variations in blood pressure caused by factors such as individual differences, time of day, or stress levels. Noise can be caused by factors such as instrument error, environmental variations, or individual differences in subjects.

Indoor Air Quality

Indoor air quality refers to the quality of the air in a home, school, office, or other building environment. On average, people in the United States spend approximately 90 percent of their time indoors. The concentrations of some pollutants are often 2–5 times higher indoors than typical outdoor concentrations. Indoor concentrations of some pollutants have increased in recent decades due in part to energy-efficient building construction that lacks sufficient mechanical ventilation to ensure adequate air exchange and the increased use of synthetic materials in building materials, furnishings, personal-care products, pesticides, and household cleaners.

Most pollutants affecting indoor air quality come from sources inside buildings, although some originate outdoors and can enter buildings through open doors, open windows, ventilation systems, and cracks in structures. Indoor sources of air pollution include combustion sources such as tobacco, wood and coal from heating, cooking appliances, and fireplaces; cleaning supplies, paints, insecticides, and other commonly used products; degrading building materials or new building materials (e.g., chemical off-gassing from pressed wood products); radon; mold; and pet dander.

MATERIALS & ADVANCE PREPARATION

FOR EACH GROUP OF FOUR

- COLORED PENCILS
  (3 different colors)

FOR EACH STUDENT

- STUDENT SHEET 2.1
  "Outdoor vs. Indoor Air Quality Measurements"
- STUDENT SHEET 1.3
  "Unit Concepts and Skills"
  (OPTIONAL)
- 2 STUDENT SHEETS 2.2
  "Frayer Model"
  (OPTIONAL)

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (15-30 MIN)

1 **Introduce the concepts of signal and noise with a tapping game.**

- Introduce the concepts of signal and noise by explaining that scientists try to separate the important information they are looking for—the signal—from other factors that might interfere with it. These interfering factors are called noise. You may want to have students record these concepts on optional Student Sheet 1.3, "Unit Concepts and Skills."
- As a class, you will model how to distinguish a signal from the noise. In this model, noise does not refer to the term *noise* in its more everyday use when it usually refers to unpleasant sounds. Noise is any information that hides, distracts from, or falsely resembles the meaningful information that is being investigated.

1) Ask one student, the Tapper, to hold their hand under their desk so no one else can see it except the person next to them, known as the Observer. Instruct the Tapper to tap the underside of the desk hard enough for all students to hear (using an object or their knuckles). Instruct all the other students to raise their hands every time they hear the Tapper tap. Each time anyone raises their hand, the Observer tells everyone whether the Tapper really did tap or not. Do this a few times. If students are quiet and the Tapper taps hard enough, it should be fairly easy for students to hear the tap only when the Tapper taps.

2) Instruct all students to record three column headings in their notebooks: "Heard Tap Correctly," "Misheard Tap," and "Missed Tap." Explain that as they continue to listen, they will keep track of their guesses by making a tally mark under each column according to the following instructions:

   - Heard Tap Correctly: Student raised their hand, and the tap is confirmed by the Observer.
   - Misheard Tap: Student raised their hand, but the Observer says there was no tap.
   - Missed Tap: Student did not raise their hand, but the Observer says there was a tap.

Conduct a few more rounds of the tapping game while students track their guesses.

3) Next, have students draw a horizontal line under their last entry in their notebooks that goes across the columns. Then, instruct half the students to tap lightly on the top of their desks while still raising their other hands when they hear the Tapper tap. Conduct a few more rounds with students tracking their guesses. This should make hearing the original Tapper difficult, with more Misheard Taps and more Missed Taps.

4) Have students start a third section in their notebooks to record a new set of guesses. Now, instruct all students to join in and tap lightly on the top of their desks. Conduct a few more rounds with students tracking their guesses. This should make hearing the original Tapper even more difficult, with more Misheard Taps and more Missed Taps.

5) Finally, have students start a fourth section in their notebooks to record their guesses and continue the game with everyone tapping as loudly as they can. This should make accurately hearing the original Tapper practically impossible.

- Ask students to explain what they just did in terms of signal and noise. Ask, Did the signal change or the noise? The signal did not change, but the noise increased when others were tapping, which made it harder to distinguish the signal of the original Tapper. Ask, How did this affect the number of errors you made in accurately identifying the original Tapper? The increase in noise increased the number of errors. More noise led to more errors.

- Further develop the concept of signal and noise by using the example of listening to one student say something when everyone else is talking. In this case, the signal (student talking) can be difficult to distinguish from the noise (everyone else talking). Point out that so far, the examples used to differentiate these concepts have used sound. Refer to the Introduction in the Student Book to explain how identifying a signal among noise can also be done visually, such as in a search-and-find book. In the activity, students will differentiate between signal and noise in graphs.

2 **Use the literacy strategy of a Frayer Model to support students' understanding of the concepts of signal and noise.**

- To support the development of new vocabulary and concepts during the activity, consider using a Frayer Model with students as shown on optional Student Sheet 2.2, "Frayer Model." For the concepts of signal and noise, the model can be introduced in the beginning of the activity, filled out as the activity unfolds, and reviewed at the end of the activity. For more information about the Frayer Model, see Appendix 1: Literacy Strategies. A sample student response of the Frayer Model for the terms *signal* and *noise* is shown at the end of this activity.

- If you have begun a word wall, support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the terms *signal* and *noise*.

3 Review how to interpret graphs (optional).

- This activity focuses on data analysis and requires the ability to interpret a graph. Depending on your student population, you may want to review how to interpret graphs. Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by reviewing relevant language associated with a graph, such as x-axis, y-axis, title, key, and line graph.

PROCEDURE SUPPORT (45 MIN)

4 Present the article found in Procedure Step 1.

- As in Activity 1, students are presented with an article based on real-world events. The article presented in Step 1 can be shared with the class in multiple ways. Read the article 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 the article 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 article independently.

5 Students examine and interpret two graphs.

- Each graph on Student Sheet 2.1, "Outdoor vs. Indoor Air Quality Measurements," provides data about air quality from air quality sensors located on the same wall of a home during a wildfire. The top graph provides data about outdoor air quality, and the bottom graph provides data about indoor air quality. If needed, support your students in interpreting the graphs.
- In Procedure Step 2, distribute 1 copy of Student Sheet 2.1 to each student and 1 set of 3 different-colored pencils to each group. A sample student response is shown at the end of this activity.
- You may wish to model how to complete Procedure Step 3a on Student Sheet 2.1.
- In Procedure Step 3b, students' hypotheses may vary.

Sample Student Response, Procedure Step 3b

- Some students may observe a correlation between wildfire smoke and increased indoor PM2.5 levels, as supported by data on September 13 night, September 15 night, September 17 day, and September 18 night where there are spikes in indoor PM2.5 levels that correspond to spikes in outdoor PM2.5 levels.
- Other students may conclude that there is not a strong correlation between wildfire smoke and indoor increased PM2.5 levels, as supported by data on September 15 day, September 18 morning, and September 19 evening where there are spikes in indoor PM2.5 levels but not in outdoor PM2.5 levels.

- In Procedure Step 5, students use Student Sheet 2.1 to look for and mark correlations in the data as well as mark when additional events occurred.

- In Procedure Step 6, the signal is the data about indoor PM2.5 levels during the wildfire that is not affected by noise. Any sources of variation are noise because they make it harder to determine the relationship between outdoor PM2.5 levels due to wildfire smoke and indoor PM2.5 levels. Students should observe the following:

  Sample Student Response, Procedure Step 6

  - Each graph shows a correlation between a spike in indoor PM2.5 levels and the activity being described (cooking, smoking, house fan).
  - Both cooking and smoking are noise in the graph for indoor air quality when looking for the effect of wildfire smoke.
  - The house fan being on near the indoor sensor made it difficult to gather data about the signal.

- In Procedure Step 7, students identify the signal and the noise in determining whether outdoor air quality is affecting indoor air quality during a wildfire by labeling each vertical box on Student Sheet 2.1 as either signal or noise.

- Students should use the additional information to adjust their hypotheses as needed. Remind students that, in science, the goal is not to be right or wrong, but to have an explanation that is supported by evidence. As more evidence is gathered, explanations may need to be revised. This is part of the process of probabilistic reasoning.

6 In Procedure Step 9, groups brainstorm ways to improve indoor air quality.

- Possible student responses include: avoid burning indoors, including fireplaces, wood stoves, gas appliances, and candles; avoid the use of airborne chemicals such as air fresheners, sprays, and cleaning products; vacuum rugs and carpets regularly; routinely wipe down household surfaces; and use an air purifier. If the outdoor air quality is good, opening windows and doors can also increase ventilation and improve indoor air quality.

- Regularly changing furnace filters and reducing humidity levels have also been shown to improve indoor air quality.

SYNTHESIS OF IDEAS (10 MIN)

7 **Highlight that identifying the signal vs. the noise depends on the information that you are interested in.**

- Revisit student responses to Procedure Step 7, in which they identified the signal and the noise on Student Sheet 2.1. Identifying the signal vs. the noise depends on the information that you are interested in. Since the focus was on indoor vs. outdoor air quality during a wildfire, data that showed a correlation between those two variables was the signal, while data that interfered with determining any potential relationship (such as smoking or cooking) was noise. Ask, When looking at the graphs, what would have been the signal if you were looking at the relationship between indoor air quality and cooking? In this case, data that showed a possible relationship between changes in indoor air quality during cooking would be the signal. Ask, When looking at the graphs, what would have been the noise if you were looking at the relationship between indoor air quality and cooking? In this case, any effect of wildfire smoke on indoor air quality would be noise because it would interfere with the signal (cooking).
- Use Connections to Everyday Life item 3 to highlight the idea that identifying the signal vs. the noise depends on the information that you are interested in.

8 **Revisit the article presented in Step 1.**

- Have students share their growing understanding of the relationship between air quality and health by asking, Do you agree or disagree with the title of the article: "Is Cooking Worse than Wildfires for Indoor Air Quality?" Point out that using the graphs to answer this question requires identifying cooking as the signal and the other possible effects on indoor air quality as noise. Many students may agree with the title because they saw spikes in the indoor PM2.5 levels on the graph for indoor air quality on Student Sheet 2.1, which matched the days when large meals were cooked indoors. On those days, the outdoor PM2.5 levels were not as high as the indoor levels.
- If you have not done so, have groups share their ideas for improving indoor air quality with the class.

9 **Explain that distinguishing the signal from noise is an essential part of data analysis.**

- Ask, How do the concepts of signal and noise affect data analysis? Noise makes it harder to interpret the data (the signal). Noise can be a source of error in interpreting data because it can be difficult to tell it apart from the signal.
- You may wish to use optional Student Sheet 1.3, "Unit Concepts and Skills," to help students organize their learning about the concepts of signal and noise.

SAMPLE STUDENT RESPONSES

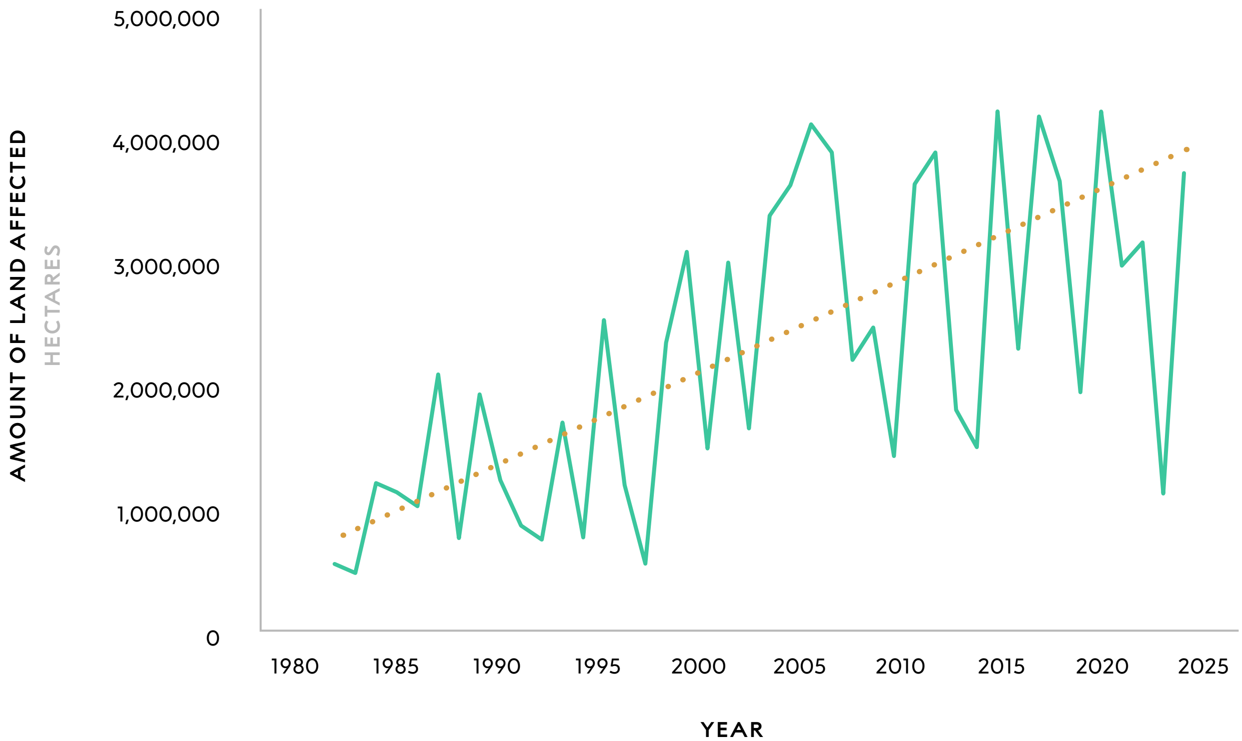
BUILD UNDERSTANDING

1. **Would you prefer to stay indoors or be outdoors on a day when there are extreme wildfires in your area and your family is cooking a large meal? Explain your reasoning and support your answer with data from this activity.**

   I would prefer to remain indoors because the graphs show that there were many days with spikes in outdoor PM2.5 levels that exceed indoor levels, such as September 13th night and September 17th early morning. I would have more control over indoor air quality. I could reduce activities that increased PM2.5 and use an indoor air purifier.

2. **Figure 2.1 is a graph that shows the land area affected by wildfires in the United States since 1983. A hectare is a metric unit for measuring land area, equal to 2.47 acres or 10,000 square meters.**

FIGURE 2.1
Land Area Affected by Wildfires in the United States, 1983–2024



a What is the signal?

The trend line provides the signal to differentiate it from individual events (noise).

b Describe what the noise looks like in the graphed data.

The noise is the lines (the number of hectares burned) going up and down a lot each year.

c Based on the signal, what can you conclude about land area in the United States burned by wildfires over time?

The land area being burned each year is increasing. (The land area affected by wildfires in the United States has increased from around 800,000 hectares—2 million acres—in the early 1980s to around 3 million hectares—8 million acres—by 2020.)

d How might this pattern be similar or different from the area in which you live? ?

I think this pattern is similar to where I live because there seems to be a lot more fires reported in the news now than before.

CONNECTIONS TO EVERYDAY LIFE

③ **You are watching a movie with friends. Another friend is joining you later.**

a Your dog is barking, making it difficult for you to hear what's happening in the movie. What is the signal and what is the noise?

The sound from the movie is the signal, and the dog's barking is noise.

b You move your dog to another room. He later barks to let you know that someone is at the door. Is your dog's bark a signal or a noise?

The dog's bark is now a signal, telling you it is likely that your friend has arrived.

c Explain how identifying the signal vs. the noise depends on the information you are interested in.

The dog's barking was both a signal and noise, depending on what information you were interested in. While watching the movie, the signal was the sound from the movie. While waiting for a friend, the signal was the arrival of the friend, as indicated by the dog barking.

4. **You may have heard warnings about contaminated food, such as to avoid eating lettuce that has been recalled. In many cases, scientists gather data from individuals who fall sick to determine the common cause of their illness. The U.S. Centers for Disease Control and Prevention (CDC) uses this information and has estimated the annual number of foodborne illnesses in the United States to be 47.8 million cases. In the case of detecting foodborne illness:**

   a. **What is the signal?**

      People falling sick from the food-borne illness that is being investigated

   b. **What is a possible source of noise in the data? (What other explanation[s] could there be for the data?)**

      People may be sick from other causes.

   c. **For its estimate, the CDC accounted for scientific uncertainty and identified that the range of actual cases of foodborne illness in the United States per year may be as low as 28.7 million and as high as 71.1 million cases. Would you expect that reducing noise in this data would increase or decrease the estimated range of the data? Explain your reasoning.**

      Reducing noise would likely decrease the range of data. This would be because other factors that could be mistaken for signal would be reduced. For example, fewer people would report being sick from other causes.

REFERENCES

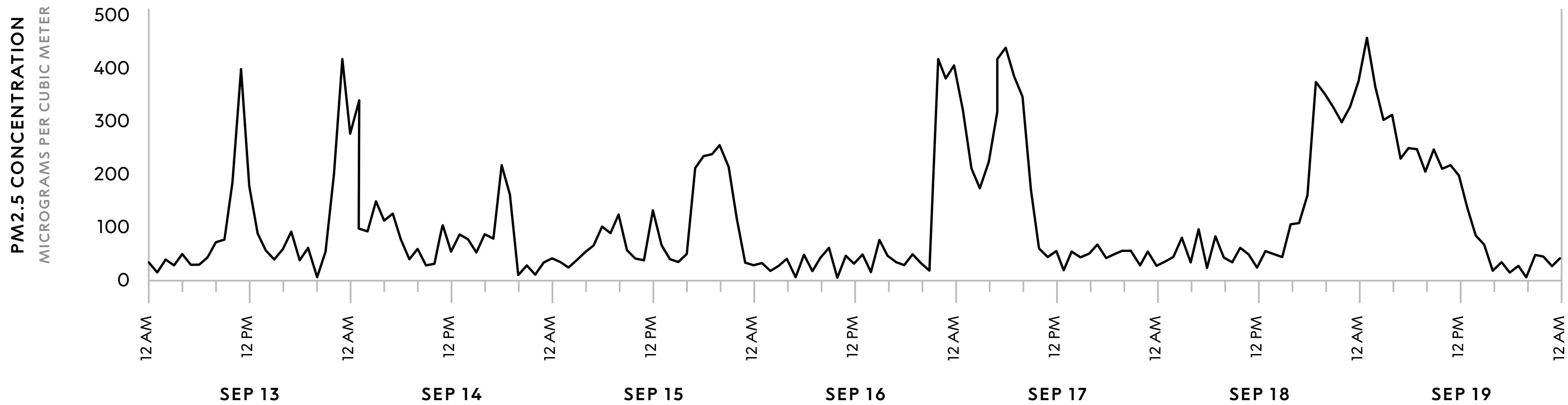
Centers for Disease Control and Prevention. (November 5, 2018.) *Estimates of foodborne illness in the United States: Findings*. https://www.cdc.gov/food-safety/php/data-research/foodborne-illness-burden/

Jones, Ben. (May 13, 2024). *Wildfires in the US: Alarming statistics and trends*. https://www.dryad.net/post/wildfires-usa-statistics

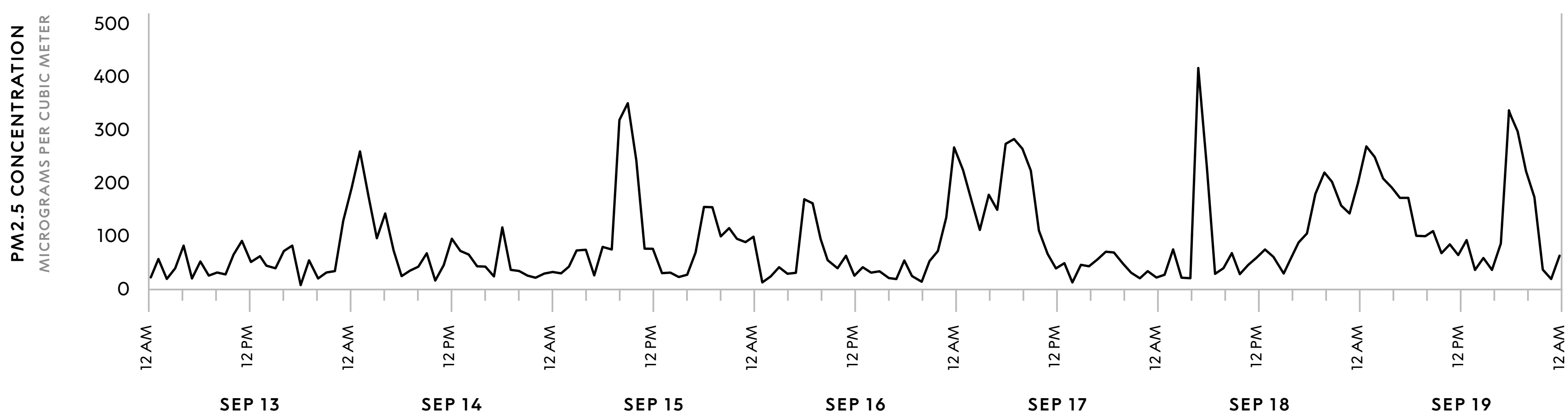
Liang, Y., Sengupta, D., Campmier, M. J., Lunderberg, D. M., Apte, J. S., Goldstein, A. H. (2021). Wildfire smoke impacts on indoor air quality assessed using crowdsourced data in California. *Proceedings of the National Academy of Science of the United States of America, 118*(36) e2106478118. https://doi.org/10.1073/pnas.2106478118

National Interagency Fire Center. (2024). *Wildfires and acres: Total wildland fires and acres (1983–2024)*. https://www.nifc.gov/fire-information/statistics/wildfires

OUTDOOR AIR QUALITY

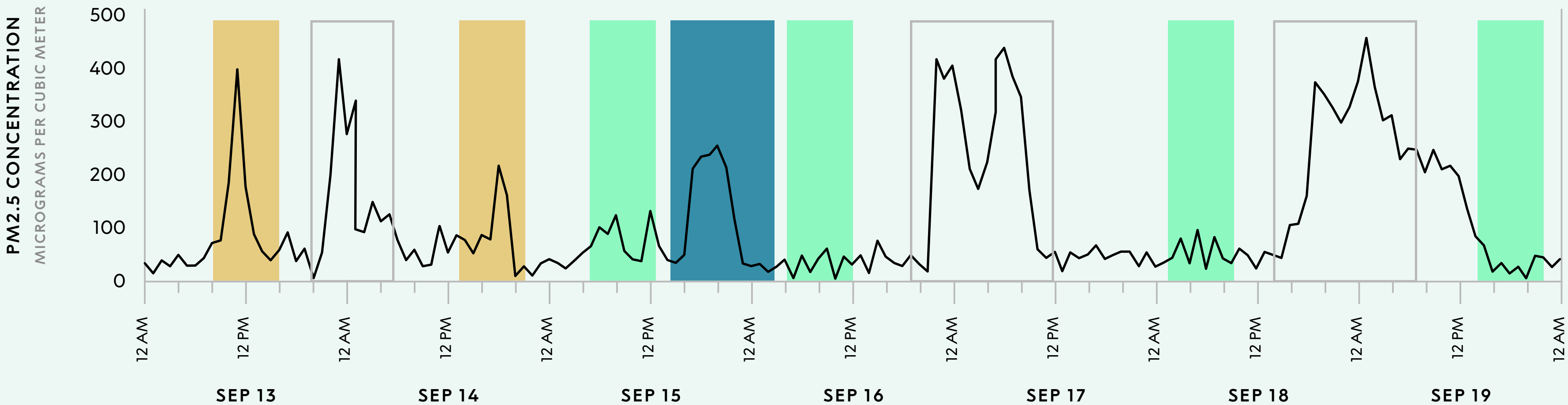


INDOOR AIR QUALITY



NAME SAMPLE STUDENT RESPONSE

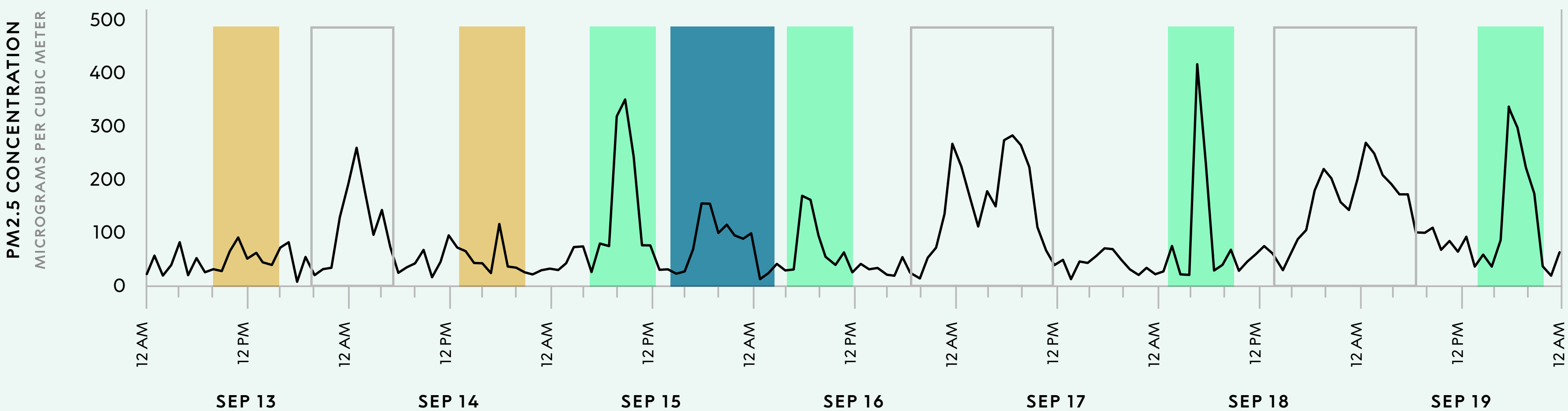
OUTDOOR AIR QUALITY



- Smoking
- Cooking
- Fan

noise | signal | noise | noise | noise | noise | signal | noise | signal | noise

INDOOR AIR QUALITY



STUDENT SHEET 2.2 | FRAYER MODEL | NAME

DEFINITION	CHARACTERISTICS

WORD

EXAMPLES	NON-EXAMPLES

STUDENT SHEET 2.2 | FRAYER MODEL | NAME SAMPLE STUDENT RESPONSE

DEFINITION

meaningful information about the phenomenon that is being investigated

CHARACTERISTICS

- *what the signal looks like depends on the question I'm trying to answer*
- *could be relevant peaks, increase/ decrease in data, gaps in data*
- *signal depends on what I'm studying and how I'm trying to measure it*

WORD

signal

EXAMPLES

- *looking at PM measurements to think about how traffic patterns affect air pollution*

Everyday example
When I do an internet search, relevant and credible sites about what I'm looking for is a signal.

NON-EXAMPLES

- *looking at the data about precipitation when I'm trying to think about how traffic patterns affect air pollution*
- *false patterns*
- *random data, mistaken data points, or irrelevant data*

Everyday example
Ads, sponsored websites, and clickbait articles are not signals.

STUDENT SHEET 2.2 | FRAYER MODEL | NAME SAMPLE STUDENT RESPONSE

DEFINITION

information that hides, distracts from, or falsely resembles the meaningful information that is being investigated

CHARACTERISTICS

- *caused by sources of uncertainty such as scientific error, irrelevant data, mistakes in data collection, malfunctioning equipment*
- *makes it hard to see signal*
- *what counts as noise depends on what type of signal you are looking for*

WORD

noise

EXAMPLES

- *data that fluctuates a lot*
- *possible outliers on a graph*
- *a graph trying to show too many types of data at once*
- *false patterns*
- *random data, mistaken data points, or irrelevant data*

Everyday example
When I do an internet search, ads, sponsored websites, and clickbait articles are noise.

NONEXAMPLES

- *best-fit line on a graph*
- *an average of the data*

Everyday example
When I do an internet search, relevant and credible sites about what I'm l ooking for is not noise.

ACTIVITY 3

Scientific Uncertainty in Data

COMPUTER INVESTIGATION

ACTIVITY 3

Scientific Uncertainty in Data

ACTIVITY SUMMARY

The concept of scientific uncertainty is further developed with the introduction of scientific error and true value. Students explore regional air quality data from online sources and begin to identify possible sources of scientific uncertainty in data. They compare data from crowdsourced applications to data from higher-quality sensors provided by government sites. Students are asked to analyze data, draw conclusions, and discuss the role of probabilistic reasoning in making determinations about air quality.

ACTIVITY TYPE
COMPUTER INVESTIGATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1. When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

2. Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS

VOCABULARY DEVELOPMENT

scientific error
the difference between a measured or observed value and the true value of a quantity

true value
the actual number that would be found if the measurement could be made without error

TEACHER BACKGROUND INFORMATION

Scientific Error and True Value

When one single measurement is compared to another single measurement of the same thing, the values are usually not identical. Differences between single measurements are due to scientific error. Scientifically accepted values are scientists' current best approximations or descriptions of nature. As information and technology improves and investigations are refined, repeated, and reinterpreted, scientists' understanding of nature gets closer to describing what actually exists.

In science, a true value refers to the actual, exact value of a quantity being measured, while a scientific error represents the difference between the measured value and that true value. A scientific error is how much a measurement deviates from the actual value due to limitations in the measuring process or instrument used. The true value is often considered theoretically perfect and cannot be precisely known in practice due to inherent limitations in measurement.

scientific error = measured value – true value

Comparing Air Quality Data

Different apps and websites employ different formulas to transform initial air quality sensor data into estimates of current and future forecasts of air quality. In the United States, the larger circles displayed on the Environmental Protection Agency's (EPA) *AirNow* map, which represent data from government monitoring stations that operate across the country, are generally considered the most accurate data source. *AirNow*'s fire map includes data from PurpleAir sensors (represented by small circles on its map) as does Watch Duty, a nonprofit app for tracking fires. Differences in the instruments, calculations, and processing means that the air quality index reported by the same sensors can vary from map to map. *AirNow* data is tracked and published on an hourly basis by the EPA. PurpleAir sensors are less accurate than the government sensors but are used more widely. They report data every two minutes, producing what the company describes as a real-time map of air quality. With an increasing global focus on air quality, new companies—such as BreezoMeter and Ambee—are working on new approaches to air quality monitoring such as using satellite data, weather information from satellites, and traffic reports in addition to data from government monitoring stations and PurpleAir sensors.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 3.1
  "Air Quality Index (AQI)"
- VISUAL AID 3.2
  "Some Sources of Scientific Uncertainty in Data"
- VISUAL AID 3.3
  "Scoring Guide: Analyzing and Interpreting Data (AID)"
- ITEM-SPECIFIC SCORING GUIDE: Activity 3, Build Understanding Item 2

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 3.1
  "Analyzing Crowdsourced Air Quality Data"
- STUDENT SHEET 3.2
  "Writing Frame: Evidence and Trade-Offs (E&T)"
  (OPTIONAL)
- SCORING GUIDE: Analyzing and Interpreting Data (AID)
  (OPTIONAL)

The number of air quality sensors varies with location. PurpleAir at https://map.purpleair.com relies on crowdsourced data and provides information from many parts of the world. Other potential sources of local air quality data include IQAir and OpenAQ. You may want to investigate other sites that provide air quality information for your region. For example, SAMHE (Schools' Air Quality Monitoring for Health and Education) at https://www.samhe.org.uk provides resources in the United Kingdom and has collaborated with the Stockholm Environment Institute to create a SAMHE web app.

In advance of this lesson, visit sites that you will use to gather data, such as the PurpleAir website and the United States' *AirNow* Fire and Smoke Map website at https://fire.airnow.gov Familiarize yourself with data available for your state or region. Since air quality data availability varies widely by region, you may find it helpful to gather and assess your local data by using the procedure steps in the Student Book to complete Student Sheet 3.1 in advance of the lesson. If there is no data available for your location, consider selecting a nearby region, another region of interest, or assigning student groups to investigate different areas of the world.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (5 MIN)

1 **Present the story found in the Introduction.**

- The story of the development of the PurpleAir website found in the Introduction can be shared with the class in multiple ways. Read the introduction 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 independently.

PROCEDURE SUPPORT (30-40 MIN)

2 **Use Visual Aid 3.1, "Air Quality Index (AQI)," to review the Air Quality Index.**

- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition as they read the information in the Air Quality Index provided in Procedure Step 1. Circulate around the room and check in with students as they use the strategy to decode scientific ideas and construct meaning as they read. You may wish to use Visual Aid 3.1, "Air Quality Index (AQI)," to review that the AQI is a measurement from 0 to 500. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 or below (green) represents good air quality, while an AQI value over 300 (maroon) represents hazardous air quality. Color is used to denote the different levels and make it easier to understand.

3 **Students explore a website providing crowdsourced air quality data, such as PurpleAir.**

- Inform students that they will use crowdsourced data to investigate one measure of air quality: PM2.5 levels.
- Have students familiarize themselves with your chosen website by first spending a few minutes exploring. Ask students to share what they observe, such as the types of features the site has and the type of information that is provided.

4 **Support students in selecting a geographical area for gathering data.**

- The number of sensors varies greatly by location. For some parts of the world, a few sensors may be found across a large geographical area of hundreds of kilometers (miles). In other places, a few sensors may be found in a neighborhood of just a few blocks. Help students navigate the size of the area being considered.
- If needed, demonstrate how to select an appropriate area. Depending on where you live, you may find it helpful to designate a boundary such as a city (e.g., New York City), a county (e.g., Los Angeles County), a state, or even an entire country.

5 **In Part A, students gather evidence about regional air quality from crowdsourced sensors.**

- Distribute one copy of Student Sheet 3.1, "Analyzing Crowdsourced Air Quality Data," to each student. Review how to complete Table 1 by either filling in a row as a class or by modeling sample data. A sample student response is shown at the end of this activity.
- You may wish to assign pairs to work with another pair of students. Pairs can compare their data and conclusions. If students need more support, you might suggest that they discuss the following questions in their groups:
  - Did the other pair find similar data as you?
  - Did the other pair have similar or different ideas about air quality based on the data?
  - Did the other pair have any data or ideas that made you change your thinking?

  Students should recognize that more sensor data reduces scientific uncertainty and increases the likelihood that the air quality determinations are closer to the true value.
- Circulate and assist students as needed.
- Students complete the "Crowdsourced Data" column of Table 2. They then compare their two air quality determinations for an area with many sensors based on: (1) the range of data [found in Table 1] with (2) an average of five data points [found in Table 2]. If the data are similar, there is likely less scientific error in the data and, therefore, reduced uncertainty. If the data are different, the data based on an average is more likely to be closer to the true value than the range because taking the average reduces the effect of differing data points (which may be a result of scientific error).

6 In Part B, students gather evidence about regional air quality from higher-quality sensors.

- Inform students that they will use data from a site that provides data from higher-quality sensors to continue to investigate PM2.5 levels. They will look for data in the same area of the map with many sensors that they investigated in Procedure Steps 5 and 6.
- Have students use data from higher-quality sensors, such as the Fire and Smoke Map at *AirNow*, to complete Table 2 on Student Sheet 3.1. *AirNow* is a partnership of the United States Environmental Protection Agency (EPA); National Oceanic and Atmospheric Administration (NOAA); National Park Service; National Aeronautics and Space Administration (NASA); Centers for Disease Control and Prevention (CDC); and tribal, state, and local air quality agencies.
- Students should compare air quality findings for the same location from high-quality sensors with crowdsourced data. If the data are similar, there is reduced uncertainty, and the air quality determination is probably closer to the true value. If the data are different, the air quality determination based on the higher quality sensor data is likely to be closer to the true value (have less scientific error) because it is collected from sensors that are more accurate and reliable. Given limited data and variability among sensors, making a determination of air quality requires making predictions or drawing conclusions based on likelihood—i.e., probabilistic reasoning.

Sample Student Response, Procedure Step 9

There were more data points for the crowdsourced sensors, but the crowdsourced data had a greater range of values. This means that there was probably more error in the individual sensor readings. We calculated that the same average air quality from both the crowdsourced sensors and the higher-quality sensors. The true value was probably close to this number because it was a result of averaging data from two different types of sensors. We used probabilistic reasoning because we don't know the true value for sure, but we had enough data that we can be pretty sure.

SYNTHESIS OF IDEAS (20 MIN)

7 Discuss the sources of uncertainty in data, using Visual Aid 3.2.

- Use Build Understanding item 1 and Visual Aid 3.2, "Some Sources of Scientific Uncertainty in Data," to discuss sources of scientific uncertainty in data. Have students share their responses to Build Understanding item 1 and discuss how the limitations of their data correspond to the categories described on Visual Aid 3.2.
- Ask, What are some ways to address these different sources of scientific uncertainty? Sample student responses are shown in the following table. You may want to use student responses to foreshadow the possibility of errors in measurement or experimental design (systematic error) or the possibility of random errors, which are formally introduced in the next activity.

missing	*gather additional data (increase sample size)*
unreliable	*gather additional data (increase sample size), compare to other data sets, test measurement equipment*
conflicting	*gather additional data (increase sample size), test measurement equipment, design additional investigations*
confusing	*gather additional data (increase sample size), compare to other data, calculate average*

- Help the class build a common vocabulary to describe sources of uncertainty: *missing*, *unreliable*, *conflicting*, and *confusing*. For example, students may be referring to missing data when describing not having enough data or highlighting areas with few sensors.

8 Discuss the strengths and limitations of crowdsourced data.

You can build on the strengths and limitations of different data sources by having a class discussion about the use of crowdsourced data. Crowdsourcing makes it possible to collect a much larger amount of data from a larger geographic area over more time than a team of professional scientists or even volunteers can do on their own. It also means that more people can be part of the process of science, contributing and learning from one another. One disadvantage is that the data may be of lower quality and reliability since the people collecting it are not all trained in common methodologies. Such data sets might also be vulnerable to people trying to influence the conclusions made from the data (i.e., trolls). It is only possible to gather data from places where people are participating and making observations that they think are worth adding, so scientists have to be careful in interpreting the data; there might be missing data in places without much participation or when observations by untrained people are determined not to be relevant.

9 Use Build Understanding item 2 to assess students' ability to analyze and interpret data.

- Build Understanding item 2 is an Analyzing and Interpreting Data assessment item. This first opportunity can be used to introduce your students to the optional Scoring Guide: Analyzing and Interpreting Data (AID). As this is the first opportunity for students to review the Scoring Guide, you may wish to have them work in pairs or small groups to discuss and/or write their responses, using the Scoring Guide to help develop their responses. See Appendix 2: Assessment Resource at the end of the Teacher's Edition for more guidance and information on using the Scoring Guide with your students.
- Do not share the item-specific version of the Scoring Guide (Item-Specific Scoring Guide: Activity 3, Build Understanding Item 2) with students as it provides specific information on how to respond to the item prompt. Review the Item-Specific Scoring Guide to support scoring this specific item.
- Visual Aid 3.3, "Scoring Guide: Analyzing and Interpreting Data (AID)," can be used to assess Build Understanding item 2. Point out the scoring levels (0–4) and review the criteria for each score. Explain that the scores are based on the quality of students' responses and reflect student growth

over time. The scores do not correspond to letter grades. A Level 4 response is complete and correct. A Level 3 response is almost complete and mostly correct, but possibly missing minor details or containing small errors. At first, many students will write Level 2 responses, and they should strive to achieve Level 3 or Level 4 responses. Let students know that you would like them to improve by at least one level as they progress through the unit. As a class, discuss what a Level 4 response to Build Understanding item 2 would include. You may develop a Level 4 exemplar as a class or share with students the Level 4 responses from the provided sample responses. To help students better understand the three levels, discuss how they are different and ask students for ideas about how to improve from Level 2 to Level 3 and from Level 3 to Level 4.

- For some students, you may wish to support a specific level of growth—this can be particularly helpful if students have an Individualized Educational Plan (IEP), a 504 plan, or other specific educational goals. Growth from a Level 1 to a Level 2 may indicate significant progress for a student and should be recognized as such. Additionally, assessments can be a good opportunity to have students evaluate one another's work and provide initial feedback for revisions prior to submitting their responses to you.
- Sample responses for Levels 1–4 are provided in the Build Understanding section. Review these responses to get an idea of what is expected for each level, alongside the Item-Specific Scoring Guide. See Appendix 2: Assessment Resource at the end of the Teacher's Edition for more guidance and information on using the Scoring Guides and assessment system with your students.

10 Support student responses with a writing frame.

Students apply the concepts of evidence and trade-offs in Connections to Everyday Life, item 4. For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 3.2, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use Student Sheet 3.2 only as a reference or as a checklist as they write their responses. A sample student response for this student sheet is shown at the end of this activity. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.

11 Revisit the Guiding Question.

Finish the activity by revisiting the Guiding Question. Ask, What are some sources of scientific uncertainty in data? In this activity, students were introduced to the concepts of scientific error and true value. They investigated sources of error in data, such as missing, unreliable, conflicting, and/or confusing data, and possible ways in which these errors could be addressed to gather data which is closer to the true value. Use responses to the guiding question to formatively assess the key concepts and process skills related to being able to identify ways in which data may be uncertain. In Activity 4, students design an experiment to explore local air quality data and formally address random and systematic errors.

EXTENSION (10 MIN)

12 **Use the Extension as an opportunity for advanced learning.**

The Extension provides an opportunity for students to examine air quality data in other regions of the world and over longer periods of time. Data about air quality for different communities across the United States and the world can raise questions of geography, climate, and equity. Students may find areas with much better or worse air quality or identify areas that have many or few sensors. They may notice that parts of Asia, such as some cities in India, have some of the worst air quality in the world. In many countries, wood is still the primary energy source for cooking, and vehicle emissions are high. Students may observe patterns of poor air quality during the periods when the majority of people are cooking or traveling to and from work. Sources of uncertainty in the data are likely to mimic the same categories that were raised in the activity—missing, unreliable, confusing, and conflicting data—and could be addressed in a similar way.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **Review your analysis of local air quality data from both sites.**

   a List two possible sources of scientific uncertainty in air quality data.

   Data can be missing, like in areas with fewer sensors. Data can also be conflicting, like when there were large differences in readings from nearby sensors. Data caused uncertainty because we could not tell if the difference was because of actual differences in air quality or if there was a problem with one of the sensors.

   b Brainstorm how each source of scientific uncertainty could be reduced.

   Missing data can be addressed by installing additional sensors in areas without data. Conflicting data can be addressed by taking additional measurements and also checking equipment to make sure it is working correctly.

2. **AID Assessment**

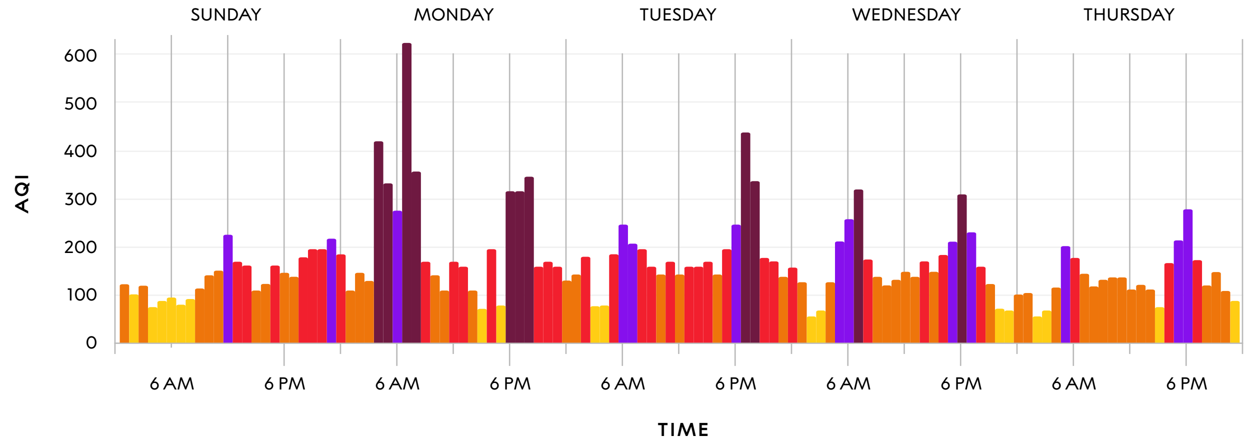
   The graph in Figure 3.2 shows a week of hourly PM2.5 measurements for the capital city of N'Djamena in the country of Chad. Explain what conclusions you can make based on the data in the graph. Refer to Figure 3.1, "Air Quality Index (AQI)," in Procedure Step 1 as needed. In your explanation, be sure to include the following:

   a Describe what patterns you observe in the air quality over time.

   b Explain what conclusions you can make about local air quality.

   c Explain at least two possible sources of scientific uncertainty, including possible scientific errors, that may have affected the data.

FIGURE 3.2
Air Quality Index (AQI) Data for Five Days in N'Djamena, Chad



Level 4 response

The worst air quality is Monday morning between 5:00 am and 8:00 am. The best air quality varies: the best air quality (moderate) compared to the other days is Sunday. I can conclude that in general, the air quality in N'Djamena is not great, since it never goes below 82 PM2.5, which is in the middle of the moderate air quality scale. There is no time when it is good (green). Also, there are many parts of the day when it is hazardous (maroon) for human health. This could be when people are commuting to and from work early in the morning and again in the evening. One source of scientific uncertainty is that we were only given 5 days of data, so it is unclear whether this pattern is always present. Another source of scientific uncertainty is that it is not clear what type of air sensors were being used. They could be low quality and not reporting accurate data.

Level 3 response

The worst air quality is Monday morning, maybe because that's when people are all driving to work and school. The best air quality is early Sunday morning. I can conclude that in general, the air quality in N'Djamena is not great because it never goes lower than 82 PM2.5, which is in the middle of the moderate range, and it's never in the good range. One source of uncertainty is that there is limited data, and it might just be showing some really bad days by chance, like maybe there was a fire on Monday somewhere in the city that affected the air quality.

Level 2 response

There is yellow air quality for a little while on Sunday and Tuesday, but there's also a lot of red, purple, and maroon times that tend to go up and down. The data is uncertain, but I think that the air quality isn't very good there.

Level 1 response

The air quality in this city isn't very good. There's lots of bad air quality. I would not want to breathe that air.

③ **Based on the data in Figure 3.2, which day would be better to be outdoors: Monday or Tuesday? Support your answer with evidence.**

It would be better to be outside on Tuesday because the air quality index does not reach hazardous levels for as many hours as it does on Monday.

CONNECTIONS TO EVERYDAY LIFE

4. **The local Air Quality Index (AQI) on the day of your team's soccer semifinals is reported as 135. A sensor near your home shows an AQI of 100. The best player on your soccer team has asthma. Would you recommend that she play in the semifinal game? Support your answer with evidence and identify the trade-offs of your decision.**

   I would recommend that she not play soccer. An AQI of 135 is unhealthy for sensitive groups. Even though one sensor showed a reading of 100, the local AQI is likely based on more sensors and has less error. Since she has asthma, a respiratory illness with possible symptoms of shortness of breath and wheezing that can be triggered by poor air quality, she may be more affected by the poorer air quality than other players who do not have asthma. The trade-off is that the team will lose our best player during the semifinals, and we may not advance without her participation. People who disagree with me may say that winning the semifinals is very important, and the air quality is not hazardous, just moderate. My friend may not experience any symptoms under those conditions. Also, one local sensor gave a lower reading of 100, so the 135 might not be accurate.

5. **People rely on data such as air quality from scientific tools and technology to make decisions. Yet data from such technology can sometimes be inaccurate. In the case of an air quality sensor, is it worse to have a false positive or a false negative? Explain your reasoning.**

   A false negative from an air quality sensor would be worse because it would incorrectly identify particulate matter as absent, but it would actually be present. If there were high PM levels or unhealthy air quality, a person relying on a sensor that provides a false negative would be misled into thinking that the air quality was better than it actually was. This might lead someone to accidentally exposing themselves to high levels of PM.

REFERENCES

Dave, P. (January 16, 2025). *Why it's so confusing to determine air quality in Los Angeles right now.* Wired. https://www.wired.com/story/confusing-air-quality-los-angeles-aqi/

IQAir. (2024). *Air quality in N'Djamena.* https://www.iqair.com/us/chad/chari-baguirmi/n-djamena

Robertson, M. (September 9, 2022). *The story behind PurpleAir, which has become a necessity for Bay Area summers.* SFGate. https://www.sfgate.com/news/article/The-story-behind-website-Bay-Area-PurpleAir-16393480.php

STUDENT SHEET 3.1	ANALYZING CROWDSOURCED AIR QUALITY DATA	NAME

Table 1: Crowdsourced Data for (date): ____________________

	RANGE OF DATA	DETERMINATION OF GENERAL AIR QUALITY	DESCRIBE HOW YOU MADE YOUR DETERMINATION	REASONS FOR SCIENTIFIC UNCERTAINTY IN DATA
My state				
Area with few sensors				
Area with many sensors				

Table 2: Data from an Area with Many Sensors

	CROWDSOURCED DATA	HIGHER-QUALITY SENSOR DATA
Five measurements		
Differing data point(s)		
Average of five measurements		
Determination of general air quality		

STUDENT SHEET 3.1 | ANALYZING CROWDSOURCED AIR QUALITY DATA | NAME *SAMPLE STUDENT RESPONSE*

Table 1: Crowdsourced Data for (date): *Oct 30, 2024*

	RANGE OF DATA	DETERMINATION OF GENERAL AIR QUALITY	DESCRIBE HOW YOU MADE YOUR DETERMINATION	REASONS FOR SCIENTIFIC UNCERTAINTY IN DATA
My state *Missouri*	*0-54*	*Healthy*	*Most sensors in the state are green.*	*Not many sensors in the state (missing data).*
Area with few sensors *Moberly, MO*	*15*	*Healthy*	*One sensor reading is green.*	*Most state data shows green, but there is only one local sensor (missing data).*
Area with many sensors *Independence, MO*	*8-23*	*Healthy*	*Sensor readings for nearby Kansas City are green.*	*Many more sensors, but they show different values (confusing, conflicting, or unreliable data).*

Table 2: Data from an Area with Many Sensors

	CROWDSOURCED DATA	HIGHER-QUALITY SENSOR DATA
Five measurements	*8, 20, 21, 23, 23*	*18, 19, 19*
Differing data point(s)	*8*	*none*
Average of five measurements	*19*	*19*
Determination of general air quality	*Healthy*	*Healthy*

WRITING FRAME: EVIDENCE & TRADE-OFFS

NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

 SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

whether to play sports outdoors during moderate air quality.

My decision is that

I would tell my friend who has asthma to not play soccer.

My decision is based on the following evidence:

First,

an AQI of 135 is unhealthy for sensitive groups.

Second,

she has asthma, a respiratory illness with possible symptoms of shortness of breath and wheezing.

Third,

she may be more affected by the poorer air quality than other players who do not have asthma.

The trade-off(s)

is that the team will lose our best player during the semifinals and may not advance without her participation.

People who disagree with my decision might say that

winning the semifinals is very important, and the air quality is not hazardous, just moderate. My friend may not experience any symptoms under those conditions. Also, one local sensor gave a lower reading of 100, so the 135 might not be accurate.

AQI CATEGORY (COLOR)	INDEX VALUE	DESCRIPTION OF AIR QUALITY
Good (green)	0–50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate (yellow)	51–100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive* to air pollution.
Unhealthy for Sensitive* Groups (orange)	101–150	Members of sensitive* groups may experience health effects. The general public is less likely to be affected.
Unhealthy (red)	151–200	Some members of the general public may experience health effects. Members of sensitive* groups may experience more serious health effects.
Very Unhealthy (purple)	201–300	Health alert: The risk of health effects is increased for everyone.
Hazardous (maroon)	301 AND HIGHER	Health warning of emergency conditions: Everyone is more likely to be affected.

* According to the American Lung Association, sensitive groups include children under 18, adults over 65, people with chronic heart or lung disease, people who are pregnant, and people with diabetes. Adults who are active outdoors, including outdoor workers and frequent outdoor exercisers, can be considered sensitive because of prolonged exposure to outside air.

Missing Data

Unreliable Data

Conflicting Data

Confusing Data

VISUAL AID 3.3 | SCORING GUIDE: ANALYZING AND INTERPRETING DATA (AID)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.

LEVEL	GENERAL DESCRIPTION
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques and/or reasoning to identify and describe patterns and relationships.
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.
X	The student had no opportunity to respond.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.	The student response: • gives detailed descriptions of patterns in the data, including within and across days. • thoroughly describes sound reasoning and evidence for conclusions about air quality. • provides at least two sources of scientific uncertainty with a thorough explanation of reasoning, including the limitations of the available data.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.	The student response: • describes patterns in the data, including within and across days. The student response may have minor errors or limited responses related to: • describing reasoning and evidence for conclusions about air quality. • providing a source of scientific uncertainty with an explanation of reasoning and limitations of the available data.
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.	The student response: • describes patterns in the data, including within and/or across days. The student response may have errors or limited responses/reasoning related to: • describing reasoning and evidence for conclusions about air quality. • providing a source of scientific uncertainty with an explanation of reasoning and limitations of the available data.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques, and/or reasoning to identify and describe patterns and relationships.	The student response: • describes patterns in the data that may be general or contain errors. The student response may have significant errors or very limited responses/reasoning related to: • describing conclusions about air quality. • providing a source of scientific uncertainty with reasoning.
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.	
X	The student had no opportunity to respond.	

ACTIVITY 4

Reducing Error in Experimental Design

LABORATORY

ACTIVITY 4

Reducing Error in Experimental Design

ACTIVITY SUMMARY

Students investigate local air quality by designing a lab to collect particulate matter data. They work to identify sources of scientific uncertainty in their experiment as they are formally introduced to random error and systematic error. By identifying errors, students consider how to reduce them and increase the certainty of their findings.

ACTIVITY TYPE
LABORATORY

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2-3

KEY CONCEPTS & PROCESS SKILLS

1. Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

2. Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS

VOCABULARY DEVELOPMENT

random error
a difference between an observed and true value that has no consistent pattern and is caused by chance and/or unpredictable factors

systematic error
a difference between an observed and true value in a consistent direction, often caused by experimental equipment or design

TEACHER BACKGROUND INFORMATION

Types of Scientific Error

Scientifically accepted values are scientists' current best approximations, and they are affected by two types of errors: systematic and random. Systematic error results in measurements that are consistently different from the true value in nature, due to limitations of either the measurement tool or the procedure. It is often caused by instruments that consistently offset the measured value from the true value, like a scale that always reads 2 grams too high.

Random error occurs due to chance. There is always some variability when a measurement is made. Random error may be caused by slight fluctuations in a measurement tool, the environment, or the way a measurement is read. It does not cause the same error every time. To address random error, scientists repeat a measurement many times and take the average.

Error cannot be completely eliminated, but it can be reduced by being aware of common sources of error and designing an experiment or making a measurement to reduce the amount of error that might occur. As information and technology improve and investigations are refined, repeated, and reinterpreted, scientists' understanding gets closer to describing what actually exists.

Systematic Error and Random Error

Systematic errors lead to measurements that are different from the true value by a set amount in one direction. In contrast, random errors lead to measurements that are different from the true value by a random amount in either direction. Although both types of error result in an inaccurate measurement, they must be corrected for in different ways.

Random errors are often caused by chance fluctuations in an instrument or the environment that lower the precision of a measurement. The more variability from trial to trial, the less certain one can be of where the true value lies. However, because these types of errors cause measurements that are randomly higher or lower than the true value, they can be dealt with by running more trials and averaging the results. If the measurements are less reliable, there will be more variability in the data set, and more trials will be needed to bring the average closer to the true value.

Systematic errors do not affect the precision or reliability of a measurement. When a systematic error is present, it is possible for measurements to be very precise, with little variability, but also inaccurate because the measurements are shifted in a predictable way. Systematic errors cannot be corrected for by collecting more trials and averaging. These types of errors can only be dealt with by discovering the source of the error and eliminating it (e.g., recalibrating an instrument or removing a factor from the environment that was not controlled for). Alternatively, if it is impossible to remove the factor, and the size of its effect is well established, it can be subtracted from the measurement to estimate the true value.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 4.1 "Guidelines for Safety in the Science Classroom"
- BLEACH SOLUTION
- DISPOSABLE GLOVES
- PROTECTIVE EYEWEAR
- LAB COAT

FOR EACH GROUP OF FOUR STUDENTS

- MICROSCOPE (OR STEREOSCOPE)
- 9 PETRI DISHES
- PETROLEUM JELLY
- TAPE
- 9 INDEX CARDS
- PERMANENT MARKER
- GRAPH PAPER
- DISPOSABLE GLOVES OR FINGER GLOVES (OPTIONAL)

FOR EACH STUDENT

- 2 STUDENT SHEETS 4.1 "Frayer Model" (OPTIONAL)
- STUDENT SHEET 1.3 "Unit Concepts and Skills" (OPTIONAL)

Preview a 7–minute 30–second video titled *Statistical and Systematic Uncertainty* (on the topic of systematic and random error) produced for the college course Sense and Sensibility and Science, from which this high school course is adapted. Note that the script was written and narrated by 2011 Nobel Prize in Physics winner Dr. Saul Perlmutter.

There are numerous ways in which to design a classroom lab to collect particulate matter, including using index cards and packing tape if petri dishes are not available, purchasing Carolina® Biological Airborne Particulates paper, or even building a classroom air quality sensor. The activity in the Student Book provides one suggested method. Determine which method is most feasible for you, given your classroom resources and student population, and adjust the procedure accordingly.

Review any safety-related guidelines provided by your district and look over Visual Aid 4.1, "Guidelines for Safety in the Science Classroom."

Set up microscopes (or stereoscopes) for student use.

Prepare for disposal of all materials used in the activity. Petri dishes can be placed in a disinfecting bleach solution prior to reuse. Wear appropriate safety equipment, including protective eyewear and a lab coat, prior to handling bleach. Follow the directions on the bleach bottle for preparing a diluted bleach solution. If your bottle does not have directions, you can make a bleach solution by mixing 5 tablespoons (⅓ cup) of bleach per gallon of room temperature water or 4 teaspoons of bleach per quart of room temperature water.

While the petroleum jelly can be spread in the dish, using a clean finger, you may want to reduce contamination by providing students with disposable gloves or finger gloves (a tubelike cap that covers the end of a finger).

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (15 MIN)

1 **Introduce the concepts of random error and systematic error.**

- Ask students to share examples of errors that they have seen in scientific experiments, either experiments they have conducted or observed. Make a list of these examples on a whiteboard or projected screen.
- You may wish to show students the video segment titled *Statistical and Systematic Uncertainty.* It explains both statistical uncertainty (random error, or precision) and systematic uncertainty (systematic error, or accuracy). Review how the language used in the video corresponds to the concepts presented in this course.
- Use the Student Book Introduction to highlight the concept of random error and systematic error, which are formally defined in Procedure Step 13. Point out that systematic errors are consistent errors that tend to skew the data in one direction.
- Work together to identify examples of systematic errors in the student examples of errors in scientific experiments, which may include miscalibrated equipment (such as a scale that always reads too low), someone routinely pressing on a scale while taking the mass of a material, or an experiment that is designed with systematic error (such as routinely taking a person's temperature while they are talking or placing an air quality sensor near an outdoor dryer vent). Do the same with random errors, which are less predictable and, therefore, more difficult to address when designing an experiment.
- To support the development of new vocabulary and concepts during the activity, consider using a Frayer Model with students as shown on optional Student Sheet 4.1, "Frayer Model." For the concepts of random error and systematic error, the Frayer Model can be provided at the beginning of the activity, filled out as the activity unfolds, and reviewed at the end of the activity. For more information about the Frayer Model, see Appendix 1: Literacy Strategies. A sample student response for the Frayer Model for the terms *random error* and *systematic error* can be found at the end of this activity.
- If you have begun a word wall, support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the terms *random error* and *systematic error.*

2 **Review classroom safety expectations.**

- Use Visual Aid 4.1, "Guidelines for Safety in the Science Classroom," to remind students to follow all classroom safety rules. Highlight the Safety Note in the Student Book.

PROCEDURE (40–60 MIN + 3 DAYS to conduct experiment outside of class)

3 **Groups set up a control.**

- Depending on your student population, you may need to review the elements of good experimental design, including a clear hypothesis, well-defined independent and dependent variables, a control, control of extraneous variables, and proper data collection and analysis.

- In order to familiarize students with the laboratory materials and setup of the investigation and to guide their experimental designs, groups begin by setting up a control. Depending on your student population, it may not be necessary to conduct this step in advance.

- If students are not familiar with the term *control*, remind them that a control is a basis of comparison for checking the effects of an experiment. Comparing the experimental results with the control allows them to see if the variable they changed in the experiment caused any effect. In this lab, a control dish that is not exposed to air indicates that the particulates came from the vaseline or were already in the dish.

- In this unit, laboratories and card-based investigations use hands-on materials to support student learning. Certain student populations—including girls, gender nonconforming students, and introverted students—often take on roles in which they do not directly engage with hands-on materials, such as recorder and observer. Incorporate strategies to ensure that all students participate over time. For example, in activities such as this one in which students conduct the investigation in groups of four, one strategy is to assign roles (such as group leader, recorder, observer, and timekeeper) ahead of time and then rotate them periodically. Another strategy is to create specific groupings of four that might encourage greater participation. Decide which strategy you will use to best support your student population.

4 **Groups work together to design an experiment to test one factor related to local air quality.**

- Students should begin by discussing locations in which to place petri dishes and what question could be investigated, such as potential differences in air quality near and far from a highway or major road, indoor vs. outdoor, homes with or without pets, distance from a heating/air conditioning vent, street vs. backyard, distance from trees and plants, and so on.

- Students should consider the weather forecast when considering outdoor data collection.

Sample Student Response, Procedure Step 3

The purpose of our experiment is to determine outdoor vs. indoor air quality in homes by measuring the PM2.5 levels. We hypothesize that the outdoor air will contain higher PM2.5 levels. Our group's procedure is to place open dishes containing a thin layer of petroleum jelly both outside and inside each of our 4 homes for 3 days. Our control will be a dish that is left unopened at school. We will monitor all the dishes to make sure they are left undisturbed. We will examine the results under a microscope to count the relative number of particles in the outdoor vs. indoor dishes and compare them to the control.

- Students can record their experimental designs in their science notebooks.

5 **Groups brainstorm possible sources of random error and systematic error in their experimental designs.**

- While responses will vary based on the type of investigation that is being conducted, some sample responses are provided here.
- Procedure Step 3 lists several questions to help students design their experiments. A sample student response is provided.

Sample Student Response, Procedure Step 4

Possible Random Errors

- *Someone moved a petri dish during data collection.*
- *An open petri dish was dropped while bringing it back to class for analysis.*
- *A petri dish went missing.*
- *Counting dust on the objective lens of the microscope (or stereoscope) vs. particulate matter in the dish.*
- *Accidentally touching the objective lens into the petroleum jelly and reducing visibility, yet counting and recording data.*
- *Removing eyeglasses before using the microscope (or stereoscope) but not being able to see clearly through the objective lens.*

Possible Systematic Errors

- *Not using enough magnification on the microscope (or stereoscope) so the particulate matter is not visible and measurable.*
- *Using too high a magnification on the microscope (or stereoscope) so only a very small area of particulate matter can be seen and counted.*
- *Not using enough light on the microscope (or stereoscope) so the particulate matter is not visible and measurable.*
- *Designing an experiment to compare particulatet matter in an area with many trees (like a backyard) and a road (like the one alongside a front yard) without accounting for numerous trees in the front yard.*

- *Designing an experiment for homes with and without pets and placing the petri dish in an area that is not frequented by the pet, like a basement or a stairwell.*
- *Designing an experiment to test the particulate matter near a vent for a system that has been turned off for the season.*

- After identifying possible sources of random error and systematic error, students should plan to address them in their designs to reduce their likelihood, if possible.

6 **After conducting their experiments, groups examine their dishes and make conclusions.**

- When having students examine their collected data, you may need to review the use of microscopes (or stereoscopes) and appropriate rules for handling microscopes.
- If a petri dish contains too many particles for students to count individually, Figure 4.3 in the Student Book provides a sampling method. By using the same template for each dish, groups can count and then compare the number of particulates collected in different dishes. Note that two different templates are shown (Figure 4.3a and 4.3b); each group should only use one template for their data collection.
- In Procedure Step 12, students are instructed to analyze their data and make conclusions. Depending on your student population, you may need to provide additional support for this step. A sample student response is provided.

Sample Student Response, Procedure Step 12

Our conclusion is that the indoor air quality was better than the outdoor air quality. On average, we observed a greater number of particles in the outdoor dishes (10–35 per square) and fewer particles in the indoor dishes (0–14 per square). There were more particles in the outdoor dishes. This supported our hypothesis.

SYNTHESIS OF IDEAS (20 MIN)

7 **Students discuss the results of their investigations and the role of random error and systematic error.**

- You may wish to have students compare their results and discuss random errors and systematic errors in their designs. Direct each student from a group to pair up with a student from another group who investigated the same variable. Have each student present their experimental results, conclusions, and sources of random error and systematic error. The two students can then discuss the similarities and differences in their groups' findings. Emphasize the value in comparing multiple data sets, as reproducibility is a key element of reliable scientific investigations and reduces error.

- Possible random errors and systematic errors are described in Teaching Step 5 and include consistent errors in observing or counting particulate matter, as well as errors in design that could result in consistent overcounting or undercounting.
- Have groups share their results with the class.
- Use Build Understanding item 1 to review the idea that addressing sources of error is a way to reduce uncertainty in scientific findings. Scientific studies are designed to reduce sources of scientific uncertainty by improving the accuracy of measurements, compensate for the imprecision of instruments, prevent outside factors from influencing the results, and ensure that there is enough representative data collected. Some of this should occur before data collection—for example, when designing an experiment—and some should occur after data collection, such as averaging.

8 Revisit the Guiding Question.

- To conclude the activity, evaluate whether your students are able to answer the Guiding Question, *How do you design a study to reduce scientific error?* Use this as a chance to revisit and summarize the key concepts and process skills of the activity.
- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about the concepts of random error and systematic error.

EXTENSION (10 MIN)

9 Use the Extension as an opportunity for advanced learning.

The Extension suggests that students investigate other methods of assessing local air quality and compare their findings with the results of their experiments. You may find it helpful to look at some suggested approaches at the AirGradient website (https://www.airgradient.com/blog/8-student-experiments-to-measure-air-quality/). Have students conduct another air quality investigation and then discuss which approach is less likely to have random errors and/or systematic errors and why.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **Review your experimental design and your results.**

   a What were possible sources of systematic error in your experiment?

   It was predicted to rain for one of the three days of our experiment. We covered the outdoor dishes for several hours during the rain but did not do the same for the indoor dishes. The dishes were not left exposed for the same amount of time.

   b How did you address these possible sources of systematic error in your experimental design?

   We were careful to address possible sources of systematic error in observing and counting our data. We cleaned the objective lenses and made sure we were using the right magnification and light levels. We had one member of our group count particles and another person check their observations.

   c What possible sources of systematic error did you not address in your experimental design? Given more time and resources, how could you address them?

   We compared indoor air quality in four different homes. We placed one dish in each home but in different rooms. Two were placed in bedrooms, one in a kitchen, and one in a living room. We could repeat the experiment and make sure we place the dishe indoors in similar places to reduce systematic error.

2. **The graph in Figure 4.4 shows annual average PM2.5 air quality in the United States over a 24–year period. PM2.5 levels have decreased by 37% during that time. A person living near an area of frequent wildfires complains that their PM2.5 levels have increased during the same period.**

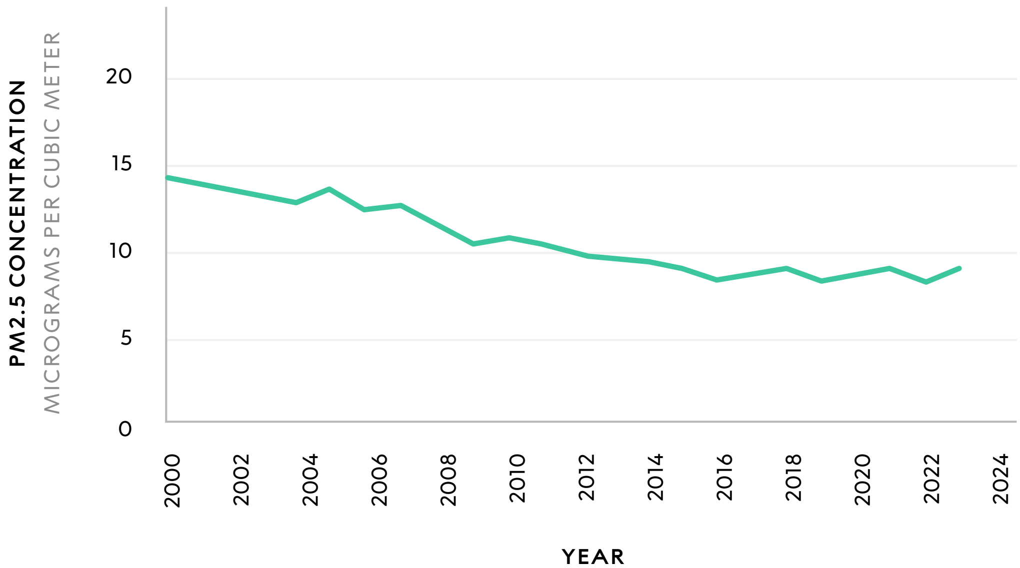
   a Explain how this could be true.

   The overall air quality could be better on average across the whole country, but it could have gotten a bit worse in certain areas, or it could have gotten worse for short periods of time that are not reflected in the annual average. The average doesn't always reflect every place or all time periods that are part of the average.

   b Figure 4.4 is from the U.S. Environmental Protection Agency, which addresses systematic and random error in its data. Explain one possible systematic error that could affect such data and how it could be addressed to reduce scientific uncertainty.

   Air quality monitoring equipment may not be collected from the same communities from year to year. Placing air quality sensors in a regular pattern in different types of communities (urban, suburban, rural) spread evenly across the United States and collected from the same sites over time could reduce systematic error.

FIGURE 4.4
PM2.5 Air Quality in the United States, 2000–2023



CONNECTIONS TO EVERYDAY LIFE

3. **Like a scientific procedure, a recipe provides a list of steps to follow in order to produce an intended outcome, such as a batch of cookies. Imagine you are in a cooking class where eight groups each baked a batch of chocolate chip cookies using the same recipe. Some of the cookies came out chewy and thin, while others were thick and dry. What are some possible sources of (a) random error and (b) systematic error?**

   Possible sources of (a) random error include human error in measuring ingredients, inconsistent mixing techniques, and environmental factors such as temperature and humidity. Possible sources of (b) systematic error include an incorrectly calibrated measuring tool, inaccurate oven temperature, and slight differences in the quality of ingredients from one brand to another.

4. **Janeen wants to improve her running speed, so she decides to experiment by running the same 1-mile route every day for a week to see if she gets faster. By the end of the week, her mile time had improved by 30 seconds. The following things happened during her experiment. Explain whether they are related to random error or systematic error and how each might have affected her results.**

   a. **Janeen starts her stopwatch a little bit early because she needs to secure her phone in her pocket before she starts running.**

This is a systematic error that would reduce her running speed because it would add time during which she is not running.

b **Midway through the week, Janeen starts drinking an electrolyte drink 20 minutes before her run.**

This is a systematic error that might increase her running speed if it provides her with more energy during her run.

c **Each time she runs, her speed varies slightly due to factors such as how much energy she has, random distractions (like a car honking), or even slight changes in the weather. Some days, she feels tired and runs a little slower.**

These are sources of random error. Being tired or distracted would likely reduce her running speed. The way in which weather affects her running speed would depend on the specific changes in the weather (for example: extreme heat or rain might reduce her running speed, while a cool overcast day might increase her running speed).

⑤ **How might you redesign Janeen's experiment from item 4 to reduce sources of scientific uncertainty in her data?**

I would recommend that she follow the same procedure and path each time prior to and during her run, that she not change her diet prior to running, and that she ask someone else to time her run so she has more accurate data about her running speed.

REFERENCES

A., Carisa. (February 16, 2020). *8 student experiments to measure air quality*. AirGradient. https://www.airgradient.com/blog/8-student-experiments-to-measure-air-quality/

Greenwald R., Sarnat J. A., & Fuller, C. H. (January 31, 2024). The impact of vegetative and solid roadway barriers on particulate matter concentration in urban settings. *PLoS One 19*(1): e0296885. https://doi.org/10.1371/journal.pone.0296885

STUDENT SHEET 4.1 | FRAYER MODEL | NAME

DEFINITION

CHARACTERISTICS

WORD

EXAMPLES

NON-EXAMPLES

DEFINITION

a difference between an observed and true value in a consistent direction, often caused by experimental equipment or design

CHARACTERISTICS

- *data affected in a predictable way*
- *graph or data points shifted in a consistent direction*
- *getting rid of the error gets rid of the shift in the data points*

WORD

systematic error

EXAMPLES

- *miscalibrated scale always reads too high*
- *air sensor is placed somewhere windy so the readings are always lower than the true value*

Everyday example
Reading a measuring tape incorrectly by always aligning the zero mark slightly off

NON-EXAMPLES

- *random changes in the environment that cacuse fluctuations in the data that are not in a consistent direction*
- *data that has natural variation in the measurements*

Everyday example
Getting slightly different measurements of your weight by weighing yourself at different times of the day on different days

DEFINITION

a difference between an observed and true value that has no consistent pattern and is caused by chance or unpredictable factors

CHARACTERISTICS

- *data affected in unpredictable or inconsistent ways*
- *data points can fluctuate or be higher or lower than the average*

WORD

random error

EXAMPLES

- *getting slightly different measurements using the same instrument*
- *unexpected weather leads to unpredictable data measurements*

Everyday example
Getting slightly different measurements of your heart rate after different activities on different days

NON-EXAMPLES

- *an instrument that always measures too high or always measures too low*
- *a factor that affects an experiment, shifting the data consistently in one direction*

Everyday example
Using a measuring cup that measures incorrectly, shifting the data consistently in one direction

BEFORE THE INVESTIGATION

- Listen carefully to your teacher's instructions and follow any steps recommended when preparing for the activity.
- Use only the materials and chemicals needed for the investigation.
- Know the location of emergency equipment such as a fire extinguisher, a fire blanket, and an eyewash station.
- Tie back or remove dangling or bulky items such as long hair, jewelry, sleeves, jackets, and bags.
- Do not wear open-toed shoes in the science lab.
- Let your teacher know if you wear contact lenses or have allergies, injuries, or any medical conditions that may affect your ability to perform the lab safely.
- Make sure that both the work surface and the floor in your work area are clear of books, backpacks, purses, and any other unnecessary materials.

DURING THE INVESTIGATION

- Follow all written and spoken instructions.
- Read the activity procedure carefully.
- Don't eat, drink, chew gum, or apply cosmetics in the lab area.
- Wear safety goggles when using chemicals.
- Do not wear contact lenses when using chemicals. If your doctor says you must wear them, notify your teacher before conducting any activity that involves chemicals.
- Read all labels on chemical bottles and be sure you are using the correct chemical.
- Keep all chemical containers closed when not in use.
- Do not touch, taste, or smell any chemical unless you are instructed to do so by your teacher.
- Mix chemicals only as directed.
- Use caution when working with hot plates, hot liquids, and electrical equipment.
- Follow all directions when working with live organisms and microbial cultures.
- Be mature and cautious and don't engage in horseplay.
- Report any accidents to your teacher immediately.
- Not sure what to do? Ask!

AFTER THE INVESTIGATION

- Dispose of all materials as instructed by your teacher.
- Clean up your work area, wash trays, replace bottle caps securely, and follow any special instructions.

ACTIVITY 5

Addressing Uncertainty in Science

READING

ACTIVITY 5

Addressing Uncertainty in Science

ACTIVITY SUMMARY

Students read about the Harvard Six Cities Study, one of the first large studies on the health effects of poor air quality, and synthesize ideas previously introduced in the unit, including scientific uncertainty and sources of error. Students learn how scientists plan for and reduce errors in experimental design and data collection. They learn that confidence intervals and confidence levels are methods scientists use to communicate uncertainty in their work.

ACTIVITY TYPE
READING

NUMBER OF
40–50 MINUTE
CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

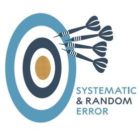
1 Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

2 Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).

3 Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS



VOCABULARY DEVELOPMENT

confidence interval
the range of data expected to contain the true value

confidence level
a statistical measure of the probability that the true value is within a specified range

confound
a factor that can distort or hide the relationship between two variables being investigated in a study

TEACHER BACKGROUND INFORMATION

Harvard Six Cities Study

The Harvard Six Cities Study, published in 1993, was a landmark investigation into the relationship between air pollution and public health. Researchers tracked over 8,000 participants from 6 U.S. cities—Portage, Wisconsin; Topeka, Kansas; Watertown, Massachusetts; St. Louis, Missouri; Kingston-Harriman, Tennessee; and Steubenville, Ohio—over 14–16 years and analyzed the effects of long-term exposure to particulate matter (PM2.5). The study revealed a strong association between higher levels of air pollution and increased mortality, particularly from cardiovascular and respiratory diseases. Individuals in the most polluted city, Steubenville, Ohio, faced a 26% higher risk of death compared to those in the least polluted city, Portage, Wisconsin. Eventually, the study was extended to collect data through 2009. The results of the extended study confirmed the earlier findings.

This research was instrumental in demonstrating that even low levels of air pollution, previously considered safe, could significantly impact health. It led to more stringent air quality standards in the United States under the Clean Air Act, emphasizing the need to control fine particulate pollution. The study also set a new benchmark for epidemiological research by combining long-term population health data with environmental exposure metrics, influencing policy and furthering our understanding of the health risks posed by air pollution.

Variability, Confidence Levels, and Confidence Thresholds

After reducing sources of random error and systematic error as much as possible, one way that scientists estimate the remaining uncertainty of their data is by considering its variability—how different all the individual data points in a group are from one another and their calculated average. (The term *variability* is not used in the student materials; however, Activity 6 refers to how spread out or close together the data points are from one another.)

Statistical measurements help scientists consider the probability that an effect they measured was due to chance by considering variability, the number of samples, and the size of the effect (for instance, the difference between two experimental groups). A higher variability of the data and collecting less samples increase the probability that the results were due to chance, whereas a larger size of the observed effect decreases it. This probability is interpreted as a confidence level for how likely the observed effect is real. Most importantly, scientists require this confidence rating to meet a certain level of confidence, known as a *confidence threshold*. Typically, experimental results are only shared and accepted by other scientists when they have a calculated confidence level that is equal to or higher than 95%.

How can I reduce uncertainty? →

Correct for systematic errors and random errors!

How much uncertainty is left? →

Measure the variability of the data.

Is my result just from chance? →

Use the variability, number of samples, and size of the effect to calculate the probability that it was caused by chance.

How sure am I?

If that chance probability is low enough, then my confidence is high enough (over 95%) to make a conclusion.

MATERIALS & ADVANCE PREPARATION

FOR EACH STUDENT

- STUDENT SHEET 5.1 "Anticipation Guide: Scientific Uncertainty"
- STUDENT SHEET 5.2 "DART: Examples of Scientific Uncertainty"

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (10 MIN)

1 **Students complete the "Before" column of Student Sheet 5.1, "Anticipation Guide: Scientific Uncertainty."**

- Use the Anticipation Guide to elicit students' initial ideas about scientific uncertainty and sources of error. Student Sheet 5.1, "Anticipation Guide: Scientific Uncertainty," provides a preview of science concepts in this activity. An Anticipation Guide gives students an opportunity to explore their initial ideas and revisit and modify them at the end of the activity. Be sure students understand that they should complete only the "Before" column for the statements at this time; they will have a chance to revisit these statements after the reading to see whether their ideas have changed. For more information on an Anticipation Guide, see Appendix 1: Literacy Strategies.
- While an Anticipation Guide supports sensemaking, it requires additional reading and interpretation and may need to be modified for some student populations, such as emerging multilingual learners and neurodiverse students. You may wish to complete Student Sheet 5.1 as a class, use it at the end of the activity to summarize key ideas, or use it as a formative assessment of students' learning.

PROCEDURE SUPPORT (40 MIN)

2 **Hand out Student Sheet 5.2, "DART: Examples of Scientific Uncertainty."**

Explain to students that DART stands for a directed activity related to text that supports students' understanding of the material. It supports reading comprehension and critical thinking by having students interact with and manipulate the information they are reading. For more information on a DART, see Appendix 1: Literacy Strategies.

3 **Students complete the reading.**

- Have students read the text. If you have begun a word wall, support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the terms c*onfidence lev-*

el, *confidence interval*, and *confound*. Provide an example of a confound, such as the pre-existing health conditions that might have influenced the health results in the Six Cities Study, as needed.

- Circulate around the room and check in with students as they use the DART strategy to decode scientific ideas and construct meaning as they read. You may need to clarify that a confound is a type of systematic error.
- Students should fill out Student Sheet 5.2 as they read. Point out that students are expected to provide examples of scientific errors in the first column. After reading, students can compare ideas and responses with another student. A Sample Student Response to Student Sheet 5.2 is provided at the end of this activity. In order to include all examples from the unit so far, it contains a more complete response than should be expected from most students.

SYNTHESIS OF IDEAS (20 MIN)

4 Students complete the "After" column on the Anticipation Guide.

After students complete the reading, direct them to complete the "After" column on Student Sheet 5.1. Discuss student responses as a class to ensure that all students understood the key concepts of the activity. A sample student response is shown at the end of this activity.

5 Review main ideas from the reading.

- Emphasize the key ideas about random errors and systematic errors and how scientists try to identify and reduce these types of errors in their work. Use Connections to Everyday Life item 3 to discuss how random errors and systematic errors can affect scientific data.
- Build Understand item 2 is a high-level question that involves identifying confidence intervals in a graph. You may wish to do this as a class or use pair-share and round-robin approaches to encourage all students to participate.

6 Lead a class discussion on understandings about science in society.

- As a class, discuss Connections to Everyday Life item 5. Science tries to get closer to the truth by testing ideas and making sure those ideas are supported by evidence. Depending on the available data, explanations may be incomplete or even incorrect. Scientists have to modify or change their ideas when faced with new evidence. When a lot of evidence points to the same conclusion, it reduces the uncertainty in a scientific conclusion. That is why it is important for scientists to consider sources of scientific uncertainty and how they could be affecting their data and conclusions. In this way, scientific uncertainty can be reduced and/or described. One way scientists communicate levels of scientific uncertainty is through confidence levels and confidence intervals.

- Finish the activity by revisiting the Guiding Question. Ask, How do scientists reduce uncertainty in science? Use responses to this question to formatively assess the key concepts and process skills related to random errors and systematic errors and methods to reduce these sources of scientific uncertainty. Student responses will vary but may include examples of scientific techniques from the reading, such as reducing random error by taking more data and averaging samples and reducing systematic error by calibrating equipment and careful experiment design.

EXTENSION (10 MIN)

7 **Use the Extension as an opportunity for advanced learning.**

The Extension provides an opportunity for students to consider ways in which local air quality can be improved by finding out more about the work being done in Louisville, Kentucky, by visiting the Green Heart Louisville Project's HEAL Study website. Encourage students to consider the role of community-based science in improving local health and well-being.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **Researchers want to determine if reducing indoor air pollution can affect the severity of flu symptoms. The first 100 volunteers to sign up are assigned to a control group and given a device that circulates indoor air. The next 100 volunteers are assigned to an experimental group and given a device that filters indoor air pollutants before circulating the air. The researchers track the severity of flu symptoms in each group and record the number of days it takes each person to recover. At the end of the study, the researchers measure the overall health of each patient.**

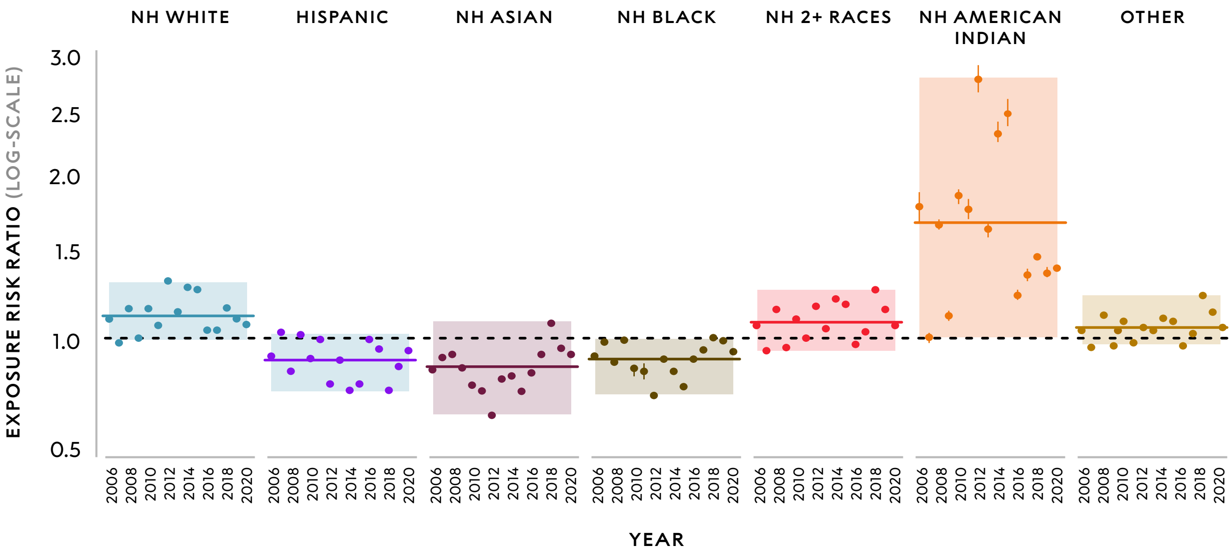
   Identify at least two scientific errors in the design of this study and explain how to improve the design to correct for these errors.

   One source of scientific error is assigning people to a group based on when they arrived and signed up. What if people arriving earlier were healthier than those arriving later? This would be a confound (a source of systematic error). The design could be improved by randomly assigning people to a group.

   Another source of scientific error could be differences between the amount of indoor air pollution in the homes of each participant. This could be a source of random error, since each participant has different living conditions. The design could be improved by monitoring the indoor air pollution levels in each person's home and comparing the averages.

2. **Figure 5.3 shows the average wildfire smoke exposure risk for different ethnic groups in California. The shaded areas of the graph represent a 95% confidence interval for each group's data set.**

FIGURE 5.3
Wildfire Smoke Exposure, in California, 2006–2020



a Explain what a 95% confidence interval means in terms of this specific data.

For this data, a 95% confidence interval means that if the researchers repeated this study 100 times, the results would fall within the shaded range 95 times.

b What conclusions can you make about the data?

I can conclude that some populations, such as white and Native American, have an increased exposure risk to wildfires, while other populations have a decreased exposure risk. The Native American population had the highest average risk.

c The graph for the Native American population (labeled on the graph as "Non-Hispanic American Indian") has the largest confidence interval. How does this affect the amount of certainty you have in the conclusions you make about the graph?

The large confidence interval means that in order to achieve 95% confidence level, there needs to include a bigger range of values. This means that there is more uncertainty in the Native American data set because the data points are more spread out. This makes me less certain about what the actual risk to the Native American population is—it could be as low as 1 and as high as 2.7.

CONNECTIONS TO EVERYDAY LIFE

③ **Johan wants to see if drinking more water will help clear up his acne. He decides to experiment by drinking 8 glasses of water every day for a month. He tracks his skin's appearance by taking pictures daily and noting the number of pimples. By the end of the month, Johan observes a lot less acne than at the beginning of the month.**

The following things happened during his experiment. Explain whether each is related to random error, systematic error due to equipment or experiment design, or a systematic error due to a confound. Explain how each might have affected his results.

a Changes in weather, schedule, and diet resulted in several days when Johan drank more than or less than 8 glasses of water in a day.

Factors such as weather, schedule changes, and diet were sources of random error because they happened unexpectedly. For example, if there was a really hot day, or if Johan ate a lot of salty chips, maybe he drank more water than usual. This might reduce how certain he could be in his results over time, since he didn't drink the same amount every day.

b Johan didn't always use the same glass when he drank the 8 glasses of water. On some days, he used a smaller glass.

This would lead to a systematic error due to equipment. On the days he used a smaller glass to drink 8 glasses of water, he drank less water than on the other days. This might reduce how certain he could be in his results over time, since he didn't drink the same amount every day.

c **After 2 weeks, Johan ran out of face soap, so he bought a different brand of face soap.**

Switching brands of face soap halfway through the month created a systematic error due to a confound. Now it is difficult to know whether Johan's improved skin was due to drinking more water or using a new face soap. It could just be that his new face soap is better at treating acne than his old one, but it's hard to tell.

4. **How would you redesign Johan's experiment from item 3 to reduce sources of scientific uncertainty in his data?**

Some ways to redesign the experiment might be to make sure Johan uses the same face soap throughout the experiment so the effects are constant. Johan can also set a minimum amount of water to drink, measured by volume—for example, 2 liters—instead of relying on the number of glasses, so the amount of water he drinks will be more constant.

5. **American physicist and Nobel Laureate Richard Feynman said, "When a scientist...has a hunch as to what the result is, he [or she] is uncertain. And when he is pretty...sure of what the result is going to be, he is still in some doubt. Scientific knowledge is a body of statements of varying degrees of certainty—some most unsure, some nearly sure, but none absolutely certain."**

Discuss with your class how uncertainty in science can sometimes mislead people into thinking that science cannot provide trustworthy information. How would you address this issue when talking to someone who says that science does not provide true information?

I would say that scientists have to make the best conclusions and explanations that they can with incomplete information. That's why it is important to consider sources of scientific uncertainty and how they could be affecting data and conclusions. Scientists have to accept the fact that they could be wrong and may need to change their thinking when faced with new evidence.

Sometimes when people hear that science isn't 100% sure about everything, they might think that science can't be trusted at all. But science is about finding the best answers based on the available evidence. I would explain that scientists try to get closer to the truth by testing ideas and making sure their ideas are supported by evidence. Scientists improve their understanding step by step. It doesn't mean science is wrong—it's just how science works.

REFERENCES

American Lung Association. (April 19, 2023). *Louisville air quality results mixed, residents exposed to unhealthy air pollution.* https://www.lung.org/media/press-releases/state-of-the-air-louisville

Casey, J. A., Kioumourtzoglou, M., Padula, A., González, D. J. X., Elser, H., Aguilera, R., Northrop, A. J., Tartof, S. Y., Mayeda, E. R., Braun, D., Dominici, F., Eisen, E. A., Morello-Frosch, R., & Benmarhnia, T. (February 13, 2024). Measuring long-term exposure to wildfire PM2.5 in California: Time-varying inequities in environmental burden. *Proceedings of the National Academy of Sciences*, *121*(8). https://doi.org/10.1073/pnas.2306729121

Dockery, D. W., C. Arden Pope, C. A., Xu, X., Spengler, J.D., Ware, J. H., Fay, M. E., Benjamin G. Ferris, Jr., B. G., & Speizer, F. E. (December 9, 1993). An association between air pollution and mortality in six U.S. cities. *New England Journal of Medicine*, *329*(24), 1753–1759. https://www.nejm.org/doi/full/10.1056/NEJM199312093292401

Fuller, G. (December 29, 2023). *Lasting legacy of the Six Cities study into harms of air pollution*. The Guardian. https://www.theguardian.com/environment/2023/dec/29/lasting-legacy-of-the-six-cities-study-into-harms-of-air-pollution

The Nature Conservancy. (August 21, 2018). *The Green Heart Louisville Project*. https://www.nature.org/en-us/about-us/where-we-work/united-states/kentucky/stories-in-kentucky/green-heart-project/

Lepeule, J., Laden, F., Dockery, D., & Schwartz, J. (March 28, 2012). Chronic exposure to fine particles and mortality: An extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environmental Health Perspectives, 120*(7), 965–970. https://ehp.niehs.nih.gov/doi/10.1289/ehp.1104660

Sand, B. (January 29, 2024). *Everyone says trees are good for us. This scientist wants to prove it.* The Washington Post. https://www.washingtonpost.com/health/2024/01/29/louisville-trees-heart-health/

STUDENT SHEET 5.1	ANTICIPATION GUIDE: SCIENTIFIC UNCERTAINTY	NAME

In the "Before" column, mark whether you agree (+) or disagree (–) with each of the following statements. Then complete the reading. In the "After" column, mark whether you agree (+) or disagree (–) with the statements. Under each statement you agree with, explain how the activity gave evidence to support or change your ideas. Under each statement you disagree with, write and explain a corrected statement.

BEFORE	AFTER	
		1 Scientific uncertainty decreases as more data are collected and analyzed.
		2 Scientists are able to get rid of all sources of error in their data if they design their experiments carefully enough.
		3 Systematic error in data is a result of unpredictable changes in the environment.
		4 Identifying sources of error in an experiment makes conclusions about the data invalid.
		5 All sources of scientific error are a result of people making mistakes in data collection.
		6 Sometimes an unidentified factor can affect study results and make it harder to determine the true cause of an observed effect.
		7 Scientists use confidence levels and confidence intervals to communicate how sure they are about their results.
		8 Scientific uncertainty in experimental data means the science is unreliable.

ANTICIPATION GUIDE: SCIENTIFIC UNCERTAINTY

NAME SAMPLE STUDENT RESPONSE

In the "Before" column, mark whether you agree (+) or disagree (–) with each of the following statements. Then complete the reading. In the "After" column, mark whether you agree (+) or disagree (–) with the statements. Under each statement you agree with, explain how the activity gave evidence to support or change your ideas. Under each statement you disagree with, write and explain a corrected statement.

BEFORE	AFTER	
	+	**1** Scientific uncertainty decreases as more data are collected and analyzed. *Scientific uncertainty due to random error decreases as more data are collected. The example from the reading was how the Six Cities Study collected data over many years and averaged the results to reduce uncertainty in the conclusions.*
	–	**2** Scientists are able to get rid of all sources of error in their data if they design their experiments carefully enough. *Scientists are not able to get rid of all sources of error. There will always be some uncertainty due to random error.*
	–	**3** Systematic error in data is a result of unpredictable changes in the environment. *Random error in data is a result of unpredictable changes in the environment. Systematic error is not due to unpredictable changes but by a consistent error that affects the results.*
	–	**4** Identifying sources of error in an experiment makes conclusions about the data invalid. *Identifying sources of error in an experiment reduces uncertainty about the conclusions from the data. According to the reading, knowing the sources of error in an experiment can help you understand the limitations of the data.*
	–	**5** All sources of scientific error are a result of people making mistakes in data collection. *Scientific error is not only a result of people making mistakes. Random error is due to unpredicted changes or chance, while systematic error can be due to experiment design and equipment problems.*
	+	**6** Sometimes an unidentified factor can affect study results and make it harder to determine the true cause of an observed effect. *An example is the confounds in the Six Cities Study. There were confounds related to the health conditions of the study participants, like their history of smoking or diet. These may have affected their life expectancies more than air quality.*
	+	**7** Scientists use confidence levels and confidence intervals to communicate how sure they are about their results. *If a scientist has a higher confidence level, it means that their results will fall within an expected range more often.*
	–	**8** Scientific uncertainty in experimental data means the science is unreliable. *Scientific uncertainty in experimental data does not mean that science is unreliable. Scientists can still make useful conclusions from data even if they can't be 100% sure about the data.*

STUDENT SHEET 5.2 | DART: EXAMPLES OF SCIENTIFIC UNCERTAINTY | NAME

EXAMPLES OF TYPES OF SCIENTIFIC ERROR FROM THE READING	EXAMPLES OF THIS TYPE OF ERROR FROM PREVIOUS ACTIVITIES	METHODS FOR REDUCING SCIENTIFIC UNCERTAINTY
Random error		
Systematic error		
Confound (a type of systematic error)		

 SAMPLE STUDENT RESPONSE

EXAMPLES OF TYPES OF SCIENTIFIC ERROR FROM THE READING	EXAMPLES OF THIS TYPE OF ERROR FROM PREVIOUS ACTIVITIES	METHODS FOR REDUCING SCIENTIFIC UNCERTAINTY
Random error *Air pollution can be affected by factors that can affect AQI in unexpected ways, like fluctuating weather, winds, and industrial pollution.* *Unexpected air currents near air sensors can cause random fluctuations in AQI readings.*	***Activity 3*** *Looking at areas with more air sensors vs. less air sensors: The area with less air sensors might have data that are more affected if there is random error because there are less data points.* ***Activity 4*** *There could be random error involved in counting the number of particulates on the petri dish, as well as the petri dishes placed in the same location may not have the same count of particulates.*	*Taking more data points, measuring data over long periods of time, and averaging data can reduce scientific uncertainty due to random errors.*
Systematic error *AQI measurements can be affected if the equipment is not working correctly, leading to over or under measurement of the AQI.* *If air sensors are placed in a location that has less air pollution than where the study participants live, their exposure might be underestimated.*	***Activity 3*** *We looked at data from low-quality and high-quality air sensors. The low-quality air sensors may have been consistently under measuring or over measuring the AQI.* ***Activity 4*** *There could have been systematic error in our experiment due to design. For example, we placed our petri dish next to an air vent when we could have placed it in the middle of the room, which would have given a more representative reading of the particles in the room.*	*Identify sources of systematic error and try to correct or remove them by calibrating or repairing equipment, improving experiment design.*
Confound (a type of systematic error) *Smoking history or dietary factors could have affected the health of study participants, making it difficult to be sure that air quality was the factor responsible for the reduced life expectancy results.*	***Activity 2*** *We investigated indoor air quality but determined that outdoor air quality can have a big effect on indoor air quality.* ***Activity 3*** *Some locations might have factors like unexpected construction projects going on, which temporarily affect the air quality.* ***Activity 4*** *The petri dish was placed in the garage without realizing that lint from the dryer is adding particles to the petri dish.*	*Try to improve experiment design, consider the effects of the confound on the data and conclusions.*

ACTIVITY 6

Quantifying Scientific Uncertainty

COMPUTER SIMULATION

ACTIVITY 6

Quantifying Scientific Uncertainty

ACTIVITY SUMMARY

Students use a computer simulation to gather data from an air quality sensor under different conditions. By analyzing the data generated by the simulation, students further explore random errors and systematic errors. They learn how collecting more data and averaging can affect the accuracy of random errors but not systematic errors. Students consider how error bars can communicate scientific uncertainty in data. They use this information to consider a decision between two air sensors.

ACTIVITY TYPE
COMPUTER SIMULATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1. Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.
2. Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results *(confounds)*.
3. Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.
4. Probabilistic reasoning can be used to identify meaningful patterns in data *(signal)* about a phenomenon being investigated. Variations in the data *(noise)* can increase scientific uncertainty by distorting or hiding the signal.

CONCEPTUAL TOOLS

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. *(Science and Engineering Practice: Analyzing and Interpreting Data)*

Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. *(Science and Engineering Practice: Analyzing and Interpreting Data)*

VOCABULARY DEVELOPMENT

accuracy
(assumed prior knowledge)
the closeness of a measured value to a standard or true value

error bars
a visual representation of the amount of uncertainty in a measurement, presented as a ± (plus or minus) range of numbers that fall above and below the average

precision
(assumed prior knowledge)
how close measurements of the same item are to each other

reliable
(assumed prior knowledge)
able to be reproduced consistently

validation
(assumed prior knowledge)
a process of determining the accuracy of a measurement

TEACHER BACKGROUND INFORMATION

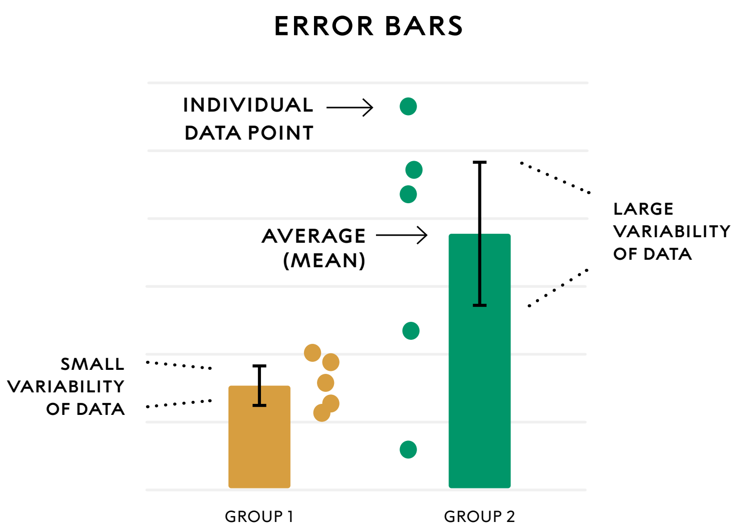
Two Graph Types Used in Computer Simulation

In the Scientific Uncertainty computer simulation used in this activity, Graph 1, "Average of All Trials," is a jitter plot. It shows data points for all trials plotted in the same place. The data points are NOT plotted over time. In order to be able to see all the data points, they are spread horizontally (slightly) so they do not overlap. This graph makes it easier to see the distribution pattern of the data points in order to determine how close the points are to one another and, therefore, how precise and reliable the photometer readings are.

Graph 2, "Current Average," also known as the running average, shows how the average of the trials changes with more trials. It shows that when there are few data points, the average has large shifts with each new measurement. As more data points are added, the average gradually shifts less with each new point and becomes more stable. The average then gets closer to the true value as more trials are added.

Error Bars: Estimating the Scientific Uncertainty

Error bars represent the variability of a data set and are drawn as lines that go above and below a point on a graph. For an average, the size of the error bars around a point is related to a measure of the variability in the data set in relation to the average and can depend on the number of measurements or samples used. The larger the error bars, the more variability and uncertainty present in the data. Although error bars can represent various statistical measures of variability (standard deviation, standard error, etc.), this computer simulation uses 95% confidence intervals to determine the error bars. Look at the following diagram, which represents error bars on a bar graph; the simulation uses line graphs. For a repeated measurement, the error bars correspond to the range of values in which you can be 95% confident of the true value falling within. Thinking about variability in data is one factor that scientists look at when considering how accurate (close to the true value) their data is, which can affect their confidence in conclusions they can make from their data.



Scientists calculate the variability of repeated measurements based on how spread apart the data points are from one another. This value can then be used to produce error bars that can represent different measures of variability (e.g., standard deviation, standard error or the mean, or 95% confidence intervals). Regardless of which measure is being used, large error bars generally correspond to more variability in the data and less certainty that the average is an accurate representation of the true value, whereas smaller error bars indicate the opposite. Note: This unit does not use the term *variability* to describe data patterns; instead, variability describes how spread apart the data points are.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 6.1 "Comparing Photometer 1 and Photometer 2"

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 6.1 "Testing Air Quality Sensors"

Arrange for classroom computer use and familiarize yourself with the Scientific Uncertainty Simulation.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (5-10 MIN)

1 **Review random error and systematic error.**

- In this activity, students will investigate the effect of random error and systematic error on data. To ensure that students are prepared, ask, Which of the following is an example of a random error or a systematic error?
  - A tape measure goes through the clothes dryer and shrinks.

    This would cause a systematic error, resulting in measurements that are consistently shorter than the true value.
  - Phone polls rely on people who answer their phones when unknown numbers call them.

    This could cause a systematic error because the results may be skewed based on some common characteristic of the people who regularly answer calls from unknown numbers, such as age.
  - After asking three classmates how much sleep they got the night before, Gavin averages the results and concludes that all his classmates sleep only five hours a night.

    This situation involves random error because each person's sleep time might be different from the next, with some above the average and some below the average.
- If students are not familiar with the basics of reliability, accuracy, precision, and validation, you may want to review these concepts by referring them to the Science Review in the Student Book.

PROCEDURE SUPPORT (25 MIN)

2 Review the scenario and the goal of the computer simulation.

- The scenario presented in Part A: Testing a Photometer, Procedure 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 the scenario 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.
- Review how the Blase-Air sensor works (shown in Figure 6.1 in the Student Book). Note that this diagram is not representative of how all air sensors work; it's representative of the specific version in the simulation.
- Before beginning the simulation, introduce the online Scientific Uncertainty Simulation as a thinking tool that can help to model how different types of scientific errors can affect experimental data. Emphasize that this simulation is a concrete tool that supports concepts related to random errors and systematic errors, along with techniques for reducing the effects of these types of errors.
- You may wish to give students time to explore the features of the simulation and/or model how to use the simulation with the class to answer any questions they may have. Point out that there is no labeled *x*-axis for Graph 1 in Experiments 1 and 2 or for Graphs 1 and 2 in Experiment 3 because the data is not represented over time. (The data points are shown vertically and are only separated horizontally for better visibility.)

TEACHER'S NOTE: Data in the simulation has natural variability, so each computer running the simulation will get slightly different results. The true value for each computer remains the same from Experiment 1 to Experiment 2; it is different in Experiment 3. Additionally, the values are changed every time the website is refreshed, so students can repeat the experiments with different air samples, if they wish.

3 Support students' conceptual development as they use the simulation.

- Distribute one copy of Student Sheet 6.1, "Testing Air Quality Sensors," to each student. Remind students to record their data on the student sheet as they complete each experiment. You may find it helpful to model Procedure Steps 3 and 4 by completing Experiment 1 on a projected version of the student sheet.
- Be sure to explain what students will record in the second row of Tables 1, 2, and 3: students should continue to run trials until their Error Bar Range is ± 3 and then record their data. Point out that the number of trials run in the second row will vary. Since the data in the simulation may be slightly different due to variability in the simulation, make sure students are recording the data from their own simulation in preparation for Experiment 2.

- Circulate and assist pairs as they work through the simulation. The simulation has three experiments that students progress through, which are described in the information that follows.

TEACHER'S NOTE: The following information is provided to support your instruction. Do not share this information with students ahead of time.

Experiment 1: Investigate how well the original photometer (Photometer 1) measures PM2.5 levels.

This experiment shows that a random error causes data points to be scattered above and below the true value with no consistent pattern. Students should also see that conducting more trials can help reduce how much the average changes from one trial to the next, bringing the average closer to the true value. Students should notice that the error bars start out large and get smaller as you add more data.

Experiment 2: Investigate whether an appliance running next to Photometer 1 affects the data from Photometer 1 and, if so, how.

This experiment shows that adding a systematic error (in this case, caused by turning on the appliance) can shift the measurements in a consistent direction away from the true value. However, this shift does not go away even after adding more trials. Also, the shift doesn't affect how spread out the data points are from one another or the size of the error bars. The only way to correct it would be to get rid of the systematic error. This is accomplished in the simulation by comparing measurements from when the appliance is off in Experiment 1 to when it is on in Experiment 2.

Experiment 3: Compare data from Photometer 1 to the new photometer (Photometer 2).

This experiment helps students practice identifying how the distribution of the data points is related to error bars—students practice identifying whether the data is showing random errors and/or systematic errors. Students evaluate the claim that one of the photometers is more accurate than the other. They find that by looking through the data, both photometers have a similar accuracy, but one of them has more data variability. In terms of decision-making, the photometer with less variability in the data is a more reliable product.

- In Procedure Steps 4 and 5, consider reviewing the graphs as a class to support students' interpretation of the data. Before students discuss the questions with their partners, review Figure 6.2 in the Student Book to help students understand how Graph 1 and Graph 2 provide different information about the experiment and to clarify how to identify the true value, average, and error bars. See the Teacher Background Information for more information on graph types created by this simulation.

4 Review the results of each experiment as a class.

- Depending on your student population, you may want to stop the class after pairs complete each experiment to discuss the results and clarify key points. Alternatively, you can wait until all pairs have completed all three experiments before discussion. Sample Student Responses for discussion questions in the procedure are as follows:

Sample Student Responses, Procedure Steps 5, 7, 9, 10, 12, and 13

PROCEDURE STEP	SAMPLE STUDENT RESPONSES
	PART A: TESTING A PHOTOMETER
Step 5	**Compare the data in Graphs 1 and 2 by discussing the following with your partner:** • your observations of each graph with your partner. *Graph 1 is easier to see how close the data pofints are to each other because you can see all of the data points at once. Graph 2 is easier to see how the average line gets closer to the true value as you conduct more trials.* • what Graphs 1 and 2 might look like if there were a) no error, b) random error, and c) systematic error. a) no error *Graph 1: All the data points would be the same, so there would only be one spot.* *Graph 2: The measurements would be the same for each trial, so the average line would be flat.* b) random error *Graph 1: The data points are spread randomly above and below the true value.* *Graph 2: The average line fluctuates but slowly approaches the true value as you get more data.* c) systematic error *Graph 1: The data points are shifted in a consistent direction away from the true value.* *Graph 2: The average line is shifted in a consistent direction away from the true value.*
Step 7	**Use the results of Experiment 1 to discuss the following with your partner:** • how the number of trials affected the true value, the average, and the error bars. *The number of trials didn't affect the true value. The average fluctuated a lot when there were fewer trials and only a little each time you conducted a new trial. The error bar range started big and got smaller as you conducted more trials.* • whether conducting more trials makes your average more accurate (closer to the true value) and why or why not. *Conducting more trials made the average more accurate because the average came closer to the true value.*
Step 9	**With your partner, determine whether the electric field of the appliance affected the measurements by:** a) comparing the size of the error bars for Experiment 1 (no appliance on) and Experiment 2 (appliance on). *The size of the error bars was about the same size by the end of Experiments 1 and 2.* b) comparing the averages for both Experiment 1 (no appliance on) and Experiment 2 (appliance on) to the true value. *The average for Experiment 1 was close to the true value. The average for Experiment 2 was shifted lower than the true value.*

PROCEDURE STEP	SAMPLE STUDENT RESPONSES
	PART A: TESTING A PHOTOMETER
Step 10	**Discuss with your partner what type(s) of error (systematic, random, or both) are likely to be occurring in Experiments 1 and 2. Be sure to explain your reasoning.** *Experiment 1 had random error because the data points varied both above and below the true value without a consistent pattern.* *Experiment 2 had systematic error because the data points were shifted in a consistent direction (lower than the true value). It also had random error because the data points were still spread higher or lower randomly, even though they were all shifted lower.*
	PART B: COMPARING TWO PHOTOMETERS
Step 12	**Uses the data from Experiment 3 to determine which photometer:** *Responses may vary slightly due to variability in the simulation.* a) has an average measurement that is most accurate (closest to the true value). *The photometers had similar accuracy. Photometer 1 average was 495.9, and Photometer 2 average was 494.4. The true value was 495, so Photometer 2 is slightly more accurate.* b) had less scientific uncertainty in the data. `HINT: for each photometer, consider the size of the error bars as well as how spread out the data points are.` *Photometer 2 resulted in less scientific uncertainty in the data because the data points are much closer together than with Photometer 1. Also, the error bars for Photometer 2 were smaller within a fewer number of trials.* c) required fewer trials for the average to reach within ± 3 particulates of the true value. *Photometer 1 required 154 trials to get within ± 3 particulates.* *Photometer 2 required 24 trials to get within ± 3 particulates.*
Step 13	**As a class, evaluate the claim that the new Photometer 2 is more accurate than the old Photometer 1. Decide which photometer Blase-Air should use in their air quality sensor design.** *The claim that the new Photometer 2 is more accurate is not supported by the data in the simulation because the two photometers have very similar averages that are not that different from the true value.* (See Teaching Step 5 for the class decision regarding which photometer to recommend for Blase-Air's sensor.)

SYNTHESIS OF IDEAS (20 MIN)

5 **Review key ideas investigated with the simulation.**

- After completing Part B, give pairs a few minutes to discuss Procedure Step 13 before sharing ideas with the class. Project Visual Aid 6.1, "Comparing Photometer 1 and Photometer 2," to reference an example of the data collected from the two photometers in Experiment 3. The data that students gathered may be slightly different from the example, but the patterns will be similar. Ask, Should the company use the sensor with Photometer 1 or Photometer 2 in their sensor and why? Students should recognize that averages of the two photometers are almost the same, but Photometer 2 is more likely to result in data points that are closer together, and it needs less trials to get an average that is close to the true value. This means that Photometer 2 is better at reliably measuring the amount of particulates in the air and would be a better choice for Blase-Air's sensor.

- Use Visual Aid 6.1 to help students understand the relationship between scientific uncertainty and error bars. Ask, What is the relationship between the size of the error bars and the amount of scientific uncertainty in the data? Students should explain that the error bars correspond to how spread out the data points are from one another. Smaller error bars will indicate more certainty in the current average because the data points are closer together. Larger error bars will indicate the opposite. If you have begun a word wall, support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the term *error bar*.

- Follow up the activity by asking, Based on the data for the two photometers, which photometer has less uncertainty in the data? Have students describe how this affects their decision and how sure they are about their choice. Student responses should indicate that Photometer 2 has less uncertainty in the data and smaller error bars, which makes students more certain about their choice. Alternatively, students might say that Photometer 1 has more uncertainty and larger error bars, which makes them more certain about their choice. As a result of this discussion, you may want to give students a moment to revise their responses to Build Understanding item 2.

- Evaluate if your students are able to identify the essential ideas of the activity by discussing their responses to Build Understanding items 1 and 4, which focus on how systematic error and random error can be identified in data, as well as how averaging multiple data points affects the different types of errors. Make sure students understand that while scientists often collect multiple measurements and average the data points, this method only helps to reduce uncertainty from random errors, not systematic errors. This is because random errors produce data points that can be higher or lower by chance, so averaging tends to cancel out their effects. The only way to reduce uncertainty from systematic error is to find and remove the source of the error or to redesign the experiment to better account for the error.

- Build Understanding item 3 is an opportunity to revisit the concepts of signal and noise from earlier in the unit. Emphasize that random errors and systematic errors can serve as a source of noise that can obscure the signal being investigated.

- Finish the activity by revisiting the Guiding Question, *How can you reduce random errors and systematic errors in data?* Use responses to this question to formatively assess the key concepts and process skills related to identifying and reducing random errors and systematic errors.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **Consider how the data changed during the experiments in the computer simulation. How does conducting more trials affect how close the average is to the true value when there is:**

a random error?

When there is random error, the data points can randomly be higher or lower than the true value. Conducting more trials makes the average change less with each trial, and the average also becomes more accurate (gets closer to the true value).

b systematic error?

When there is systematic error, the average is shifted in one direction away from the true value. Conducting more trials does not make the average more accurate (does not shift it closer to the true value).

② **Error bars play an important role in communicating about scientific uncertainty in data. Describe how the size of the error bars can affect scientific uncertainty in a conclusion. Include an example from the computer simulation in your response.**

The size of the error bars is related to how spread out the data points are from each other, and it is mostly related to the amount of random error in the sample. If the error bars are very small, it means that there is little random error in the sample, and there can be more certainty in the conclusion than if the error bars were very large. For example, in Experiment 3 of the simulation, Photometer 1 had very large error bars, and Photometer 2 had very small error bars even though they both had an average that was close to the true value. This tells me that there is more uncertainty in Photometer 1's data and maybe it is not as reliable as Photometer 2, which has very similar measurements across all the samples.

③ **Think back to the concepts of signal and noise from Activity 2: Signal and Noise. Explain how the presentation of data in the computer simulation helped differentiate the signal from the noise.**

The graphs in the simulation help us see the signal in the data by showing us the average of the data. For example, in the simulation, photometer data points are distributed all over the place if you look at Graph 1, and it is hard to see trends in the data. The average line gives you a more useful signal because it gives you a single value to use to make comparisons. If you look at Graph 2, you can see how the average changes and how many trials the photometer requires to reach an average that is close to the true value.

④ **Figure 6.3 shows air quality data from five sensors in the same location. Each line represents a different sensor.**

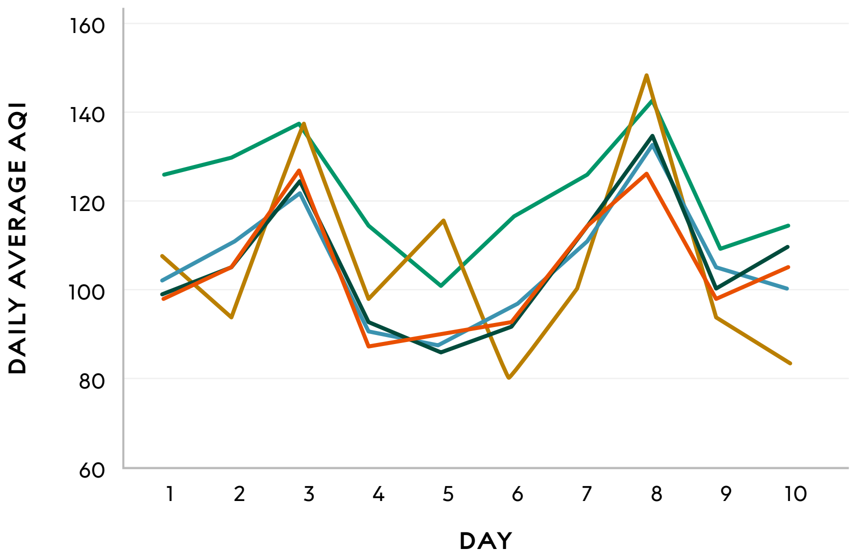


FIGURE 6.3
Data from Five Air Quality Index (AQI) Sensors

a **Which sensor is most likely to have a systematic error? Explain your reasoning.**

Sensor 1 because it is consistently higher than the other sensors.

b **Which sensor appears to have random error? Explain your reasoning.**

Sensor 5 because it fluctuates a lot and is most different from the other sensors, but not consistently below or above them.

CONNECTIONS TO EVERYDAY LIFE

⑤ **Glucose is a type of sugar that your body uses for energy. Imagine that you read about a study comparing two different glucose meters for measuring glucose levels in the blood of patients with diabetes. Each glucose meter measured the same blood sample 20 times (N = 20). Figure 6.4 shows glucose level averages, shown with error bars, that were calculated for each glucose meter.**

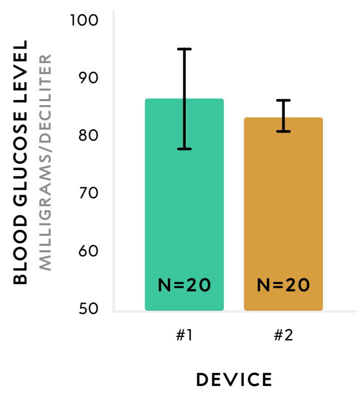
a What can you determine about the uncertainty of the data collected by each device?

You can tell that #1 has more uncertainty in the data than #2, meaning the data points are more spread out in #1. This means that there's more random error in the data for #1, and it also means that with #1, you might not always get a result that is close to the average.

b Can you be sure which device is measuring blood glucose levels closer to the true value? Explain why or why not.

You can't be sure which device is more accurate because you don't know what the true value is. It's hard to tell from this graph whether or not a systematic error is affecting the data, because a systematic error wouldn't be shown by error bars.

FIGURE 6.4
Comparing Glucose Meters



REFERENCES

Koigi, B. (April 22, 2024). *A Ugandan innovation to tackle air pollution*. Fair Planet. https://www.fairplanet.org/editors-pick/african-innovations-to-tackle-air-pollution/

Nguyen, N. , Nguyen, H. , Le, T. & Vu, C. (2021). Evaluating low-cost commercially available sensors for air quality monitoring and application of sensor calibration methods for improving accuracy. *Open Journal of Air Pollution, 10*(1). https://doi.org/10.4236/ojap.2021.101001

U.S. Government Accountability Office. (December 7, 2020). *Science & tech spotlight: Air quality sensors*. https://www.gao.gov/products/gao-21-189sp

Table 1: Experiment 1

PHOTOMETER 1

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5			
		± 3	

Table 2: Experiment 2

PHOTOMETER 1 (APPLIANCE TURNED ON)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5			
		± 3	

Table 3: Experiment 3

PHOTOMETER 1 (OLD MODEL)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5			
		± 3	

PHOTOMETER 2 (NEW MODEL)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5			
		± 3	

Table 1: Experiment 1

PHOTOMETER 1

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5	517	± 18.17	503
142	505.6	± 3	503

Table 2: Experiment 2

PHOTOMETER 1 (APPLIANCE TURNED ON)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5	471.8	± 12.4	503
179	483.3	± 3	503

Table 3: Experiment 3

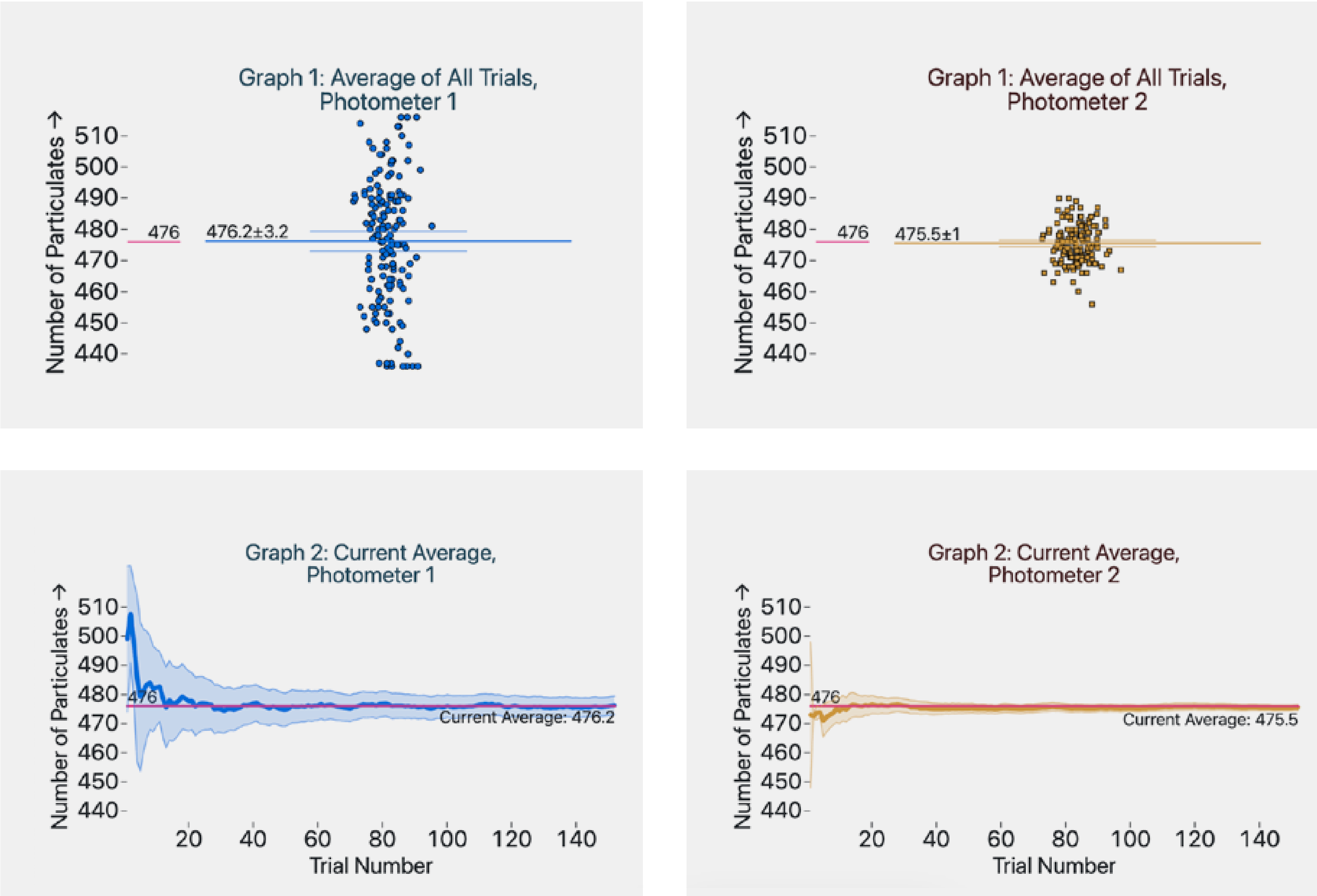
PHOTOMETER 1 (OLD MODEL)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5	491.2	± 8.8	495
154	495.9	± 3	495

PHOTOMETER 2 (NEW MODEL)

NUMBER OF TRIALS RUN	AVERAGE	ERROR BAR RANGE	TRUE VALUE
5	495.8	± 9.1	495
24	494.4	± 3	495

VISUAL AID 6.1 | COMPARING PHOTOMETER 1 AND PHOTOMETER 2



ACTIVITY 7

Reducing Scientific Uncertainty

INVESTIGATION

ACTIVITY 7

Reducing Scientific Uncertainty

ACTIVITY SUMMARY

Students map air quality sensor data for a fictional town before and after work begins at a construction site. They consider the sources of uncertainty in the data and brainstorm ways to reduce that uncertainty. They calculate how the mean varies from the range and its implications for air quality. Limitations of the data include small sample size and systematic error. Students discuss how addressing limitations of the data can lead to new conclusions.

ACTIVITY TYPE
INVESTIGATION

NUMBER OF
40–50 MINUTE
CLASS PERIODS
1–2

KEY CONCEPTS & PROCESS SKILLS

1 When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

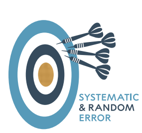
2 Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal.

3 Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

4 Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).

5 Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.

CONCEPTUAL TOOLS



NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 7.1 "Scoring Guide: Analyzing and Interpreting Data (AID)"
- ITEM-SPECIFIC SCORING GUIDE: Activity 7, Connections to Everyday Life Item 5
- VISUAL AID 3.1 "Air Quality Index (AQI)" (OPTIONAL)

FOR EACH PAIR OF STUDENTS

- SET OF 6 COLORED PENCILS: green, yellow, orange, red, purple, and maroon
- RULER

FOR EACH STUDENT

- 2 STUDENT SHEETS 7.1 "Map of Kairoba"
- STUDENT SHEET 7.2 "Writing Frame: Evidence and Trade-Offs (E&T)" (OPTIONAL)
- SCORING GUIDE: Analyzing and Interpreting Data (AID) (OPTIONAL)

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (5 MIN)

1 **Present the fictional scenario in Procedure Step 1.**

- 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 the scenario 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.

PROCEDURE SUPPORT (30 MIN)

2 **Guide students in completing Procedure Part A.**

- Divide students into groups of four who will work in pairs. Each pair will map the data for one date (Procedure Steps 3–7) and then compare their air quality data with the data from the other pair (Procedure Step 8) to see if there is any change between Oct. 25 and Nov. 1, one week after work at the construction site began.
- In Procedure Step 2, students discuss how a construction project might affect the air quality (both short-term and long-term) at three proposed sites for a housing development. Site A is closest to the construction site, while Site C is the furthest away. Students may hypothesize that initial work on a site, particularly when previous buildings are demolished or the foundation is being dug, could result in increased particulate matter, particularly at Site A. When construction is complete, the particulate matter levels would be expected to return to previous levels. Air quality data that would support these ideas would be higher AQI levels after the start of construction, and AQI levels similar to preconstruction levels after construction is completed. Emphasize the role of data in reducing scientific uncertainty in scientific claims.

- In Procedure Step 4, distribute 1 copy of Student Sheet 7.1, "Map of Kairoba," to each student and a set of 6 colored pencils to each pair. If you don't have maroon pencils, let students know that they should use another color, such as brown, to represent the "Hazardous (maroon)" entry in Figure 7.1: "Air Quality Index (AQI)." While students are mapping and assessing the AQI of the data, you may wish to project optional Visual Aid 3.1, "Air Quality Index (AQI)"; this makes it easier for students to identify where on the AQI index each value falls.
- A sample student response to Student Sheet 7.1 (from Parts A and B) can be found at the end of this Teacher Edition, while additional sample responses are shown here:

DATE	AQI RANGE	AIR QUALITY	AQI AVERAGE
Oct 25	*Sensors 1–10: 22–101*	*Good — Unhealthy for Sensitive Groups*	*Sensors 1–10: 64*
Nov 01	*Sensors 1–10: 35–141*	*Good — Unhealthy for Sensitive Groups*	*Sensors 1–10: 64*
Nov 08	*Sensors 1–13: 14–301*	*Good — Hazardous*	*Sensors 1–13: 86*

- Have both pairs in each group share their responses to the questions in Procedure Step 8. Sample responses are shown here:

Sample Student Responses, Procedure Step 8

- How did the air quality compare on October 25 vs. November 1?

  For both dates, the range of air quality data fell into the same AQI categories (good, moderate, and unhealthy for sensitive groups), and the average AQI was the same for October 25 and November 1. But on October 25 there were only 3 sensors showing good AQI, while on November 1 there were 6.

- Does the mapped data support the claim from the article that the air quality is not affected by construction? Why or why not?

  Yes, because it shows that the average AQI did not change after construction began. Also, there were more sensors with good AQI readings on November 1 (one week after construction began) than on October 25 (no construction).

- Explain what additional data would increase your certainty in this conclusion.

  Additional evidence that would make me more certain includes having additional sensors placed near the construction site, having more sensors throughout the town, and having more information about the quality of the sensors.

3 Guide students in completing Procedure Part B.

- In Part B, students are provided with data for three additional sensors as well as an additional date (November 8). In Procedure Step 9, students map the three additional data points near the construction site for either Oct. 25 or Nov. 1 on their original copies of Student Sheet 7.1. This data indicates that the construction site did worsen the air quality, but only in the neighborhood closest to the site.

- In Procedure Step 10, distribute a second copy of Student Sheet 7.1 to each student so they can record the additional data for November 8. Students should observe that the air quality on November 8 (while construction was ongoing) was good in all areas except those closest to the construction site.

- Sample student responses for the additional data follow.

Sample Student Responses, Procedure Step 12

- What systematic error from the initial data set was corrected for when you found the three additional sensors?

  Missing data.

- Does this larger data set support the article's claim that the construction has no impact on AQI? Use the data to explain your answer.

  No, it doesn't support the claim because the additional sensor data shows poorer air quality near the site. For example, on November 8 (when construction was still happening), data from the 3 sensors closest to the construction site ranged from 212–301 (very unhealthy and hazardous).

- What additional evidence would you want to collect to reduce uncertainty in your conclusion?

  I would want to have additional sensors placed near the construction site, more sensors placed throughout the town, more information about the quality of the sensors, and more long-term data.

4 Highlight the cause of the systematic error in the data.

The answers to Procedure Step 12 are a key insight, so make sure students make the connection: There was a systematic error in the initial data set caused by the lack of any sensors near the construction site, which caused the data set to miss the effect of the site on AQI. Without sensors in this crucial area, the data supported the claim that the factory had no effect on AQI. With sensors in this area, it begins to look as if the factory may be affecting air quality after all.

SYNTHESIS OF IDEAS (20 MIN)

5 **Use Build Understanding and Connections to Everyday Life items to synthesize ideas.**

- You may wish to supply additional scaffolding for Build Understanding item 3 by inviting students to consider what factors might impact air quality at the neighborhood level and asking them to think about how population density and/or average income might (a) affect air quality or (b) serve as proxies for other factors that could affect air quality. For example, a higher population density might mean more cars, which could worsen air quality. Or it might mean less green space within private property, as apartment buildings tend to take up more of a property's footprint than single-family houses, which could also worsen air quality. Average income in cities tends to correlate inversely with population density—wealthier families tend to live in houses or larger apartments, and poorer families tend to live in smaller apartments.
- For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 7.2, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use Student Sheet 7.2 only as a reference or as a checklist as they write their responses. A sample student response for this student sheet is shown at the end of this activity. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.

6 **Assess student growth using the Analyzing and Interpreting Data (AID) Scoring Guide for Connections to Everyday Life item 5.**

- The graph in Figure 7.4 represents days when the number of ER visits due to asthma is excessive. If a dot is present for an age group on a certain day, it means that there were excessive asthma visits for that age group on that day. It could be the case that various age groups had slightly elevated asthma visits, which did not constitute being marked as excessive for that age group, but when all age groups were combined, it was enough to be marked excessive for all ages. It can also be the case that there are some age groups that were marked excessive on a day, but when all age groups were combined, there were not enough cases to be marked as excessive for the "all ages" category (perhaps some groups had few cases, reducing the overall average).
- Remind students of the Analyzing and Interpreting Data Scoring Guide. You may wish to project Visual Aid 7.1, "Scoring Guide: Analyzing and Interpreting Data (AID)," for your students to review each level and clarify your expectations.
- Do not share the item-specific version of the Scoring Guide (Item-Specific Scoring Guide: Activity 7, Connections to Everyday Life Item 5) with students as it provides specific information on how to respond to the item prompt. Review the Item-Specific Scoring Guide to support scoring this specific item.
- Remind students that you expect to see them demonstrate growth in their analysis and interpretation of data, and they may want to review their responses to the assessment in Activity 3 (Build Understanding item 2). You may also want to let students know that they will have one more opportunity in the unit to be assessed (Activity 10, Build Understanding item 2).

- Depending on your students, you may want to have them provide feedback on one another's work for revision prior to turning in their work to you for scoring. Alternatively, consider having students turn in a rough draft to you for feedback and revision.
- Sample responses for Levels 1–4 are provided for Connections to Everyday Life item 5. Review these responses to get an idea of what is expected for each level alongside the Item-Specific Scoring Guide. See Appendix 2: Assessment Resource at the end of the Teacher's Guide for more guidance and information on using the Scoring Guides and assessment system with your students.

7 To conclude the activity, evaluate if your students are able to identify the essential ideas of the activity by revisiting the Guiding Question, *What are ways to collect and analyze data to reduce scientific uncertainty?* Students should recognize that addressing systematic error when designing an experiment is an important part of reducing scientific uncertainty.

SAMPLE STUDENT RESPONSES

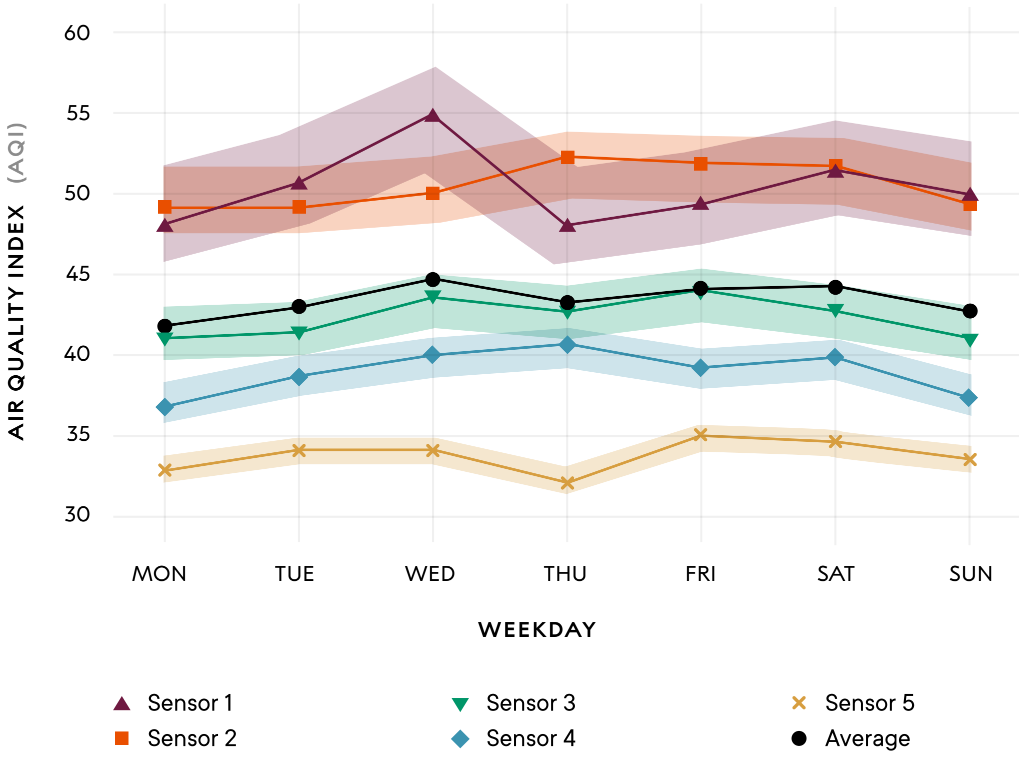
BUILD UNDERSTANDING

① **Describe at least two possible sources of systematic error when collecting and analyzing air quality data. Then explain how you could address each of these errors to reduce your uncertainty in the data.**

The placement of air quality sensors and any miscalibration of a sensor can result in systematic error. Carefully planning the placement of sensors and checking that they are taking accurate measurements can reduce systematic error.

② **The graph in Figure 7.2 shows daily average AQI at 5 sites in 1 city over the course of a week. The shaded areas indicate the 95% confidence interval of the daily averages at each site. The black line represents the average of the 5 sites for each day.**

FIGURE 7.2
AQI Readings for 5 Sites in 1 City



a **Based on the confidence intervals of each sensor, identify which sensor has the least uncertainty and which has the most uncertainty. Describe how this affects your conclusions about the data.**

Sensor 5 has the least uncertainty because it has the smallest confidence interval, and Sensor 1 has the most uncertainty because it has the largest confidence interval. I am not confident that the AQI at the Sensor 1 location is regularly good because it has a large confidence interval and the data fluctuates a lot in the good-moderate AQI range.

b **A city official proudly claims that the city's AQI is always good (0–50). Do you agree? Support your answer with evidence.**

Students may have different responses and should support their answers with evidence.

- *I agree because four of the five sensors provided an average of good air quality readings over a period of seven days.*
- *I disagree because Sensors 1 and 2 have air quality readings that are in the moderate AQI range. If you live near those sensors and are part of a population is sensitive to poor air quality, you are not always experiencing good air quality.*

c **Would you be more concerned about your local air quality if you lived near Sensor 1 or Sensor 5? Explain.**

I would be more concerned about air quality if I lived near Sensor 1. Sensor 1 has higher average PM2.5 readings than Sensor 5, and some of the individual readings go higher than "good" on the AQI. So I would be more concerned that my air quality could sometimes be bad for my health.

③ **It is time for the city of Kairoba to make a decision about which site to build. As part of their decision-making, they have created a table of additional considerations. Based on your work in the activity and the information in Table 7.3, where would you recommend the city build? Support your answer with evidence and identify the trade-offs of your decision.**

TABLE 7.3
Additional Housing Considerations

	SITE A	SITE B	SITE C
NUMBER OF PROPOSED APARTMENTS	100	100	75
RELATIVE COST TO BUILD	$$	$	$$$

I recommend that they build on Site C because it will have the best air quality for future residents. The sensor data showed that the poorest air quality was closest to the construction site. Site C is the farthest from the current construction site. Also, it has three parks in that area, likely improving *the air quality. The trade-offs are that the air quality in the cleanest part of the city will decrease for a period of time, and it will cost the most money for the fewest units (75). But I think it will be worth it in the long run.*

CONNECTIONS TO EVERYDAY LIFE

④ **The U.S. Environmental Protection Agency (EPA) provides air quality forecasts for cities and counties around the United States. Look at the air quality forecast in Figure 7.3, which shows PM2.5 levels over a period of six days.**

FIGURE 7.3
Air Quality Forecast

TODAY	TOMORROW	THURSDAY	FRIDAY	SATURDAY	SUNDAY
GOOD PM2.5	MODERATE PM2.5	MODERATE PM2.5	GOOD PM2.5	GOOD PM2.5	GOOD PM2.5

a **What do you predict the PM2.5 levels are likely to be on Monday? Explain your answer, using probabilistic reasoning.**

I predict the PM2.5 levels to be good because it will have been good for the previous three days as well as four out of the previous six days.

b **What additional information could reduce uncertainty in your prediction?**

Having more information about local weather conditions and local sources of PM2.5.

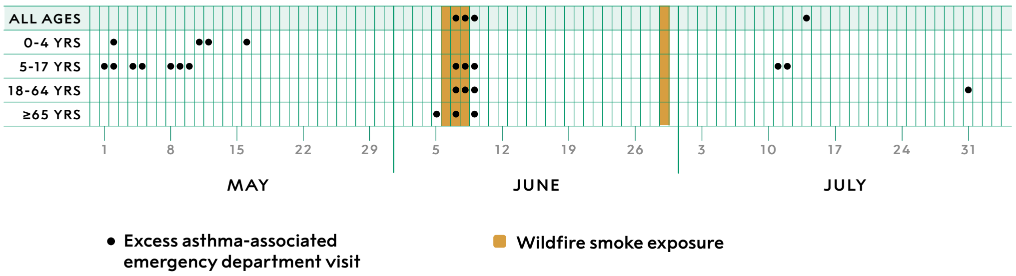
⑤ **Examine Figure 7.4, which shows dots when emergency room (ER) visits due to asthma are higher than average.**

Suppose you want to know if wildfire smoke was a cause for this increase. Explain what conclusions you could make from the data in this graph. Be sure to include the following in your explanation:

- **Describe the patterns you observe between wildfires and ER visits due to asthma.**
- **Describe the part of the graph that looks like a signal.**
- **Considering the relationship between wildfires and ER visits due to asthma, describe which day(s) appear to be noise.**
- **Explain what could have created this noise in the data.**
- **Explain what conclusions you can make about the relationship between wildfires and ER visits due to asthma.**

FIGURE 7.4

Emergency Room Visits for City Region 1



Level 4 response

The data shows that there is an increase in ER visits due to asthma on June 7, 8, and 9, and there is wildfire smoke exposure on June 6, 7, and 8. There is wildfire smoke on June 29 but no increase in ER visits due to asthma. There are also increased visits in early May and a few days in July but no wildfire smoke during those times. The signal we are investigating is an increase in ER visits due to asthma when there are wildfires. The noise appears to be the increased visits in early May and various dates in July when there was no wildfire smoke. There are lots of triggers of asthma besides wildfire smoke that could have caused increased visits. The increase in visits in early May might be because of increased pollen during spring, which could trigger more asthma attacks. The days in July might be from air pollution that isn't from wildfire smoke. There appears to be a relationship between wildfire smoke and ER asthma visits because every age except 0–4 had increased ER visits due to asthma for several days during smoke events in early July.

Level 3 response

There is wildfire smoke exposure on June 6, 7, and 8, and there are increased ER visits due to asthma on June 7, 8, and 9. There's one other day of wildfire smoke, and days in May and July where there are increased ER visits due to asthma but no wildfire smoke. The signal is increased ER visits due to asthma when there is wildfire smoke. The noise is when there is no wildfire smoke, but there are increased visits. This might happen because other things can trigger asthma. This data shows there is probably a relationship between wildfire smoke exposure and increased ER visits due to asthma.

Level 2 response

When there is wildfire smoke exposure on June 6, 7, and 8, there are increased ER visits due to asthma a day later (June 7, 8, and 9). The signal is more ER visits, and the noise is maybe because of other things on other days. I think wildfire smoke triggers asthma.

Level 1 response

When there is wildfire smoke exposure there are usually more ER visits due to asthma. Wildfire smoke can trigger asthma. It's a signal, but other things can also trigger asthma.

REFERENCES

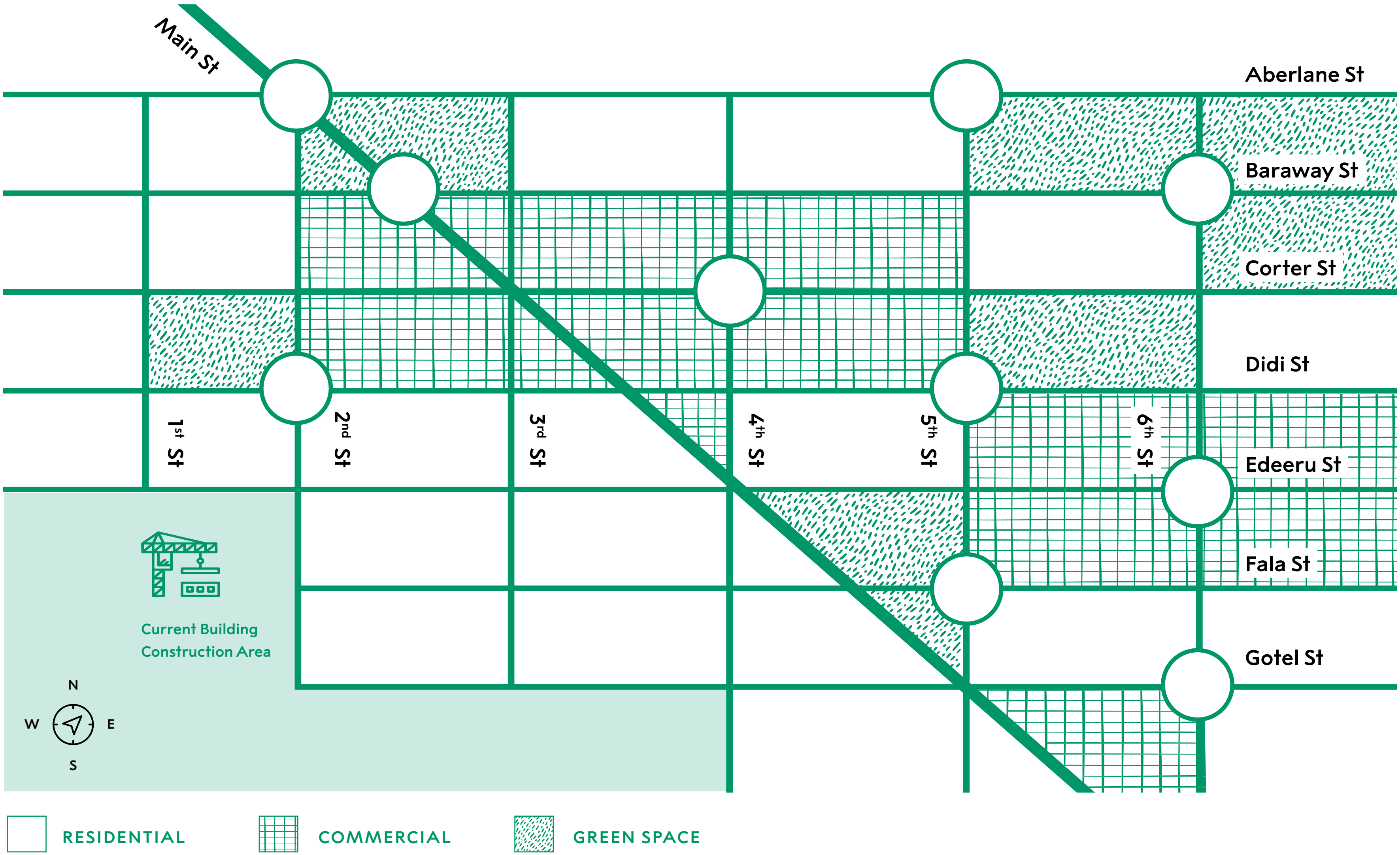
McArdle, C. E., Dowling, T. C., Carey, K., et al. (2023). Asthma-associated emergency department visits during the Canadian wildfire smoke episodes—United States, April—August 2023. *Morbidity and Mortality Weekly Report*, *72*:926—932. http://dx.doi.org/10.15585/mmwr.mm7234a5

U.S. Environmental Protection Agency. (2023). *Particulate matter (PM2.5) trends: National trends PM2.5 AIr Quality 2000—2022*. https://www.epa.gov/air-trends/particulate-matter-pm25-trends#:~:text=Nationally%2C%20average%20PM2.5%20concentrations,our%20Particulate%20Matter%20Pollution%20page.

Yan, H., Li, Q., Feng, K., & Zhang, L. (2023). The characteristics of PM emissions from construction sites during the earthwork and foundation stages: An empirical study evidence. *Environmental Science and Pollution Research International*, *30*(22), 62716-62732. https://pmc.ncbi.nlm.nih.gov/articles/PMC10167100/

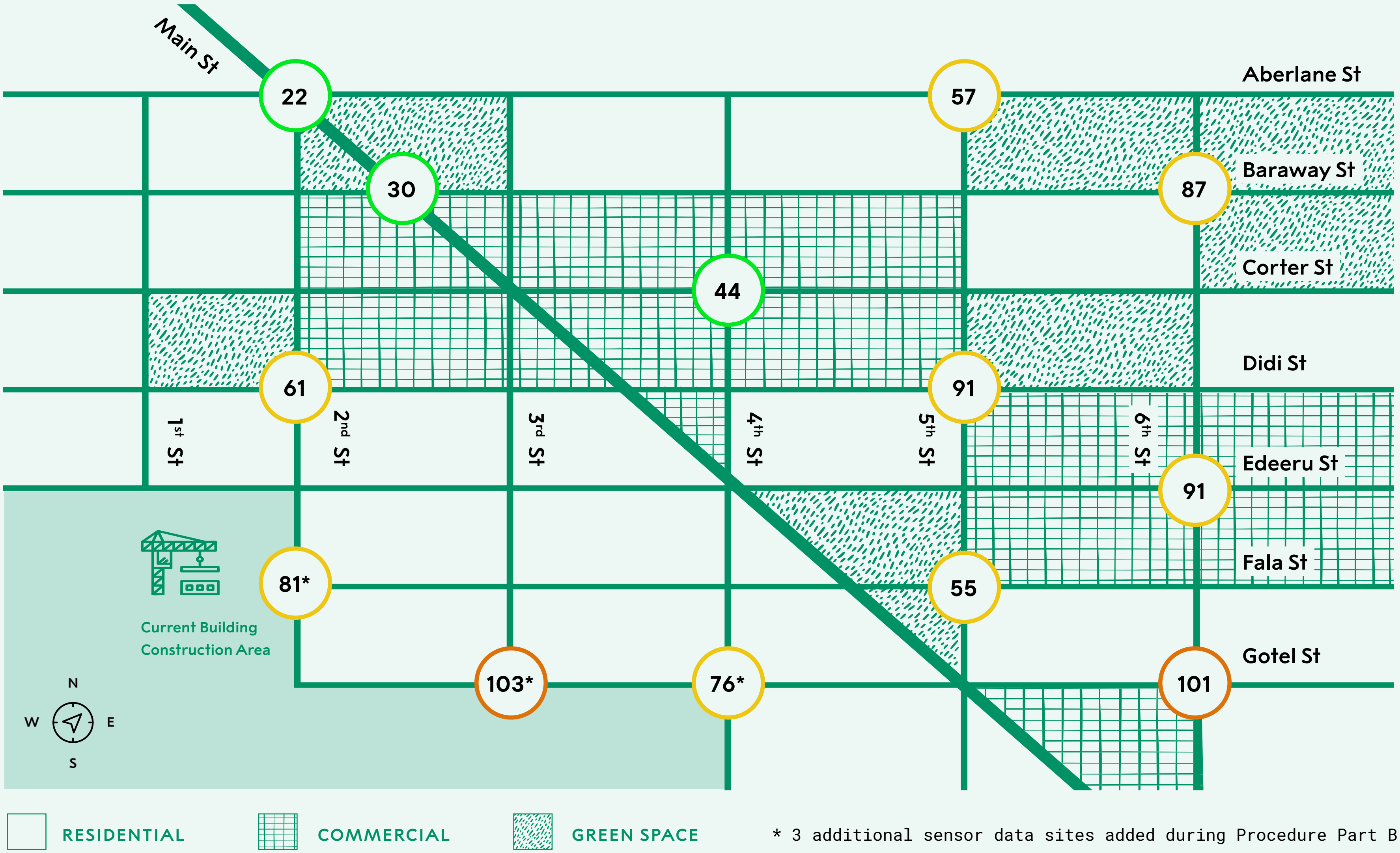
STUDENT SHEET 7.1 | MAP OF KAIROBA | NAME

DATE OF DATA COLLECTION [ ] AVERAGE AQI [ ]



STUDENT SHEET 7.1 | MAP OF KAIROBA | NAME SAMPLE STUDENT RESPONSE FOR OCT 25

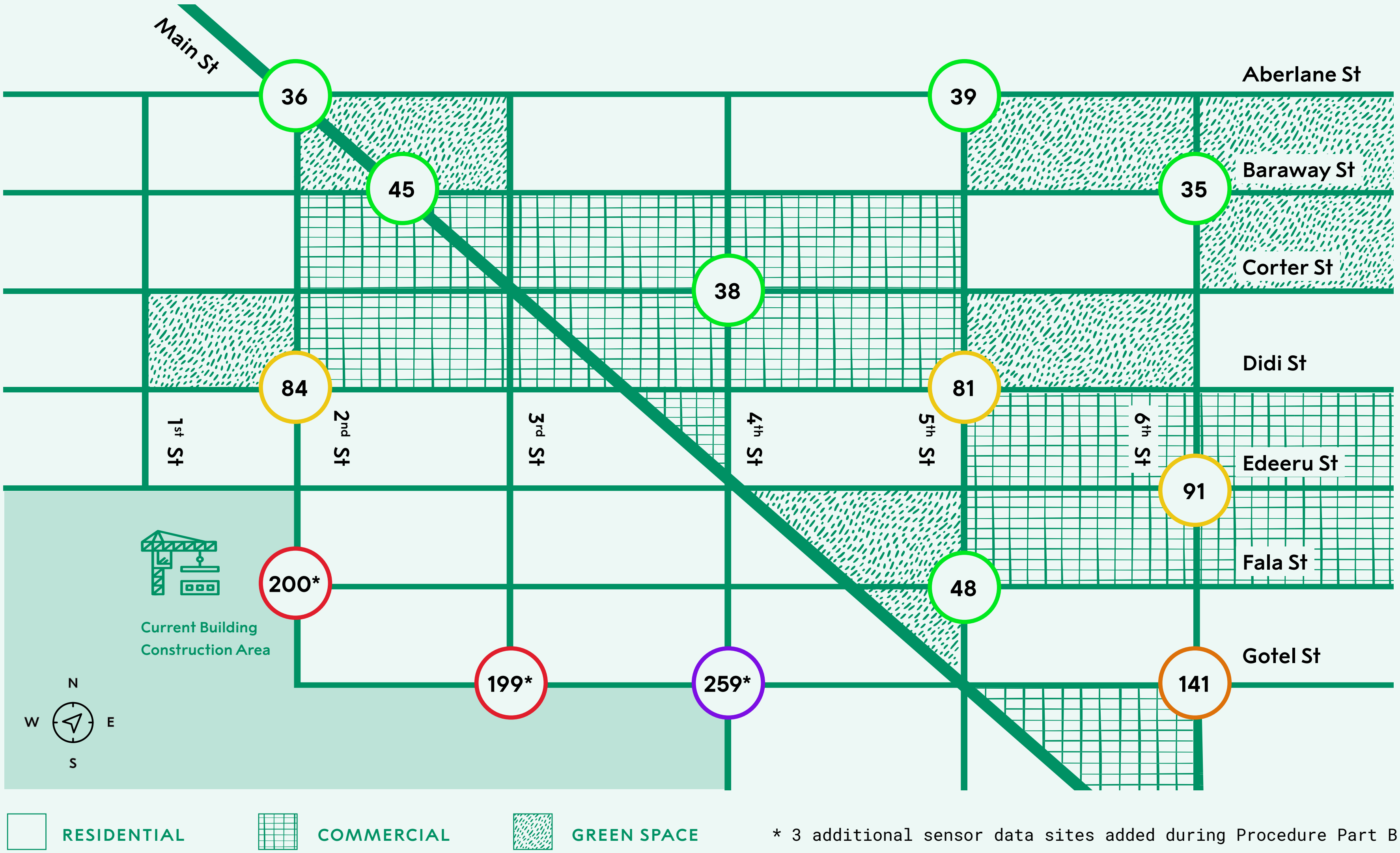
DATE OF DATA COLLECTION Oct 25 AVERAGE AQI 64



* 3 additional sensor data sites added during Procedure Part B

STUDENT SHEET 7.1 | MAP OF KAIROBA | NAME *SAMPLE STUDENT RESPONSE FOR NOV 1*

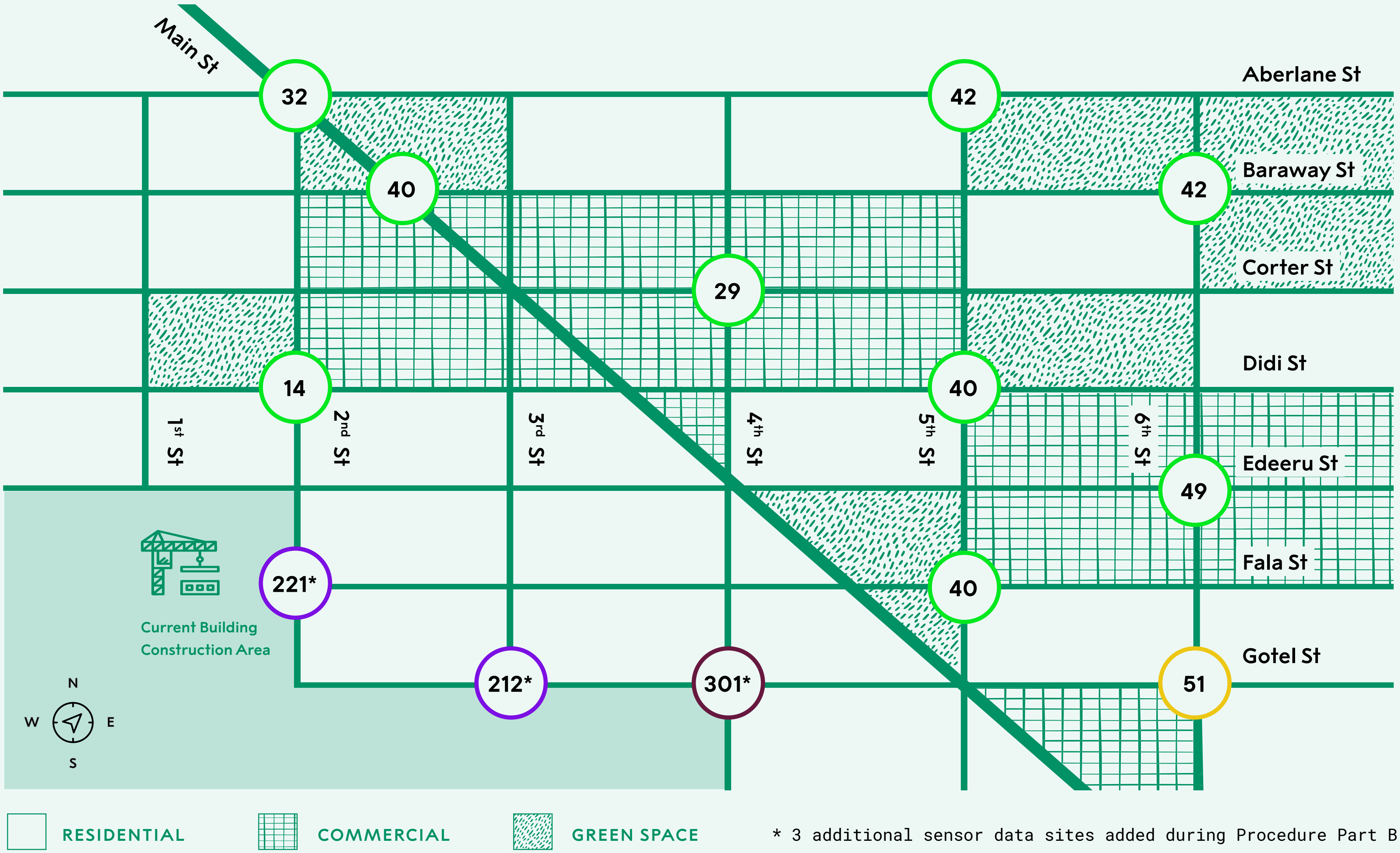
DATE OF DATA COLLECTION *Nov 01* AVERAGE AQI *64*



* 3 additional sensor data sites added during Procedure Part B

STUDENT SHEET 7.1 | MAP OF KAIROBA | NAME SAMPLE STUDENT RESPONSE FOR NOV 8

DATE OF DATA COLLECTION Nov 08 AVERAGE AQI 86



* 3 additional sensor data sites added during Procedure Part B

STUDENT SHEET 7.2 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

STUDENT SHEET 7.2 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

where to build new housing.

My decision is that

Site B is the best location.

My decision is based on the following evidence:

First,

the poorer air quality due to the construction site will likely improve once construction stops.

Second,

the building of new housing is also a construction project and will decrease air quality for nearby residents while it is being built. Site B is farther from the current site than Site A.

Third,

Site B is the cheapest location on which to build a large number of units (100).

The trade-off(s)

is that nearby residents will continue to have poor air quality for a period of time.

People who disagree with my decision might say that

if everyone keeps building near the same neighborhoods, those residents will never have good long-term air quality.

VISUAL AID 7.1 | SCORING GUIDE: ANALYZING AND INTERPRETING DATA (AID)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.

LEVEL	GENERAL DESCRIPTION
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques and/or reasoning to identify and describe patterns and relationships.
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.
X	The student had no opportunity to respond.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.	The student response: • gives detailed descriptions of patterns in the data, including within and across days. • thoroughly describes sound reasoning and evidence for conclusions about air quality. • provides a potential source of noise in the data with a thorough explanation of reasoning, including the limitations of the available data.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.	The student response: • describes patterns in the data, including within and across days. The student response may have minor errors or limited responses related to: • describing reasoning and evidence for conclusions about air quality. • providing a potential source of noise in the data with an explanation of reasoning and limitations of the available data.
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.	The student response: • describes patterns in the data, including within and/or across days. The student response may have errors or limited responses/reasoning related to: • describing reasoning and evidence for conclusions about air quality. • providing a potential source of noise in the data with an explanation of reasoning and limitations of the available data.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques, and/or reasoning to identify and describe patterns and relationships.	The student response: • describes patterns in the data that may be general or contain errors. The student response may have errors or limited responses/reasoning related to: • describing conclusions about air quality. • providing a potential source of noise in the data, with reasoning.
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.	
X	The student had no opportunity to respond.	

AQI CATEGORY (COLOR)	INDEX VALUE	DESCRIPTION OF AIR QUALITY
Good (green)	0–50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate (yellow)	51–100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive* to air pollution.
Unhealthy for Sensitive* Groups (orange)	101–150	Members of sensitive* groups may experience health effects. The general public is less likely to be affected.
Unhealthy (red)	151–200	Some members of the general public may experience health effects. Members of sensitive* groups may experience more serious health effects.
Very Unhealthy (purple)	201–300	Health alert: The risk of health effects is increased for everyone.
Hazardous (maroon)	301 AND HIGHER	Health warning of emergency conditions: Everyone is more likely to be affected.

* According to the American Lung Association, sensitive groups include children under 18, adults over 65, people with chronic heart or lung disease, people who are pregnant, and people with diabetes. Adults who are active outdoors, including outdoor workers and frequent outdoor exercisers, can be considered sensitive because of prolonged exposure to outside air.

ACTIVITY 8

Collecting Experimental Data for Predictions

LABORATORY

ACTIVITY 8

Collecting Experimental Data for Predictions

ACTIVITY SUMMARY

One increasingly challenging source of particulate matter is wildfire smoke, which can travel hundreds or even thousands of miles and affect air quality far from the fire. Students apply their knowledge of scientific uncertainty and probabilistic reasoning to collect experimental data to make predictions about the real world. They conduct an experiment to measure the ignition time and the heat of combustion of different vegetation to model wildfire fuel sources. Students use their laboratory results to make predictions about how fuel sources affect wildfire spread.

ACTIVITY TYPE
LABORATORY

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

2 Probabilistic reasoning can be used to identify meaningful patterns in data (*signal*) about a phenomenon being investigated. Variations in the data (*noise*) can increase scientific uncertainty by distorting or hiding the signal.

3 Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

4 Scientific methods can reduce sources of uncertainty. Techniques to reduce random error include taking repeated measurements and averaging across many samples. Techniques to reduce systematic errors include calibrating equipment more carefully and designing investigations to control for other factors that could influence the results (*confounds*).

CONCEPTUAL TOOLS

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

VOCABULARY DEVELOPMENT

calorie
(assumed prior knowledge)
the amount of energy it takes to raise the temperature of 1 gram of water by 1°C

calorimeter
(assumed prior knowledge)
a device used to measure the heat released or absorbed during a chemical reaction or physical change

heat of combustion
(assumed prior knowledge)
amount of energy released as heat when a substance is burned

ignition time
(assumed prior knowledge)
how easily or quickly a material will catch on fire

law of conservation of energy
(assumed prior knowledge)
energy cannot be created or destroyed, so the total amount of energy in a system is constant

TEACHER BACKGROUND INFORMATION

Wildfire Fuel Sources

Fuels are one of three main components that drive wildfires. The other two are terrain and weather (especially wind). Fuels can be split into two classes or components: live and dead. The live component is generally related to the growing season. During the course of the year, there are typically one or two growing periods (e.g., spring and summer) with a dormant period during winter. The dead fuel consists of wood logs and twigs and includes a duff layer, which consists of several years' worth of accumulating tree needles and leaf litter. The drier and deeper the duff layer, as well as the drier the soil, the more susceptible this fuel bed is to lightning strikes. Fire will smolder for days and even weeks within a dry and deep duff layer.

To reduce flammable material—such as dry grass, fallen trees, dense forests, logs, and shrubs—land management agencies strategically remove and reduce fuels on the landscape. Fuel management practices include burning, thinning, pruning, chipping, and mechanically removing fuels to reduce the amount and continuity of burnable vegetation.

MATERIALS & ADVANCE PREPARATION

FOR EACH GROUP OF FOUR STUDENTS

- METAL SODA CAN OR SOUP CAN
- 50 mL GRADUATED CYLINDER
- RULER WITH CENTIMETERS (cm)
- WATER 50 mL PER SAMPLE
- GLASS THERMOMETER, LONGER THAN 14 cm (5.5 INCHES)
- ALUMINUM FOIL
- WIRE GAUZE MINIMUM ABOUT 7.5 x 7.5 cm (3 X 3 INCHES)
- METAL TONGS
- 2–3 PAPER CLIPS
- RING STAND, WITH CLAMP AND RING SUPPORT (or coat hanger that can hold the can)
- LONG-REACH LIGHTER OR MATCHES
- STOPWATCH OR OTHER TIMER
- ELECTRONIC OR MECHANICAL BALANCE THAT MEASURES TO AT LEAST 0.1 GRAMS
- SAMPLES OF OUTDOOR VEGETATION

FOR EACH STUDENT

- STUDENT SHEET 8.1 “Testing Fuel Sources”
- SAFETY GOGGLES
- LAB COAT (OPTIONAL)
- DISPOSABLE FACE MASK (OPTIONAL)

Gathering Fuel Sources

Select various types of vegetation for groups to test as fuel sources. Depending on your location, you can collect grasses, leaves, shrubs, and twigs from your surrounding area. Results can vary for this lab, based on available materials. In order to facilitate ignition, make sure the following criteria are met:

- Vegetation samples should be less than a pencil width in diameter or thickness and should be collected with enough time in advance of the lab that they can dry out sufficiently.
- To control fire size, all vegetation samples should be trimmed to less than 2 inches long and should weigh no more than 0.5–1.0 grams before burning.

Test materials yourself beforehand to ensure that the samples will ignite as expected and meet the safety requirements as noted in the Safety Notes section. Items that are too thick, too wet, or have certain types of bark may be difficult to ignite. Natural oils, a waxy coating, or other substances will affect how well the materials ignite or how large the flame will be. Avoid placing samples in windy areas or near air drafts that can affect the ignition and burn time of the samples.

While the goal of the lab is to simulate natural fuel sources involved in wildfires, you may find it easier to purchase other materials to test. Some suggestions for alternative fuels are listed in the following table. If you use alternative fuel sources, be sure to help students make analogies to natural fuel sources and think about the effects on a wildfire.

GRASS		DRY VEGETATION		TREES	
NATURAL MATERIALS	NOT AS REALISTIC, BUT EASY TO FIND	NATURAL MATERIALS	NOT AS REALISTIC, BUT EASY TO FIND	NATURAL MATERIALS	NOT AS REALISTIC, BUT EASY TO FIND
Dried grasses: should be long/tall and dry. May need to fold them into a loose bundle. Dried moss, fine wood shavings (uncolored and not preserved)	Shredded paper or tissue paper Thin strips of crushed paper Food model: marshmallow	Dried leaves Dried pine needles Dried shrubs or herbs	Thin strips of cardboard Toothpicks: loosely bundle several together Food model: popcorn cheese puffs	Dried sticks of wood Dried bark	Wooden craft sticks Wooden paint stirrers Food model: almonds walnuts

Calorimeter Setup

Review the calorimeter setup instructions in Procedure Steps 4–6 in the Student Book, which include a diagram of a ring stand with a clamp from which to hang a soda can by the tab and a ring support with a piece of wire gauze to hold the fuel source. Wire gauze is a wire mesh with a woven ceramic center that provides a surface that can hold the vegetation as it burns. Determine if you need to alter the instructions based on the equipment you have available. In lieu of a ring support and wire gauze, you can build a fuel holder out of various materials such as clay and paper clips. If you don't have access to ring stands and clamps, search online for "high school or home school calorimetry labs" to find a setup that could work with your available equipment.

Safety Notes

Review your school's fire safety plan and ensure your classroom has access to fire safety equipment as needed. Also alert others at the school about the experiment and that they may smell burning materials. Review safety rules and behavioral expectations with students before beginning the lab. Remind students:

- to wear safety eyewear during this investigation.
- that long hair must be tied back and loose sleeves rolled up.
- to clear all items near the test area and be especially careful not to get hair or clothing near the flame. If anything besides the fuel sample begins to burn, get help immediately.
- to keep a cup of water nearby as a fire safety precaution.
- that burning samples can make lab equipment hot to the touch. Use metal tongs to pick up the wire gauze and the burned sample.

Depending on your classroom setup, you may wish to light each group's sample yourself (instead of having students do it). You can also design and perform the experiments as a class demonstration or provide students with sample data.

All samples should be tested in a clear area outdoors or in a very well-ventilated classroom to minimize exposure to smoke. Students may wish to wear masks during the ignition procedure. If a sample fails to ignite after 15 seconds of applying the flame from the lighter, students should stop using that sample. Instruct students to take care, as the lighter, sample holder, and sample will be extremely hot.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (10 MIN)

1 **Brainstorm ideas about how different types of fuels affect wildfires.**

- Support students in sharing their knowledge about wildfires while remaining sensitive to individual student's experiences. Validate students' points of view by eliciting students' observations, experiences, and knowledge as assets to building understanding. Ask, What are some types of fuel sources that burn in wildfires? Student responses may include descriptions of different types of plants such as trees, grasses, and shrubs. Buildings can also be fuel sources for a wildfire. Students may also have some ideas that are not related to vegetation, such as oil or homes. Follow up with a prediction question. Ask, What ideas do you have about how the type of fuel affects wildfires? Students may already know that vegetation that is really dry can catch fire more easily or be more involved in wildfires. Students might suggest that trees may burn a long time because they are so substantial and provide more fuel.
- Read the Introduction, either as a class or individually. Point out that being able to accurately predict the behavior of wildfires can also help scientists make predictions about wildfire smoke and, therefore, air quality. In this activity, students will investigate fuel sources as one of the factors influencing wildfires, and they will apply their lab results to probabilistic reasoning related to wildfire spread.

PROCEDURE SUPPORT (60 MIN)

2 **Review classroom safety expectations.**

- This lab involves burning various materials, so it is important to review the safety rules and behavioral expectations before students begin the procedure. Remind students to wear lab coats and safety goggles, tie hair back, pull up long sleeves, and follow all other classroom safety rules.
- Point out that the lighters or matches must be used responsibly. Review any additional guidelines you have for their use in the classroom.
- Optionally, students may want to wear masks to protect themselves from any smoke.

3 Prepare students to conduct their experiments.

- As a class, read the fictional scenario in Procedure Step 1. Clarify the purpose of the lab. Explain to students that they will be conducting experiments to find out how different fuel sources affect the heat, speed, and smoke of a fire for the purpose of informing probabilistic reasoning related to wildfire smoke and spread. Groups will choose two different types of vegetation to test, and group members will eventually make predictions about each fuel source's effects on a wildfire.

- Reading the scenario 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.

- Review the terms *ignition time* and *heat of combustio*n defined in Procedure Step 2. Explain to students that they will be measuring both of these values, but they can also observe and record other variables (e.g., how long it takes the fuel source to burn or how much smoke it produces). If needed, review the concepts of combustion, calories, and how a calorimeter works based on the law of conservation of energy from the Science Review in the Student Book.

- Since this is an inquiry-based lab, you may want to use heterogeneous groups to help support the needs of all learners and encourage all students to participate. You may find it useful to assign roles to each group member, as there are many experiment setup and data collection tasks that can be divided up.

- In Procedure Steps 4–6, students refer to Figure 8.1 in the Student Book to set up the calorimeter. Give students any special instructions or modifications related to the available equipment for building the calorimeter and fuel sources to test. It may be useful to demonstrate how to build the holder for the fuel source, prepare the sample, and set up the calorimeter.

4 Support students as they test their samples and analyze their data.

- In Procedure Step 4, distribute lab materials (except lighters or matches) to each group and one copy of Student Sheet 8.1, "Testing Fuel Sources," to each student. Before groups begin testing their samples in Procedure Part B, you may want to demonstrate how to properly weigh the samples, safely light and burn the samples, and record data and observations in Table 1 on Student Sheet 8.1. Sample Student Responses for several types of samples are provided at the end of this activity even though students are only expected to test two samples.

- Circulate and assist groups as they test their samples in Part B, if needed.
  - Before lighting vegetation samples, check each group's calorimeter setup for safety.
  - Remind students that they must mass the sample both before and after burning. Depending on the equipment available to you, review how to mass a vegetation sample in order to accurately calculate the change in mass (in Procedure Step 16). Inform students that they may empty and refill their can to help reset the water temperature in between tests. Also remind students to wait until the can is cool to the touch before handling it.

- Students may observe that materials used to represent trees are hard to ignite and often will not remain burning without a constant flame source. In a natural setting, trees are very difficult to ignite, but once ignited, they will burn for a longer period of time. You can help students think about how this plays a role in wildfires, especially in places that have mixed vegetation. (Grasses ignite and spread the flame quickly to other areas, dried vegetation ignites easily and burns for longer, trees can be ignited when there is a lot of nearby dried vegetation that is burning and then burn the longest and hottest of all the fuel sources.)
- Remind students to clean up and safely dispose of their samples before moving on to Procedure Part C.
- In Part C, if you have students who need math support, project Table 2 on Student Sheet 8.1 and model how to complete the calculations described in Procedure Steps 15 and 16, using the data from Table 1.
- In Procedure Step 17, give students instructions for sharing their findings with one or two other groups. You may want to have students record notes from their discussions in their science notebooks.

SYNTHESIS OF IDEAS (20 MIN)

5 Have students share results.

- Ask a student from each group to share with the rest of the class their conclusions about the samples they tested and observed. You may want to compile the results on the board so students can compare across groups.
- Ask, Based on everyone's data, which sources will cause a fire to spread most quickly and burn for longer? Student responses may vary depending on the fuel sources they tested. Help the class develop the understanding that drier fuel sources will ignite a lot faster and tend to produce less smoke (burn more cleanly) than fresh fuel sources. Also, grasses (or leaves) will ignite faster and burn more quickly than dry wood. However, since there is generally more mass in a piece of wood than in an equivalent volume of grass (or leaves), wood will produce more heat if it catches fire, though it is more difficult to ignite.
- Follow up by asking, How do you think each of the fuel sources tested will affect the way an actual wildfire behaves? An area with grass will likely cause a fire to spread more quickly than a fuel source area with wood. But wood will be more likely to keep the wildfire burning because it will generate more heat.

6 **Review key concepts from the activity.**

- Ask, What role does probabilistic reasoning play in your prediction of wildfire behavior? Students should recognize that the experiment provided data that could be use for determining the likelihood of wildfire behavior.

- To conclude the activity, evaluate whether your students are able to answer the Guiding Question, *How can you use experimental results to make predictions about the real world?* Use this as a chance to revisit and summarize the key concepts and process skills of the activity by reviewing their answers to Build Understanding items 2, 3, 4 and Connections to Everyday Life item 5. Build Understanding item 2 provides an opportunity for students to use their experiment results from the lab to make a prediction about a wildfire in fictional Koheegee Park. This item also previews the map and fuel sources they will be working with in Activity 9: Probabilistic Modeling. Build Understanding items 3 and 4 give students an opportunity to use real scientific data to make predictions about real wildfires. Connections to Everyday Life item 5 gives students an opportunity to use scientific data to make predictions related to an everyday decision.

EXTENSION (10 MIN)

7 **Use the Extension as an opportunity for advanced learning.**

Students can learn more about fire science, the effects of fires on wildlife, and fire suppression by watching the *Inside the Lab That Starts Fires For Science* video about the Missoula Fire Sciences Lab.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

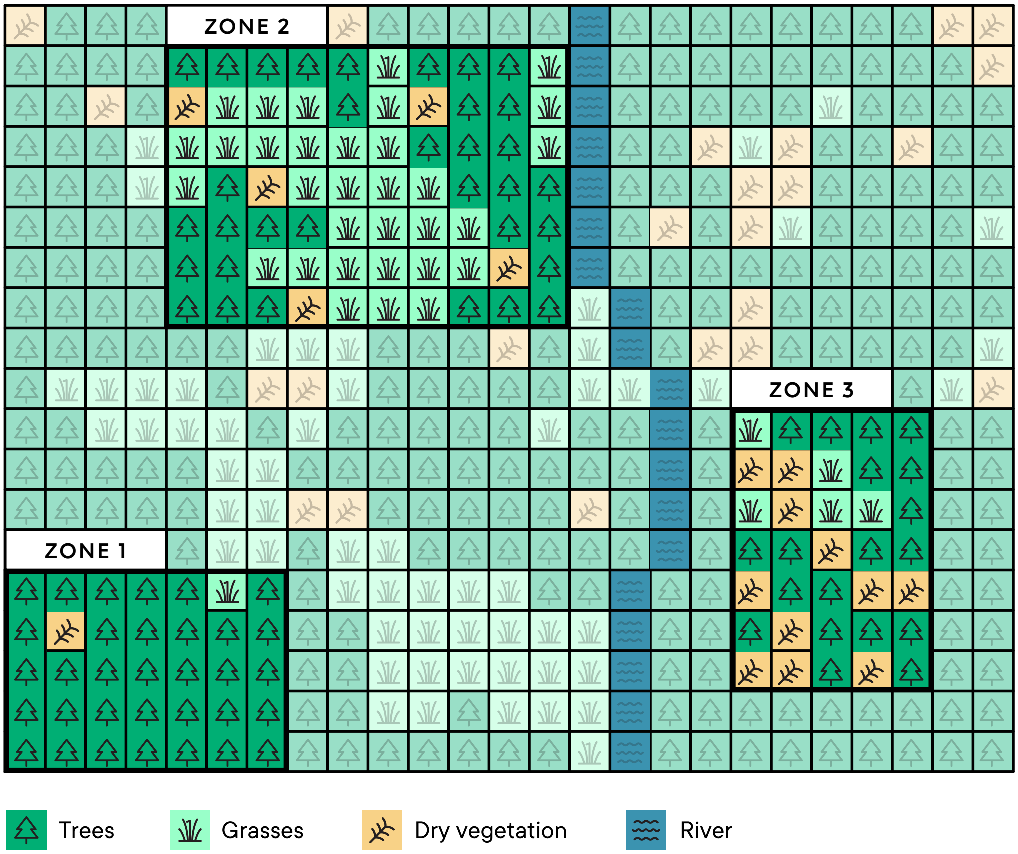
① **You conducted an experiment to compare two different fuel sources. Which of the fuel sources do you think is more likely to be ignited in a wildfire? Use the results from your experiment as well as probabilistic reasoning to explain your prediction.**

Responses will vary based on which samples were tested.

We tested a piece of bark and a bundle of dried grasses. The bark was really difficult to catch on fire, and it wouldn't stay burning, while the grass was very easy to ignite and quickly burned the whole sample. Based on this, I predict that grasses are more likely to be ignited in a wildfire, while trees (which are covered with bark) are less likely to be ignited.

② **Examine Figure 8.2, which shows a map of a fictional place called Koheegee Park.**

FIGURE 8.2
Map of Koheegee Park with 3 Zones



a **Which of the fuel samples tested by your class would best represent each type of fuel source (trees, grasses, dry vegetation) found in Koheegee Park?**

Grasses: We tested dried lawn grass, and I think this would represent grasses in Koheegee Park because it is similar to other dried grass in nature.

Trees: We tested twigs, and I think those would represent trees because they were the thickest and more woody than the other samples.

Dry vegetation: We tested toothpicks, and I think those would represent dry vegetation because they are thin and snapped easily like dried wood.

b **Which section of the park (Zone 1, 2, or 3) is most at risk from a rapidly spreading wildfire? Explain.**

I think the section of the park that will be most at risk from a rapidly spreading wildfire is Zone 2 because that zone has the most grasses. According to our results, materials like grasses catch fire really quickly and can spread the flame the fastest.

③ ***Fuel load*** **is the amount of combustible material in a given area, measured as weight per unit of area. Examine Table 8.1, which shows the annual fuel load in four different regions by latitude.**

TABLE 8.1
Annual Fuel Load for Four Regions, 2010–2019 (measured in petagrams)

REGION	LIVE FOLIAGE	LIVE WOOD	DEAD FOLIAGE	DEAD WOOD
A (50°N–90°N)	3	76	27	21
B (23.5°N–50°N)	4	61	19	10
C (23.5°S–23.5°N)	9	347	25	34
D (50°S–23.5°S)	1	18	4	5

a **Based on this data and the results from your experiment, which region do you think is most at risk for wildfires? Explain your reasoning.**

Based on our results, I think the region that will be most at risk for wildfires is Region C because it has the most dead vegetation (dead foliage and dead wood, combined). From our experiment, we saw that things that are moist are harder to catch on fire than things that are dry. Live vegetation has more moisture than dead vegetation.

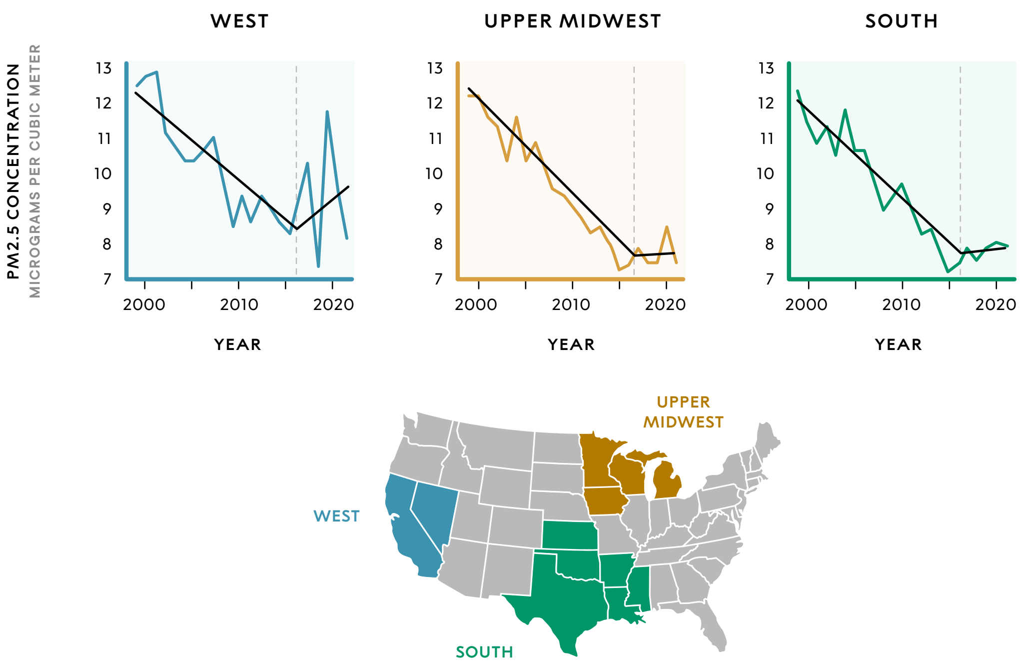
b **What other factors could influence the wildfire risk in each region?**

I think that weather patterns and local features such as lakes and rivers might affect the wildfire risk in each region.

④ **Researchers examined the contribution of wildfire smoke to average annual PM2.5 concentrations in different regions of the United States by using a combination of ground-based and satellite-based air pollution data from 2000 to 2022. Examine their results, which are shown in Figure 8.3.**

FIGURE 8.3

Regional Trends in the United States of PM2.5 Concentrations, 2000–2022



a **For each graph, describe the patterns you see in the data both before and after 2016, the year indicated by the dashed vertical line.**

West: The amount of PM2.5 generally decreases until 2016. After 2016, the PM2.5 level increased sharply.

Upper Midwest: The amount of PM2.5 generally decreases until 2016. After 2016, the PM2.5 level stayed the same.

South: The amount of PM2.5 generally decreases until 2016. After 2016, the PM2.5 level increased a little bit.

b **Based on this data, which part of the United States is most likely to have PM2.5 levels that are influenced by wildfire? Explain your reasoning.**

I think that the western region is most likely to have PM2.5 levels that are influenced by wildfire because the PM2.5 levels have increased since 2016. I heard on the news that there are lots of wildfires in the west. Wildfires can result in increased levels of PM2.5 because the burning and smoke can release small particles into the air.

c **Explain how the trend line on the graph helps you differentiate the signal from the noise.**

The trend line helps differentiate the signal from the noise because of all the fluctuations in the data. The noise makes it hard to see the longer-term pattern in the data. The trend line shows the general pattern and also makes it easier to compare the date from one location to another.

CONNECTIONS TO EVERYDAY LIFE

5 **Imagine you have been saving to go on a trip to an outdoor amusement park during a school break. A ticket costs $100. If you buy your ticket one month in advance, you will get a 20% discount. So far, the weather has been mild and warm with little rain and no snow. Table 8.2 shows local weather data for the last 5 years for the month you plan to go.**

TABLE 8.2
Five-Year Average of Local Weather Data during Annual School Break

YEAR	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	TOTAL PRECIPITATION
2020	-1.1°C (30°F)	5.6°C (42°F)	0.1 cm (0.04 in)
2021	3.9°C (39°F)	10.0°C (50°F)	0.2 cm (0.08 in)
2022	0.6°C (33°F)	9.4°C (49°F)	1.0 cm (0.4 in)
2023	11.6°C (53°F)	19.4°C (67°F)	0.0 cm (0.0 in)
2024	5.0°C (41°F)	14.4°C (58°F)	3.0 cm (1.2 in)

a **Use probabilistic reasoning to explain whether or not you would buy a ticket in advance.**

I would not buy a ticket in advance right now. The data from the previous 5 years shows that the temperatures and precipitation are unpredictable from year to year. The weather forecast is only useful a few days out. More than a few days, you are taking a big chance. Even though I would save $20, if it is wet or very cold on that day, I would either not go and lose my money or go and be miserable.

b **What information would reduce the uncertainty in your decision?**

It would help to look at data from more than just the weeks of the school break. That could give a better sense of what the range of weather is like during this time of year. I also want to know more about what conditions would cause some of the rides to be shut down and whether or not I can get a refund if we decide not to go due to bad weather.

REFERENCES

Burke, M., Childs, M. L., de la Cuesta, B., *et al*. (September 20, 2023). The contribution of wildfire to PM2.5 trends in the USA. *Nature, 622*, 761–766. https://doi.org/10.1038/s41586-023-06522-6

McNorton, J. R., & Di Giuseppe, F. (2024). A global fuel characteristic model and dataset for wildfire prediction. European Geoscience Union: *Biogeoscience*, *21*(1), 279–300. https://doi.org/10.5194/bg-21-279-2024

STUDENT SHEET 8.1	TESTING FUEL SOURCES	NAME

TABLE 1: OBSERVATIONS AND MEASUREMENTS

SAMPLE	MASS OF WATER (g)	SAMPLE MASS INITIAL (g)	SAMPLE MASS FINAL (g)	WATER TEMPERATURE INITIAL (°C)	WATER TEMPERATURE FINAL (°C)	IGNITION TIME (seconds)
	BURN OBSERVATIONS					
	BURN OBSERVATIONS					

TABLE 2: CALCULATIONS

SAMPLE	Energy released by the sample (calories) = mass of water (g) X temperature change of water (°C)			Heat of combustion (calories/gram) = $\frac{\text{energy released by the sample (cal)}}{\text{change in mass of sample (g)}}$	
	MASS OF WATER IN CAN (g)	TEMPERATURE CHANGE OF WATER (°C)	ENERGY RELEASED BY SAMPLE (cal)	CHANGE IN MASS OF SAMPLE (g)	HEAT OF COMBUSTION (cal/g)

STUDENT SHEET 8.1 | TESTING FUEL SOURCES | NAME SAMPLE STUDENT RESPONSE

TABLE 1: OBSERVATIONS AND MEASUREMENTS

SAMPLE	MASS OF WATER (g)	SAMPLE MASS INITIAL (g)	SAMPLE MASS FINAL (g)	WATER TEMPERATURE INITIAL (°C)	WATER TEMPERATURE FINAL (°C)	IGNITION TIME (seconds)
dry wooden stick broken into 4 short pieces	50	0.54	0.40	18	28	10
	BURN OBSERVATIONS: *Had a medium flame at first, but the flame quickly grew smaller and then went out. Had to relight, and then it burned for about 30 seconds, smoldered for about 15 seconds before going out all the way. Medium amount of smoke.*					
pile of wood shavings	50	0.35	0.01	58	64	2
	BURN OBSERVATIONS: *Lit quickly, stayed burning. Very large flame burned consistently. Flame spread quickly through the sample, burned quickly and all the way. Burned 10–20 seconds, light smoke.*					
4 toothpicks	50	0.54	0.14	24	40	2
	BURN OBSERVATIONS: *Lit quickly, stayed burning. Toothpicks burned consistently until they were burned all the way through. Burned for more than 30 seconds. Not a lot of smoke until the flames went out, then smoked.*					
pile of crinkled paper strips	50	0.94	0.10	40	60	2
	BURN OBSERVATIONS: *Lit quickly, burned consistently and evenly, spreading quickly from where it was lit to the rest of the pile. Burned about 20 seconds. Flame height was large. Light smoke.*					

* Students are only expected to test two samples. Additional responses are provided for teacher reference.

TABLE 2: CALCULATIONS

SAMPLE	Energy released by the sample (calories) = mass of water (g) X temperature change of water (°C)			Heat of combustion (calories/gram) = energy released by the sample (cal) / change in mass of sample (g)	
	MASS OF WATER IN CAN (g)	TEMPERATURE CHANGE OF WATER (°C)	ENERGY RELEASED BY SAMPLE (cal)	CHANGE IN MASS OF SAMPLE (g)	HEAT OF COMBUSTION (cal/g)
dry wooden stick	*50*	*28 – 18 = 10*	*50 x 10 = 500*	*0.54 - 0.40 = 0.14*	*500 /0.14 = 3,571*
wood shavings	*50*	*64 – 58 = 6*	*50 x 6 = 300*	*0.35 - 0.01 = 0.34*	*300/0.34 = 882*
toothpicks	*50*	*40 – 24 = 16*	*50 x 16 = 800*	*0.54 - 0.14 = 0.40*	*800/0.40 = 2,000*
paper strips	*50*	*60 – 40 = 20*	*50 x 20 = 1,000*	*0.9 - 0.1 = 0.8*	*1,000/0.8 = 1,250*

* Students are only expected to test two samples. Additional responses are provided for teacher reference.

ACTIVITY 9

Probabilistic Modeling

MODELING

ACTIVITY 9

Probabilistic Modeling

ACTIVITY SUMMARY

Students use a probabilistic model of a fictional wildfire to make predictions about its spread through a community and calculate the probability of its spread based on the model. Students practice using probabilistic reasoning to make recommendations about water drops and controlled burns in order to reduce the spread and risk of the fire.

ACTIVITY TYPE
MODELING

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

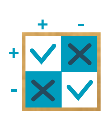
KEY CONCEPTS & PROCESS SKILLS

1. When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.
2. Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.
3. Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS



VOCABULARY DEVELOPMENT

probabilistic model

`a tool that uses patterns in data to predict the likelihood of different outcomes`

TEACHER BACKGROUND INFORMATION

Probabilistic Models vs. Deterministic Models

Scientists use statistics to uncover patterns in real-world data. To understand these patterns, they build models that mimic real-life situations. Models can vary in their complexity based on the number of factors, the interactions between factors, and the scientific principles that are built into the model. The more factors and the better the model simulates the relationships between the factors, the better its predictive power.

Probabilistic models are models that are based on data from observations; assumptions about the context; and consideration of probability theories, chance, variation, and randomness. Probabilistic modeling is used in contexts such as weather forecasting, diagnostic medicine, and artificial intelligence (AI). One example is what is called machine learning in AI applications. Machine learning uses probability theories and large data sets to train the computer algorithm to be able to recognize images or speech, generalize information, or perform tasks without instructions. Probabilistic models can be used to test hypotheses, predict what might happen in the future based on current trends, and solve problems by finding the best course of action in different scenarios. Given the same initial inputs, a probabilistic model is likely to produce different outcomes every time it is run. It accounts for uncertainty by including the probability of different parameters and gives the likelihood of different outcomes. Like other types of models, probabilistic models are most effective when they are frequently compared to real data and updated to improve the accuracy of their predictions.

In contrast, a deterministic model does not include random elements or consider the probability of events. Given the same initial information or inputs, a deterministic model will always result in the same outcome. An example might be using a simple equation to model the bounce of a ball. If a certain starting point and force are known, it will allow you to predict exactly how high the ball will go. Deterministic modeling is used for processes such as resource allocation, inventory management, automation processes in manufacturing, and projection of long-term investments. Deterministic models are not referenced in this unit.

Probabilistic Models and Wildfire Prediction

Wildfire modeling uses computational tools to make simulations of fire dynamics in specific locations. It is a tool that complements fire risk assessment, which assesses the likelihood and intensity of a fire should it occur. Wildfire modeling is used to forecast fire spread, shape, spotting potential (when new fires start because of flying embers or other materials), and even how much heat a fire may generate. Newer wildfire models based on research are sophisticated enough to include details such as spread by ground (surface fire); treetops (crown fire); and/or terrain including slope steepness, direction of approach (up vs. down a slope), fuel characteristics (density and moisture), fire intensity, and weather conditions. Some models include mathematical models of propagation and historical data from previous fires.

As the models improve, they are increasingly being used as fire management tools to prepare for, prevent, and fight wildfires. Wildfire modeling can help suppress fires in real time by informing where to deploy firefighting resources and can boost safety for firefighters and the public. Models can also help in pre- and post-fire management by informing where preventative measures such as controlled burns might be most effective to reduce the impacts of fires on watersheds, air quality, and sensitive habitats. Some new models use AI algorithms to help detect new fires. For example, in 2023, the University of California at San Diego worked with California's state firefighting agency, CAL FIRE, to develop a new fire monitoring system that uses more than a thousand camera feeds from across the state. The system is trained to detect smoke and other early signs of fire by machine learning.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- TAPE (OR TACKS)

FOR EACH PAIR OF STUDENTS

- 2 NUMBER CUBES
- SET OF 8 COLORED PENCILS (red, orange, yellow, green, blue, purple, brown, and grey)

FOR EACH STUDENT

- 2 STUDENT SHEETS 9.1 “Map of Koheegee Park”
- 2 STUDENT SHEETS 9.2 “Modeling Wildfire Spread”
- 2 STUDENT SHEETS 9.3 “Data from the Wildfire Model”

Familiarize yourself with the Wildfire Model, using the model instructions in the Student Book. Since there are many potential outcomes of the model, It will be useful for you to be familiar with all 8 rounds of rolls, data collection, and mapping. Teaching Step 2 includes more information to support filling out the map, using the model rules.

Ensure that your students have similar sets of colored pencils with the appropriate colors. Students compare their maps during the activity, so the comparison will be easier if they are using similar colors in each round.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (10 MIN)

1 **Students think about why multiple factors can make a prediction difficult.**

- In the previous activity, students tested various types of fuel sources, but there are many other factors that can affect a fire. Ask, Why do you think it can be very difficult to predict where and how fast a fire will spread? Student responses may include: there are many factors that affect wildfire spread; some of the factors interact with each other; some factors (such as rain) may change during the course of a wildfire, and some factors may not be accounted for.
- After students read the Introduction, review the term *probabilistic model.* If you have begun a word wall, support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the term probabilistic model to the word wall. It may help to provide an example of a *probabilistic model*, such as weather apps, which provide a range of possible outcomes along with the likelihood of each one occurring. Ask, What factors do you think these weather models are using? Students may respond that weather apps rely on various data collected about atmospheric conditions such as temperature, precipitation, and air pressure as well as satellite and doppler readings that track the movement of storms. All these data are factored into a prediction about the likely weather in the near future.
- Point out that the purpose of many probabilistic models is to help people make predictions and inform decisions. This could include helping scientists learn more about how a natural phenomena behaves, preparing communities for a hazardous event, or even just making everyday plans (as in the case of a weather app). Let students know that in this activity, they will be using a probabilistic model to make predictions about wildfire spread.

PROCEDURE SUPPORT (60 MIN)

2 **Prepare students to use the wildfire models.**

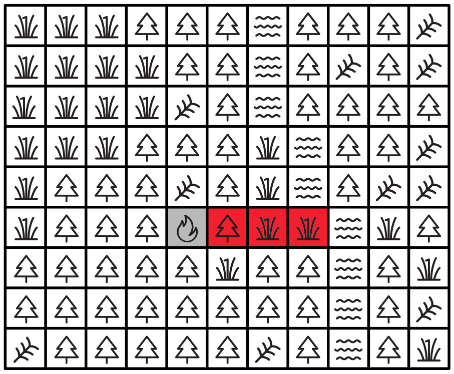
- Distribute one copy of Student Sheet 9.1, "Map of Koheegee Park," one copy of Student Sheet 9.2, "Modeling Wildfire Spread," and one copy of Student Sheet 9.3, "Data from the Wildfire Model," to each student. Have students read the fictional scenario in Procedure Step 1 and review the map on Student Sheet 9.1. Answer any questions students have about the scenario and the map. Depending on your student population, you may wish to review the use of the compass and the abbreviations for north, south, east, and west.

- Wait to hand out the number cubes and colored pencils until after students have made their predictions in Procedure Step 2 and you have reviewed the model rules in Procedure Step 3.
- Demonstrate how to complete the first few rounds of the model, ideally by projecting Student Sheets 9.1 and 9.3 on a document camera so you can roll the number cube, record the data on Student Sheet 9.3, and color the map on Student Sheet 9.1. Follow the rules in Procedure Step 3 for the Wildfire Model. Make sure students know that they will need to proceed through each action in order—rolling the number cube and coloring the map—before moving on to the next action. Sample data for the first 3 hours of the teacher demonstration is shown in the following table and maps. Let students know not to copy the data from the demonstration onto their student sheets.

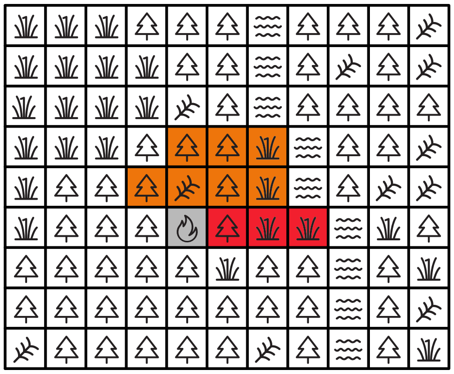
Sample Data for the First 3 Hours

HOUR 0: **Fire starts**	STEP 1: **Wind Direction** Roll #: Action	STEP 2: **Wind Speed** Roll #: Action	STEP 3: **Fuel sources that cause spread**
Hour 1 (red)	*Rolled 3: moved East*	*Rolled 4: Wind 15 mph*	*grasses*
Hour 2 (orange)	*Rolled 1: moved North*	*Rolled 5: Wind 15 mph*	*grasses and dry vegetation*
Hour 3 (yellow)	*Rolled 5: moved South*	*Rolled 3: Wind 5 mph*	*grasses*

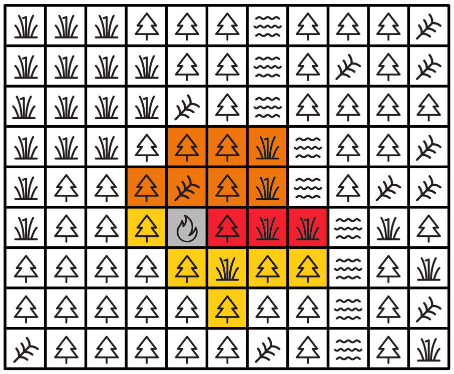
Map After Hour 1



Map After Hour 2



Map After Hour 3



- In Procedure Step 4, students calculate probabilities of various factors in the Wildfire Model before using the model themselves. Students who struggle with math may require additional support to calculate the probabilities. You may want to have students read the Science Review in Activity 1 of the Student Book and model how to complete the probability calculations. Review the responses as a class and have students update their predictions from Procedure Step 2 as needed.

  Sample Student Response, Procedure Step 4

  a The probability of each wind direction:

  North = 1:6 (16.7%)
  East = 2:6 or 1:3 (33.3%)
  South = 2:6 or 1:3 (33.3%)
  West = 1:6 (16.7%)

  b The probability of each wind speed:

  5 mph = 3:6 or 1:2 (50%)
  15 mph = 2:6 or 1:3 (33.3%)
  30 mph = 1:6 (16.7%)

  c The fuel type that is least likely to spread a fire:

  Trees, because during the fuel source action, trees don't spread the fire to additional squares, whereas grasses and dry vegetation do.

3 Support students as they use the Wildfire Model in Part A.

- In Procedure Step 5, hand out 2 number cubes and a set of colored pencils to each pair of students. Partners begin working with the Wildfire Model together. Have students label the fire on Student Sheet 9.3 as Fire A. A sample student response is shown at the end of this activity.

- Decide whether you want partners to take turns rolling the number cubes to create two different maps of Fire A, or if you want them to roll together, which would result in both students creating the same map. For students who are more advanced, rolling separately will give them an additional opportunity to see how chance and probability can affect the path of the fire. For students who struggle to follow the model's instructions, we recommend having partners roll together so students can help each other to follow the steps of the model by comparing their maps and results as they progress through the model.

- Circulate to ensure students are following the rules of the model and color-coding each hour on the map properly.

- In Procedure Step 7, have students display their maps of Fire A by taping them on the wall. If partners created the same map, only one student needs to post their map. Allow partners time to observe and compare the results across all the maps.

- Ask, Based on everyone's results, is there a shape, direction, and size of the fire that seems more likely to occur in the park? Students may recognize that the fire tends to go east and south but that sometimes, random variations can cause the fire to go in other directions and have a different shape every time the model is run. As a class, discuss the differences in the maps and then ask, Which factors in the model do you think have the biggest impact on where and how the fire spreads and why? Students may recognize that wind speed played a big role in spreading the fire very quickly when the wind was really strong. Vegetation type also had a big role in spreading the fire, especially dry vegetation, which could spread the fire in all directions. Wind direction determined the general direction of the fire but could also make the fire spread randomly in other directions.

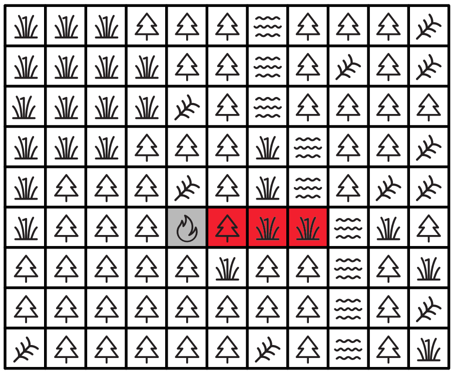
4 **Support students as they use the Wildfire Model to manage a second fire in Part B.**

- For Part B, provide each student with a second copy of Student Sheets 9.1, 9.2, and 9.3. A sample student response for Student Sheet 9.1 for Fire B is shown at the end of this activity.

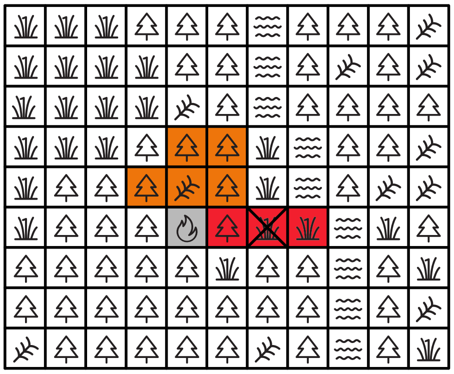
- Have students read the scenario in Procedure Step 8 and record a prediction (on their new copy of Student Sheet 9.2) for the second fire. Have students label this fire as Fire B. Explain that now that students are familiar with the model, they will have a chance to prevent the fire from spreading by dropping water on a single burning square on the map *at the beginning of each hour, starting in Hour 2*. By marking the square with an X (on their new copy of Student Sheet 9.1), the water will prevent fire from spreading from this square in any future hours. Point out that water drops are often used to contain real wildfires, but they must be planned carefully to avoid wasting resources and time.

- If needed, model how to conduct the first few hours of Fire B with water drops, using the modified instructions from Procedure Step 8. (Sample data for the first 3 hours are shown in Teaching Step 2.) The following maps show the data as it is recorded for each roll with the water drops added after Hour 1 and Hour 2.

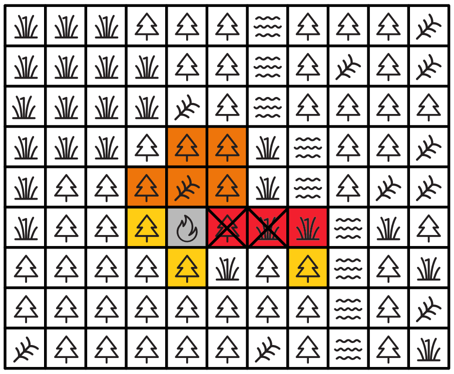
Map After Hour 1



Map After Hour 2
with Water Drop After Hour 1



Map After Hour 3
with Water Drop After Hour 2



- In Procedure Step 9, have students share their results from Part B and the insights they gained when comparing their map to the map of another pair of students.

Sample Student Response, Procedure Step 9

Compare your results with another pair of students. Determine:

- in which direction the fire moved the most.

  The fire is still most likely to move east and south

- what factor(s) most influenced the outcome.

  The wind strength and type of fuel had big effects on how easily the fire spread throughout the region, though being able to drop water on certain areas helped us reduce the spread of the fire.

- how the different factors interacted in a way that caused the fire to spread.

  The wind direction and speed were due to chance, but the spread of the fire depended on what types of vegetation were present in that direction. This made it so that everyone's maps were a little different.

SYNTHESIS OF IDEAS (20 MIN)

5 **Facilitate a class discussion to highlight that probabilistic reasoning is useful because it can be based on available data, even when the data is incomplete.**

- Ask students to share and explain their results from Procedure Part B. Ask, Why were you successful or unsuccessful in preventing the fire from spreading? Student responses will vary. Many students will report that they were able to use the probabilities of wind speed and direction along with what they knew about the different fuel types to limit the fire spread. Some students may report that they were unsuccessful due to the randomness of rolling the number cubes, which could have made the fire behave in ways that were different than expected.
- Ask, How did completing the model in Part A help you make your choices for water drops in Part B? Student responses should indicate that completing Part A gave them a better understanding of what is more likely and less likely to happen, even though their predictions were not always correct. Point out that this is what makes probabilistic reasoning useful—it allows people to use what they know, even when what they know is incomplete.
- Ask, What happens if you run the model numerous times? Student responses should indicate that it provides different possible outcomes of the fire and improves the quality of predictions based on which outcomes are most likely.
- Evaluate if your students are able to identify the essential ideas of the activity by reviewing student responses to Build Understanding items 1 and 2. Students apply what they've learned using the model to make a recommendation about controlled burns as well as to make a prediction about air quality in nearby cities.
- Build Understanding item 3 gives students an opportunity to reflect on the limitations of the Wildfire Model and how it is an example of a probabilistic model. Students may realize that the model did not incorporate all the complex aspects of wildfire conditions, such as the wetness of the area, complexities in wind movement, landscape features, and location to resources. These aspects make modeling more of a challenge than in the model they ran. Even so, a more sophisticated model would include a combination of aspects that can be accurately predicted and aspects that cannot.
- Build Understanding items 4 and 5 give students an opportunity to connect the use of the probabilistic model back to concepts learned earlier in the unit: false positives, false negatives, and confidence levels. Students may need additional review of these concepts to support their responses to these items.
- Connections to Everyday Life item 6 provides the class an opportunity to discuss how AI uses probabilistic reasoning and how sometimes this can be a problem because it can reinforce harmful stereotypes.
- To conclude the activity, evaluate whether your students are able to answer the Guiding Question, *How can probabilistic reasoning be used to predict an outcome?*

EXTENSION (50 MIN)

6 **Use the Extension as an opportunity for advanced learning.**

- National Oceanic and Atmospheric Administration's (NOAA) HYSPLIT computer model is an online probabilistic model used to predict the trajectory of air parcels across a location. Students can use HYSPLIT to simulate the spread of smoke in their local area over an 8-hour period from a controlled burn, also called a prescribed burn. Note that the model allows for many different inputs, many of which can be ignored for the purposes of this Extension.

- Important steps for students when using the model:
  - On the first page of the model, go to "Release Type" and select one of the two PRESCRIBED BURN options.
  - For "Source Location," select a location on the map that you would like to model. Then scroll to the bottom of the page and select the NEXT button.
  - On the second page of the model, go to "Choose an archived meteorological file" and select any file other than "Current7days." Then select the NEXT button.
  - On the third page of the model, it is possible to change many parameters (burn area, flaming burn duration, etc.). Go to "Runtime Parameters" and set the "Total duration" to 8 hours at most (longer times take longer to run) and the "Averaging period/Output interval" to 1. You may also find it helpful to scroll down to "U.S. county borders" and select "yes." Then scroll to the bottom of the page and select the REQUEST DISPERSION RUN button.
  - On the final page of the model, the page will reload every 10 seconds until the model and graphics have finished uploading. Note that the graphics may take up to 5 minutes (or longer) to display. Students should eventually observe a plume indicating the general direction of the likely spread of particles in the selected location, and they can zoom in or out of this location on the map. (If impacts are not very clear, go to "Burn Area" under "Source Term Parameters" on the third page of the model and input 1,000 acres. Students may need to troubleshoot—for example, the model may crash if using a location in Canada.)

- After examining the data from the model, have students reflect on how local officials and residents could use the information from the model to make plans or decisions related to controlled burns in the area.

- Though not a probabilistic model, a user-friendly website for looking at wildfires and wildfire smoke plumes from satellite data is https://worldview.earthdata.nasa.gov/ where it is easy to select dates. For example, you can select August 21, 2020 for California Wildfires, turn on "place layers," add "Fires - thermal anomalies" layer and zoom in to California.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **Based on the Wildfire Model from this activity, make a recommendation to Koheegee Park Rangers about what areas would benefit from controlled burning. Support your reasoning with evidence from the model.**

   Based on the Wildfire Model, I would recommend doing a controlled burn in the southeast section of the park, especially east of the river. My reasoning is that according to the model, the most likely wind directions are south and east. Looking at the data from our whole class, a lot of groups had fires that progressed south and east. Setting a controlled burn in that direction might make a wildfire less likely. Second, near the southeast part of the river, there was a lot more dried vegetation. In the Wildfire Model, this type of fuel spreads the fire a lot more than any other type of fuel, even grasses, because the fire can spread in any direction.

2. **Kairoba City is north of Koheegee Park, while Meso City is east of Koheegee Park. According to the Wildfire Model, which city is more likely to have poor air quality as a result of the fire in Koheegee Park? Explain your reasoning.**

   According to the Wildfire Model, the winds in the area are more likely to blow toward the south (33.3% chance) and the east (33% chance) compared to the north (16.7% chance). I think that Meso City is more likely to have poor air quality than Kairoba City because Meso City is east of Koheegee Park.

3. **Consider the factors that contribute to wildfire in the model.**

   a **What are some ways that the model is realistic?**

   The model is realistic in that it shows the randomness of wind patterns, which can often be unpredictable in real life. It also shows that a fire can't move across rivers as easily and that different types of vegetation spread fires at different rates.

   b **What are some other factors that could affect wildfire spread that are not included in the model?**

   Rainfall and humidity are not included in the model, as well as other physical features of the land such as mountains, hills, and roads. These things all might affect the direction and speed of fire spread.

   c **How is the Wildfire Model an example of a probabilistic model?**

   The model has probability built into it. It can help you see that while there is most likely a wind direction and wind speed, it doesn't always happen that way. By running the model many times, you can see the possible different outcomes of the fire and then make predictions based on which outcomes are most likely.

④ **Suppose you want to use the Wildfire Model to plan water drops to contain a fire in Koheegee Park. You have numerous helicopters and can drop water on as many locations as you want. However, each water drop costs $2,000 and can be dangerous to firefighting crews that will need to navigate difficult weather conditions and terrains**

a **A probabilistic wildfire model predicts a fire to spread south of the park. People there are warned, and firefighters are sent to assess the situation and do a water drop if needed. When they arrive, there is no fire. What might be one consequence of this false positive?**

One consequence might be that they send a firefighting team out somewhere that it is not needed when they could have gone somewhere it was needed. Also, people who were warned probably got worried and started to evacuate even though it wasn't necessary.

b **Describe how a probabilistic wildfire model could result in a false negative and what one consequence of this false negative could be.**

A false negative in this situation would be when the Wildfire Model did not predict a fire at a location that ended up actually having a fire. A consequence would be that there was no firefighting team on hand to control the fire, and people would not be given enough warning to evacuate, so there could be injuries or damage to property.

⑤ **Imagine 2 different wildfire models are being tested to make predictions about local wildfires. Model A predicts that a fire at a particular location will burn between 1,000 and 2,000 hectares (2,471–4,942 acres) under certain wind and weather conditions and has a 95% confidence level. Model B predicts that a fire at the same location will burn between 1,000 and 2,000 hectares under certain wind and weather conditions and has a 90% confidence level. Explain which model you would prefer to use when making wildfire predictions for this area and why.**

I prefer to use Model A to make predictions because it has a higher confidence level than Model B. This means that Model A is more successful at predicting wildfires within the correct range and is only incorrect 5% of the time compared with Model B, which is incorrect 10% of the time.

CONNECTIONS TO EVERYDAY LIFE

6. **Probabilistic reasoning is a key component of several decision-making systems, including those used in AI tools. For example, an image-generating AI tool learns to make images by looking at millions of images in a database. It finds patterns in the data it is given and uses those patterns to project how things should look. A problem arises because the data the AI learns from can be unbalanced or biased. For example, if most of the pictures the AI learns from show only certain types of people (such as men as doctors and women as nurses), the AI might recreate those stereotypes in its images. Discuss with your class whether this represents random error, systematic error, or both in the AI image-generator system.**

   This is an example of systematic error. The data used to train the AI doesn't include representation from all groups of people in society. This affects the products it generates, leading to images that also misrepresent all groups of people. The error is not random because it does not come about from chance but by a consistent bias in the images it is using.

REFERENCES

Elbein, S. (January 18, 2021). Wildfire modeling: What the complex math of fire modeling tells us about the future of California's forests. *MIT Technology Review*. https://www.technologyreview.com/2021/01/18/1016215/complex-math-fire-modeling-future-california-forests/

Hansen, J., & Schmidt, J. (July 26, 2018). *Timber treatments successfully reduce wildfire risk in Utah*. Fire Adapted Communities Learning Network. https://fireadaptednetwork.org/timber-treatments-and-chip-wattles-reduce-wildfire-risk-in-utah

Jolley, A. (October 25, 2018). *Does wildfire mitigation work? 16 examples and counting!* Fire Adapted Communities Learning Network. https://fireadaptednetwork.org/does-wildfire-mitigation-work-16-examples-and-counting

Morgan, R. (June 17, 2017). *Fire threatens Brian Head; town evacuated, highway closed*. KSL.com. https://www.ksl.com/article/44682869/fire-threatens-brian-head-town-evacuated-highway-closed

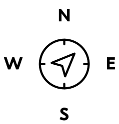
Pinto, R. M., Benali, A., Sá, A. C. L. *et al*. (2016). Probabilistic fire spread forecast as a management tool in an operational setting. *SpringerPlus 5*, 1205. https://doi.org/10.1186/s40064-016-2842-9

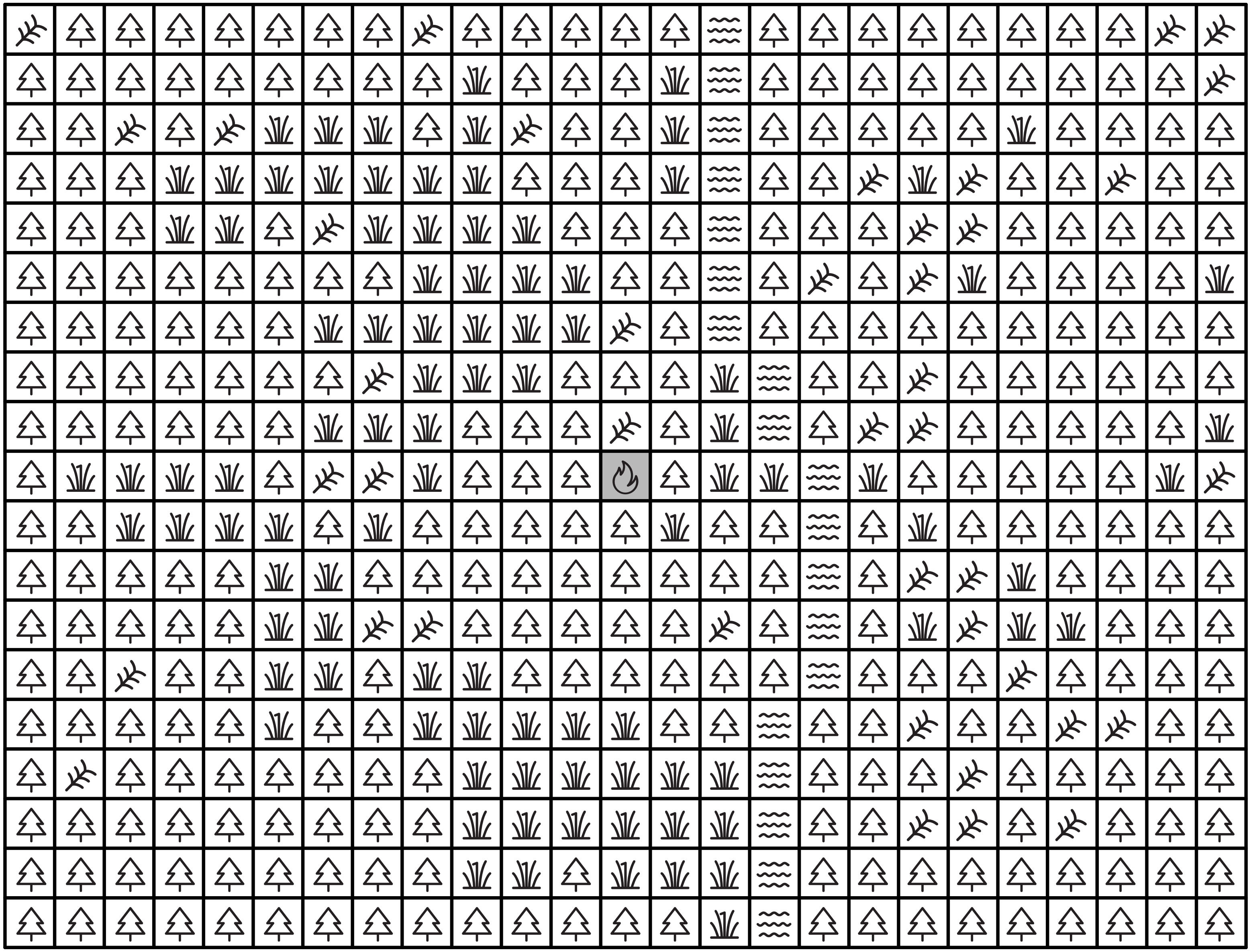
Prell, A. (June 23, 2017).*'Extreme' Brian Head fire destroys 13 homes*. RedZone. https://www.redzone.co/2017/06/23/extreme-brian-head-fire-destroys-13-homes/

USDA and the U.S. Forest Service. (2024). *Wildfire risk to communities*. Wildfirerisk.org https://wildfirerisk.org/

STUDENT SHEET 9.1 | MAP OF KOHEEGEE PARK | NAME

FIRE





KEY

Start of fire

Trees

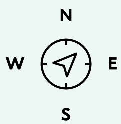
Grasses

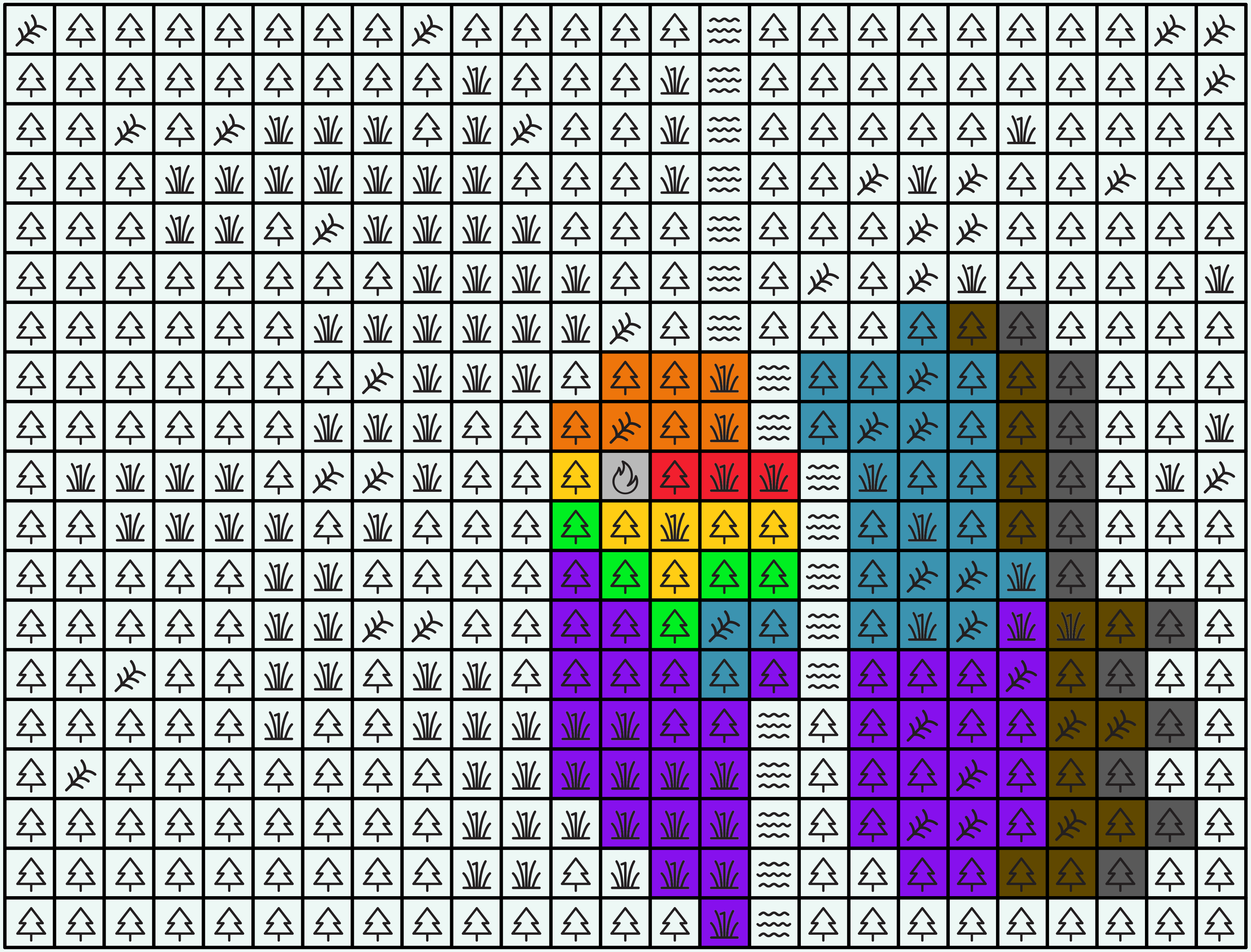
Dry vegetation

River

STUDENT SHEET 9.1 | MAP OF KOHEEGEE PARK | NAME SAMPLE STUDENT RESPONSE

FIRE A





KEY

Start of fire

Trees

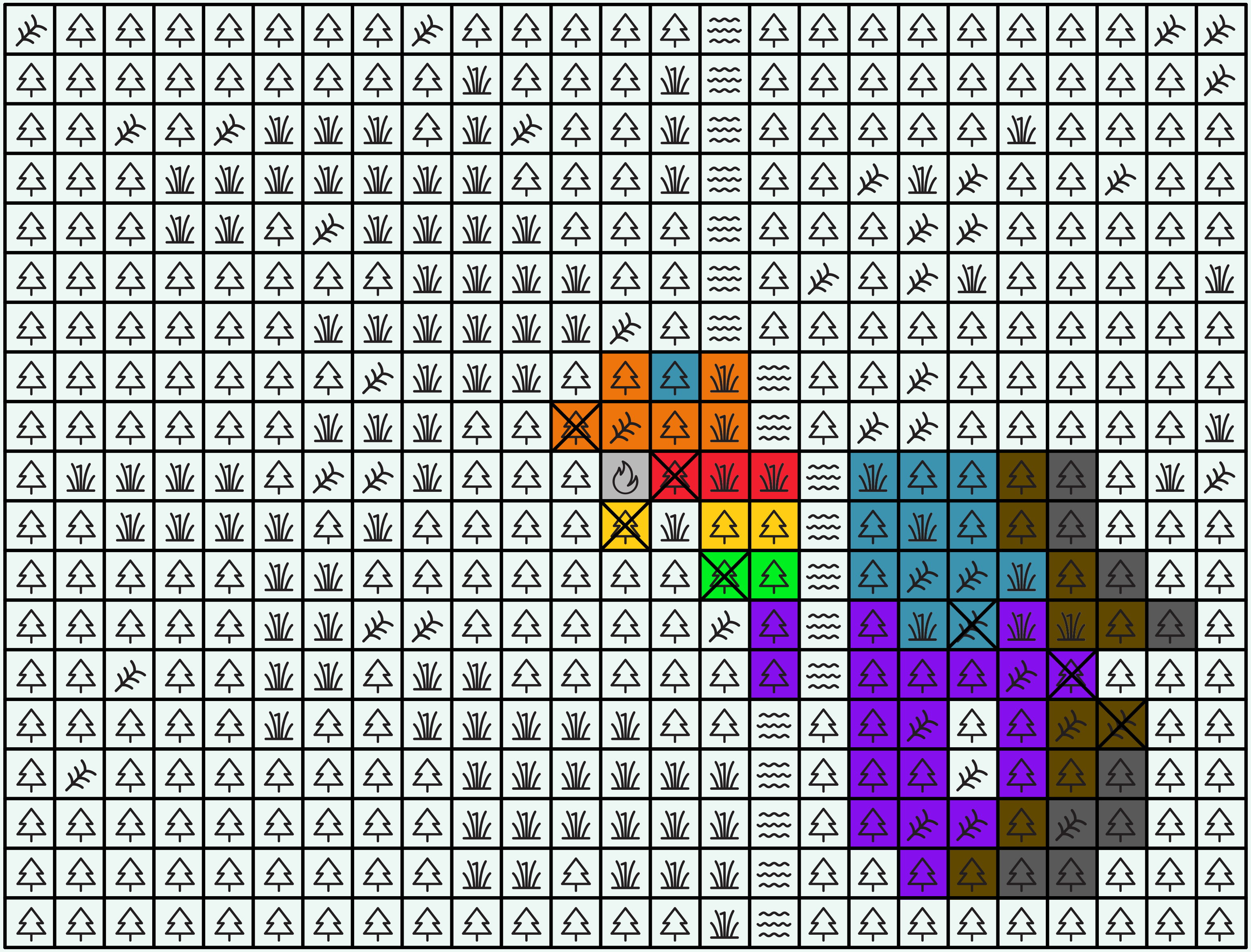
Grasses

Dry vegetation

River

STUDENT SHEET 9.1 | MAP OF KOHEEGEE PARK | NAME SAMPLE STUDENT RESPONSE

FIRE B

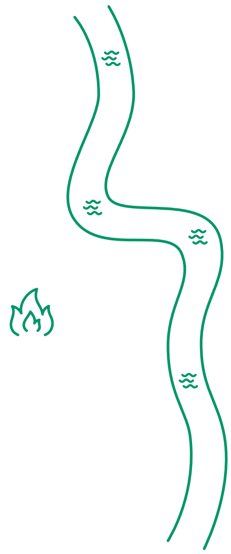


KEY

- Start of fire
- Trees
- Grasses
- Dry vegetation
- River

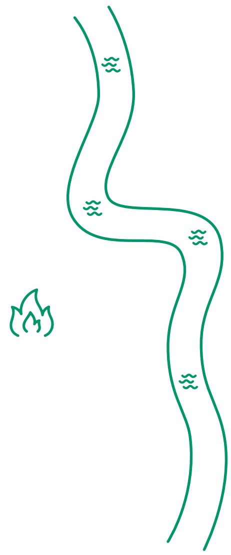
FIRE

Prediction *before* the fire:
Sketch a shape on this miniature map to predict where you think the fire will spread over the next 8 hours.



What factors did you base your prediction on?

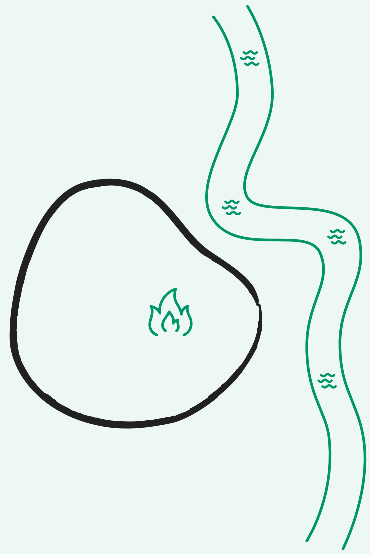
Actual fire spread:
Sketch a shape to represent where the fire spread *after 8 hours.*



What factors affected the outcome the most?

FIRE A

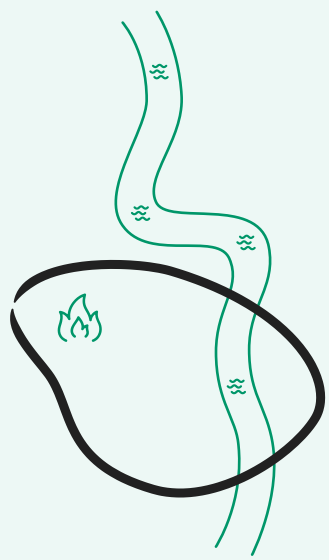
Prediction *before* the fire:
Sketch a shape on this miniature map to predict where you think the fire will spread over the next 8 hours.



What factors did you base your prediction on?

There are a lot of grasses in this area that burn easily.

Actual fire spread:
Sketch a shape to represent where the fire spread *after 8 hours.*



What factors affected the outcome the most?

Wind direction and speed had huge effects, especially when there was a firestorm.

STUDENT SHEET 9.3 | DATA FROM THE WILDFIRE MODEL | NAME

FIRE

HOUR 0: Fire starts	STEP 1: Wind Direction Roll #: Action	STEP 2: Wind Speed Roll #: Action	STEP 3: Fuel sources that cause spread
Hour 1 (red)			
Hour 2 (orange)			
Hour 3 (yellow)			
Hour 4 (green)			
Hour 5 (blue)			
Hour 6 (purple)			
Hour 7 (brown)			
Hour 8 (grey)			

STUDENT SHEET 9.3 | DATA FROM THE WILDFIRE MODEL | NAME *SAMPLE STUDENT RESPONSE*

FIRE *A*

HOUR 0: Fire starts	STEP 1: Wind Direction Roll #: Action	STEP 2: Wind Speed Roll #: Action	STEP 3: Fuel sources that cause spread
Hour 1 (red)	*Rolled 3: moved East*	*Rolled 4: wind 15 mph*	*grasses*
Hour 2 (orange)	*Rolled 1: moved North*	*Rolled 5: wind 15 mph*	*grasses and dry vegetation*
Hour 3 (yellow)	*Rolled 5: moved South*	*Rolled 3: wind 5 mph*	*grasses*
Hour 4 (green)	*Rolled 4: moved South*	*Rolled 2: wind 5 mph*	*trees, no spread*
Hour 5 (blue)	*Rolled 2: moved East*	*Rolled 6: wind 30 mph Firestorm!*	*grasses and dry vegetation*
Hour 6 (purple)	*Rolled 4: moved South*	*Rolled 6: wind 30 mph Firestorm!*	*grasses and dry vegetation*
Hour 7 (brown)	*Rolled 2: moved East*	*Rolled 1: wind 5 mph*	*grasses and dry vegetation*
Hour 8 (grey)	*Rolled 2: moved East*	*Rolled 1: wind 5 mph*	*trees, no spread*

ACTIVITY 10

Applying Probabilistic Reasoning

CARD-BASED INVESTIGATION

ACTIVITY 10

Applying Probabilistic Reasoning

ACTIVITY SUMMARY

Using a fictional scenario, students investigate different risk factors related to wildfire ignitions from electric power lines. Students analyze various data and use probabilistic reasoning to recommend where and when a power shutoff is necessary.

ACTIVITY TYPE
CARD-BASED INVESTIGATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 When there is scientific uncertainty in data, probabilistic reasoning is a method for determining the likelihood of different outcomes on which to base a decision.

2 Uncertainty in data is often a result of errors. Scientific errors can be random or systematic and can lead to conclusions that are less likely to be correct.

3 Confidence intervals, confidence levels, and error bars describe the uncertainty of data and the probability that data are accurate.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (*Science and Engineering Practice; Analyzing and Interpreting Data*)

CONCEPTUAL TOOLS

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 10.1 "Scoring Guide, Analyzing and Interpreting Data (AID)"
- ITEM-SPECIFIC SCORING GUIDE: Activity 10, Build Understanding Item 2

FOR EACH GROUP OF FOUR STUDENTS

- CALCULATOR
- SET OF FIRE RISK CARDS (4 CARDS)

FOR EACH STUDENT

- STUDENT SHEET 10.1 "Determining Fire Risk"
- STUDENT SHEET 10.2 "Writing Frame: Evidence and Trade-Offs (E&T)" (OPTIONAL)
- SCORING GUIDE: Analyzing and Interpreting Data (AID) (OPTIONAL)

Prepare a set of four location signs (A, B, C, D) for the Walking Debate.

TEACHING NOTES

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

Strategies for the **equitable inclusion of diverse students** are highlighted in mint.

GETTING STARTED (5 MIN)

1 **Introduce the concept of power shutoffs as an approach to reducing wildfire risk.**

- Read the Introduction, either as a class or individually. It revisits the idea of probabilistic models as a tool for managing the risk of wildfires. Let students know that they will act as advisors to a power company about where and when a power shutoff is necessary. Some topics in this unit may require particular care and sensitivity, depending on student's individual experiences. For example, you may have students who have experienced trauma or loss due to a wildfire.
- Depending on your location, students may have experienced power shutoffs due to wildfire risk. Have students who are willing, share their experiences. If you are not located in a region that has power shutoffs due to wildfire risk, you might ask students to think of a time when their power went out, maybe due to a bad storm, and share what that was like and what was difficult about being without power.

PROCEDURE SUPPORT (45 MIN)

2 **Present the fictional article found in Procedure Step 1.**

- Throughout the unit, students have been presented with fictional articles based on real-world events. The article presented in Procedure 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.

3 **Students examine the map in order to make initial predictions about wildfire risk.**

- Hand out Student Sheet 10.1, "Determining Fire Risk," to each student. Initially, students will not have a complete set of data; instead, they will complete the table over the course of the activity by looking at the map and several Fire Risk cards. However, they will stop in Procedure Steps 3 and 9 to reflect on which locations have the highest fire risk based on the information they have gathered.
- In Procedure Step 2, students complete the first three rows of the table on the student sheet, using the map in Procedure Step 1 as a reference, before making a preliminary assessment of wildfire risk. You may want to remind students that the symbols use in Figure 10.1 are the same as those in the previous activity and that they represent trees and grasses. Students can answer Procedure Step 3 in their science notebooks.

Sample Student Response, Procedure Step 3

a Record your prediction in your science notebook and explain your reasoning.

At this point, I predict that Location D has the highest fire risk because it has a lot of grasses, and the power line runs through there. From my experience in the lab and with the model, this type of vegetation burns very easily.

b Determine how sure you are of your decision, using a scale of 0–100% where:

0% = there is no chance your prediction will be correct

50% = your prediction is just as likely to be wrong as it is to be correct

100% = you are absolutely sure that your prediction will be correct

I'm only about 60% sure because I don't really know much else about the locations yet, like their weather or wind patterns.

4 **Support students as they analyze the Fire Risk cards.**

Hand out a set of 4 Fire Risk cards to each group of 4. Circulate and assist groups as they examine data on each new Fire Risk card and record information on Student Sheet 10.1. Remind students to think about how each new piece of data might affect the risk for wildfire at each location. Specific support for each Fire Risk card is as follows:

Fire Risk 1: Vegetation Dryness by Location

Students examine information about dryness of vegetation at each location. Remind students to think back to their experiences in Activity 8 (burning various types of fuels) and Activity 9 (making predictions, using the Wildfire Model) to apply what they learned about different types of vegetation fuels when thinking about the wildfire risk for each location.

Fire Risk 2: Past Fire Data by Location

Students examine historical data about the frequency of fires in the region over the last 50 years. They are asked to calculate the percentage likelihood of a significant fire in any given year in each location based on the historical frequency of wildfires greater than 41 hectares (100 acres) in the last

50 years. They should divide the number of historical wildfires by the length of time they occurred (50 years) and multiply by 100 to get a percentage. Students may require additional support understanding that this calculation gives a likelihood because the average of fires per year doesn't always match the actual number of fires per year. We make a prediction using this number knowing that it probably won't match, but it gives an idea of how likely a fire could be.

Fire Risk 3: 8-Hour Forecasted Maximum Wind Speed in Each Location

Students need to use the information on this card along with Fire Risk Card 4 in order to estimate the size of a potential fire at each location based on the forecasted wind speed.

Fire Risk 4: Wildfire Size Relative to Maximum Wind Speed

Students examine a graph that shows the size of wildfires in the region relative to maximum wind speed. Students were introduced to the concept of error bars in Activity 6, but they may need additional support thinking about how the error bars in the graph could affect their conclusions about the data. Point out to students that the graph is unusual in that the *x*-axis provides data in both hectares and acres; this is because the scientific study was completed in acres (e.g., 0–100 acres) and has been converted to the metric unit of hectares.

Sample Student Response, Procedure Step 7

Examine the graph on Fire Risk 4: Wildfire Size Relative to Maximum Wind Speed and describe:

- any patterns you see in the graph.

  The graph shows that at higher maximum wind speeds, larger fires result.

- what conclusions you can make about the relationship between maximum wind speed and fire size.

  When it is windy, the wind contributes to spreading the fire, causing larger fires.

- what role the size of error bars plays in your conclusions about the data.

  The error bars are smaller for smaller-sized fires and larger for the larger fires. This makes me less sure about my conclusions about the larger-sized fires resulting at specific higher wind speeds.

Sample Student Response, Procedure Step 9

Based on all the data in Table 1 on your student sheet so far, revise your prediction about which location(s) has the highest risk for wildfire in the next 8 hours.

a Record your revised prediction in your science notebook and explain your reasoning.

I think that Location A is at highest risk for wildfire because it has the highest wind, is near a large park with mixed vegetation, is extremely dry, and the power lines run near one side of the park. If a fire ignited there, it could easily spread to the town.

b Determine how sure you are of your decision and compare how it has changed as you gathered more data. Use a scale of 0–100% where:

0% = there is no chance your prediction will be correct

50% = your prediction is just as likely to be wrong as it is to be correct

100% = you are absolutely sure that your prediction will be correct

I am about 85% sure in my prediction because Location A does not have the highest likelihood based on past fires. Also, I don't know the direction of the winds at that location, and I know from past activities that wind direction is an important factor.

c Share your revised prediction and reasoning with the rest of your group.

Student responses will vary.

d Work with your group to describe at least two sources of scientific uncertainty, including systematic errors or random errors, that could have affected the data or your predictions.

One source of uncertainty could be systematic error from the wind measurements used to make the forecast for each location. I'd want to check the instruments to make sure they were calibrated correctly. Readings that are lower than normal could result in underestimating the risk from the wind at each location.

Another source of uncertainty could be random error related to calculating the likelihood of a fire, using past data. There were not very many fires at each location over the past 50 years, so the calculation of the likelihood of having a fire in any given year might not be very accurate. It might be helpful to look at the data over more than 50 years so we could be more sure of the fire frequencies at each location.

5 Students consider the trade-offs of a power shutoff to each location in order to make a recommendation about where to shut off the power.

In Procedure Step 10, students consider additional factors beyond wildfire risk in making their recommendations. They consider the energy load of the power lines, the population size, and a vulnerability index described in Table 10.1 in the Student Book. Since these factors extend beyond the science but are part of decision-making, students will discuss their recommendations with their groups in Procedure Step 11. Students will then participate in a Walking Debate and respond to Build Understanding item 1 about evidence and trade-offs. A summary of the potential trade-offs at each location is included in the sample student response for Student Sheet 10.1 at the end of this activity.

6 Facilitate a discussion by using a Walking Debate in Procedure Step 12.

- Use the literacy strategy of a Walking Debate to encourage students to discuss their final recommendations for a power shutoff. See Appendix 1: Literacy Strategies at the end of the Teacher's Edition for more guidance and information on using the Walking Debate with your students.

- Post the four location signs (A, B, C, D) in four distinct areas of the room. Have students stand near the sign that represents their recommended location for a power shutoff. (If students have more than one recommended location, have them pick the one they think is most at risk.) If most students already agree on a particular location, you may want to assign some of them to the other locations to foster the skills of debate and evidence analysis.
- Within the groups that formed, have students discuss the reasons for their choices and have them appoint a spokesperson to report to the class. The spokesperson for each group will explain the reasons that members of the group chose that location.
- Once each group has presented its rationales, allow students to change their minds and move to another location.

SYNTHESIS OF IDEAS (20 MIN)

7 **Students make a final recommendation.**

- Build Understanding item 1 has students making their final recommendations for which location would be best for shutting off the power during an 8-hour period to reduce wildfire risk. Students support their recommendations with evidence and identify the trade-offs of their decisions.
- For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 10.2, “Writing Frame: Evidence and Trade-Offs” to compose their responses. Students could also use Student Sheet 10.2 only as a reference or as a checklist as they write their responses. A sample student response for this student sheet is shown at the end of this activity. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.

8 **Assess student growth, using Scoring Guide: Analyzing and Interpreting Data (AID) for Build Understanding item 2.**

- Remind students of the Analyzing and Interpreting Data (AID) Scoring Guide. You may wish to project Visual Aid 10.1, “Scoring Guide: Analyzing and Interpreting Data (AID),” for your students to review each level and clarify your expectations.
- Do not share the item-specific version of the Scoring Guide (Item-Specific Scoring Guide: Activity 10, Build Understanding Item 2) with students as it provides specific information on how to respond to the question prompt.
- Remind students that you expect to see them demonstrate growth in their analysis and interpretation of data, and they may want to review their responses to the assessment in Activity 7 (Connections to Everyday Life item 5) and/or Activity 3 (Build Understanding item 2). Sample responses for Levels 1–4 are provided in the Build Understanding section that follows. Review these responses

to get an idea of what is expected for each level alongside the Item-Specific Scoring Guide. See Appendix 2: Assessment Resource at the end of the Teacher's Guide for more guidance and information on using the Scoring Guides and assessment system with your students.

- Depending on your students, you may want to have them provide feedback on one another's work for revision prior to turning in their work to you for scoring. Alternatively, consider having students turn in a rough draft to you for feedback and revision.
- To conclude the activity, evaluate whether your students are able to answer the Guiding Question, *How can you use probabilistic reasoning to reduce risk?* Use this as a chance to revisit and summarize the key concepts and process skills of the activity.

9 Revisit the Unit Driving Question, *How do you address scientific uncertainty when investigating claims about air quality?*

- Over the course of the unit, students have been introduced to the complexity of modern air quality issues that can have important effects on human health and are affected by weather events such as wildfires. Have students share their responses to Connections to Everyday Life item 4.
- Have a class discussion about what students have learned about the sources of scientific uncertainty; methods to reduce scientific uncertainty; and the usefulness of probabilistic reasoning to make conclusions, predictions, and decisions even when you are not certain about something. Addressing scientific uncertainty when investigating claims about air quality involves a combination of rigorous scientific methods and an understanding of the complexities in environmental science. It helps to have accurate measurements, well-designed monitoring networks, and robust error analysis. These approaches are key to reducing uncertainty.

SAMPLE STUDENT RESPONSES

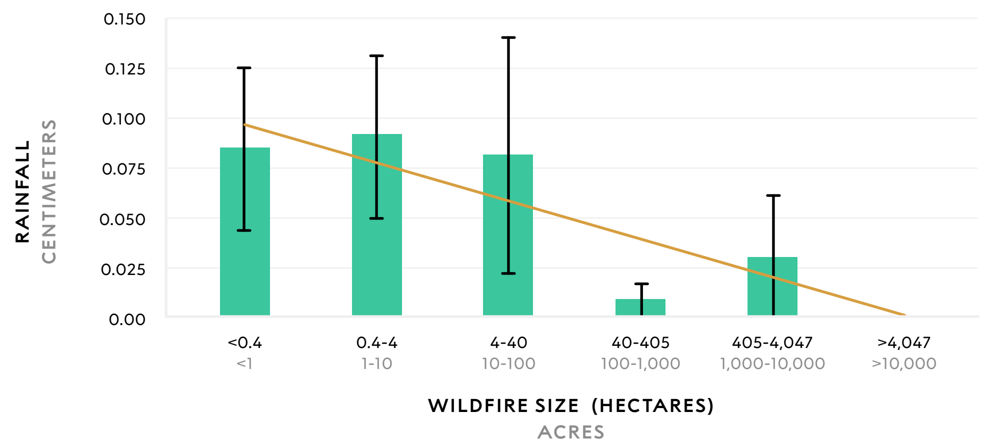
BUILD UNDERSTANDING

1. **With the available data and under current conditions, in which location(s) do you recommend shutting off the power during the next 8 hours to reduce wildfire risk? Support your answer with evidence and identify the trade-offs of your decision.**

   I recommend shutting off the power in Location A. It has forecasted wind gusts of 61 km/hr (36 mph) that could result in a possible fire of greater than 4,047 hectares (> 10,000 acres), which is the biggest in the range. It is an extremely dry area that is next to a large park with mixed vegetation, which would provide a lot of fuel for a wildfire. The trade-off of my decision is that the 4,672 people living in the area have a medium vulnerability index, and some may need power generation for medical needs.

2. **Figure 10.2 shows the average size of wildfires in this region when there are different amounts of rainfall during the wildfire events. Explain what conclusions you can make based on the data in the graph. Be sure to include the following in your explanation:**
   - **Describe what patterns you observe between wildfire size and rainfall.**
   - **Explain what conclusions you can make about the relationship between wildfire size and rainfall.**
   - **Explain at least two possible sources of scientific uncertainty, including scientific errors, that may have affected the data.**

FIGURE 10.2
Regional Wildfire Size During Different Rainfall Amounts



Level 4 response

The data shows that when there is more rain, wildfires are smaller but they do still occur. The larger wildfires occur when there is less rain. The data indicates that wildfires over 41 hectares (100 acres) are less likely when there is any rain, even less than 0.03 centimeters (0.01 inches). This likely means that there is a relationship between wildfire size and rainfall. If rain is falling, even a little bit, the fire will likely be smaller. If more than 0.03 centimeters of rainfall occurs, the fire is more likely to be under 41 hectares. One source of scientific uncertainty affecting the data is that there might be a lot of random error because the error bars are pretty big, which means the data points must have been really spread out. Another source of uncertainty is that I do not know anything else about the area, and there may be other factors that are affecting the wildfire size, like lots of dead trees and shrubs or a pattern of strong winds. However, I do know that wet materials (like trees and leaves) do not burn as easily.

Level 3 response

The data shows that when there is more rain, wildfires are smaller, but they do still occur, and that larger wildfires occur when there is less rain. This probably means that if rain is falling, the wildfires will be smaller. One source of scientific uncertainty affecting the data is that there could be other factors affecting wildfire size in that area, like there being lots of dead trees.

Level 2 response

The data shows that when there is more rain, wildfires are smaller. This is because rain gets everything wet. Something uncertain is that maybe something else happened to make the fires smaller.

Level 1 response

More rain means smaller wildfires because rain puts out fires. Uncertainty happens because maybe something else happened.

3. **The power company decides to install sensors along power lines that would result in an automatic shutoff if a tree branch touches a power line.**

   a. **What would be a false positive in this situation?**

   A false positive would be when an automatic shutoff occurs even though a tree branch didn't touch the power line.

   b. **What would be a false negative in this situation?**

   A false negative would be when an automatic shutoff did not occur even though a tree branch touched the line.

   b. **Which would be a greater concern for community safety: a false positive or a false negative from the shutoff sensor? Explain your reasoning.**

   Even though a false negative might increase the risk of fire, tree branches don't always break a power line every time they touch one. So, I think it would be a bigger concern for the community to have a false positive, which triggers an unnecessary power shutoff. If power shutoffs are triggered for no reason, it would be very disruptive to the community to have their power going out all the time.

CONNECTIONS TO EVERYDAY LIFE

④ **Your friend says that since there is uncertainty in science, no one can really know anything in science. Explain why you agree or disagree with your friend. Support your answer with an example from this unit.**

I disagree because even though there is always going to be some uncertainty in scientific data or conclusions, scientists use methods to reduce uncertainty and consider the limitations of their data before they can make a conclusion. This was shown in Activity 3 when we reduced uncertainty by comparing data from different types of air sensors (PurpleAir and AirNow) before making final conclusions about a region's air quality.

REFERENCES

Reid, A., Fuhlendorf, S., & Weir, J. (2010). Weather variables affecting Oklahoma wildfires. *Rangeland Ecology & Management*. *69*(5), 599–603. https://www.researchgate.net/publication/258627094_Weather_Variables_Affecting_Oklahoma_Wildfires

Taylor, S., Setyawan, G., Cui, B., Zamzam, A., & Roald, L. A. (2023). *Managing wildfire risk and promoting equity through optimal configuration of networked microgrids*. e-Energy '23: Proceedings of the 14th ACM International Conference on Future Energy Systems, pages 189–199. https://dl.acm.org/doi/10.1145/3575813.3595196

Weir, J., Fuhlendorf, S., & Reid, A., (April 2017). *Wildfires in Oklahoma*. Oklahoma State University Extension. https://extension.okstate.edu/fact-sheets/wildfires-in-oklahoma.html

STUDENT SHEET 10.1 | DETERMINING FIRE RISK | NAME

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
Number of Power Lines				
Type and Amount of Vegetation				
Proximity of Power Lines to Vegetation				
Current Dryness Level				
Likelihood of Fire Each Year (%)				
Forecasted Maximum Wind Speed				
Size of Possible Fire Under Forecasted Maximum Wind Speed				
Trade-Offs of Power Shutoff				

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
Number of Power Lines	*3*	*1*	*3*	*1*
Type and Amount of Vegetation	*mix of trees and grasses in large regional park*	*mostly trees and a few grasses in a forested area*	*few trees in an urban area*	*mostly grasses and a few trees in a grassland area*
Proximity of Power Lines to Vegetation	*a power line passes close to the edge of the park and near the town*	*power line is close to one edge of forest and near town*	*power lines are not close to vegetation*	*power line runs through the middle of the brush areas*
Current Dryness Level	*extremely dry*	*moderately dry*	*moderately dry*	*moderately dry*
Likelihood of Fire Each Year (%)	*14%*	*6%*	*2%*	*24%*
Forecasted Maximum Wind Speed	*61 km/hr (38 mph)*	*43 km/hr (27 mph)*	*35 km/hr (22 mph)*	*55 km/hr (34 mph)*
Size of Possible Fire Under Forecasted Maximum Wind Speed	*> 4,047 hectares (> 10,000 acres)*	*41–405 hectares (100–1,000 acres)*	*< 0.4 hectares (< 1 acre)*	*405–4,047 hectares (1,000–10,000 acres)*
Trade-Offs of Power Shutoff	*The people here use the most power and have medium vulnerability. So if they lose power, many of them may be negatively affected by it.*	*People here are the least vulnerable, have a smaller population, and use the least amount of energy. Few may experience negative effects of a power shutoff..*	*A power shutoff here would affect the most people who use a medium amount of power. However, the vulnerability index is low, so they won't have as many negative effects.*	*This area has the smallest population, and they don't use a lot of energy. But they have the highest vulnerability, so many people here may experience negative effects of the shutoff.*

STUDENT SHEET 10.2 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

which power line to shut off to reduce wildfire risk.

My decision is that

I recommend shutting off the power to Location D.

My decision is based on the following evidence:

First,

it has power lines running through an area with lots of grasses and trees that are moderately dry.

Second,

it has a 24% fire risk, the highest of any of the 4 locations.

Third,

the size of a potential fire, given forecasted wind conditions, is large (405–4,047 hectares / 1,000–10,000 acres).

The trade-off(s)

are that the location has a population with the highest vulnerability, so the population here may experience negative effects of the shutoff.

People who disagree with my decision might say that

this location has a small population, so they can easily be relocated for safety.

VISUAL AID 10.1 | SCORING GUIDE: ANALYZING AND INTERPRETING DATA (AID)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.

LEVEL	GENERAL DESCRIPTION
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques and/or reasoning to identify and describe patterns and relationships.
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.
X	The student had no opportunity to respond.

ITEM-SPECIFIC SCORING GUIDE | ACTIVITY 10, BUILD UNDERSTANDING ITEM 2

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

WHAT TO LOOK FOR:

- Response describes patterns and trends in data.
- Response interprets patterns and trends to describe possible causal relationships.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data and interprets them completely and correctly to identify and describe relationships. When appropriate, the student: • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data. • states how study design impacts data interpretation.	The student response: • gives detailed, accurate descriptions of patterns in the data. • thoroughly describes a plausible conclusion from the data. • provides at least two possible sources of scientific uncertainty with a thorough explanation of reasoning, including the limitations of the available data.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 3 **Almost there**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.	The student response: • accurately describes patterns in the data. The student response may have minor errors or limited responses to: • describing a plausible conclusion from the data. • providing a possible source of scientific uncertainty with an explanation of reasoning, including the limitations of the available data.
Level 2 **On the way**	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.	The student response: • describes patterns in the data. The student response may have errors or limited responses/reasoning to: • describing a conclusion from the data. • providing a possible source of scientific uncertainty with an explanation of reasoning and/or data limitations.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 1 **Getting started**	The student attempts to analyze the data BUT does not use appropriate tools, techniques, and/or reasoning to identify and describe patterns and relationships.	The student response: • describes patterns in the data, may be general, or contain errors. The student response may have significant errors or very limited responses/reasoning to: • describing a conclusion from the data. • providing a possible source of scientific uncertainty with an explanation of reasoning and/or data limitations
Level 0 **Missing or off task**	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.	
X	The student had no opportunity to respond.	

FIRE RISK 1

Vegetation Dryness by Location

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
Current Dryness Levels	extremely dry	moderately dry	moderately dry	moderately dry

FIRE RISK 2

Past Fire Data by Location

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
Number of fires > 41 hectares (100 acres) in the last 50 years	7	3	1	12

SCIENTIFIC THINKING FOR ALL: A TOOLKIT UNIT 3: Scientific Uncertainty & Probabilistic Reasoning ACTIVITY 10

FIRE RISK 3

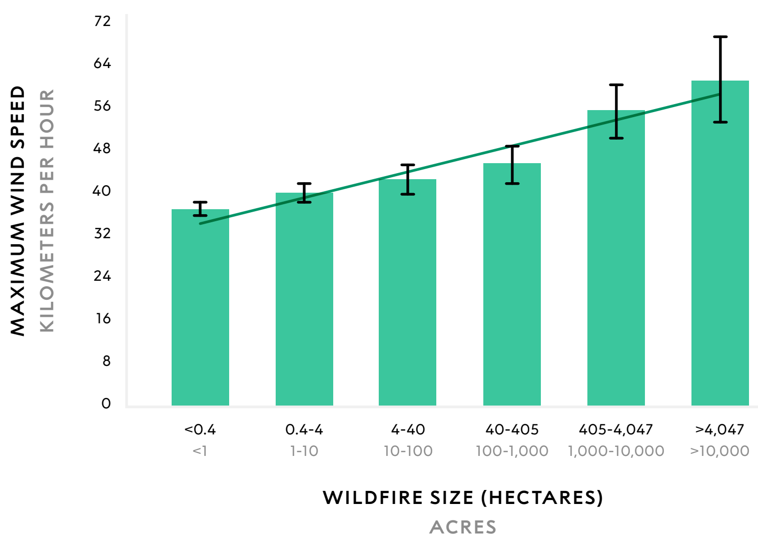
8-Hour Forecasted Maximum Wind Speed in Each Location

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
Forecasted Maximum Wind Speed	61 km/hr (38 mph)	43 km/hr (27 mph)	35 km/hr (22 mph)	55 km/hr (34 mph)

FIRE RISK 4

Wildfire Size Relative to Maximum Wind Speed

Researchers at a nearby university have graphed the size of wildfires in the region relative to maximum wind speed.



APPENDIX 1

LITERACY STRATEGIES

Teaching ***Scientific Thinking for All: A Toolkit*** provides constant opportunities for students to improve their English language skills. For example, students are expected to read informational text and procedures, write clearly to respond to assessment items, and use oral language skills during discussions. Research-based support strategies are embedded throughout the activities to help students process new content, develop analytical skills, connect concepts, become more proficient readers, and express their knowledge.

The literacy strategies offered in the curriculum depend on the instructional needs of the activity in which they are embedded. Because a full explanation of each research-based strategy is not practical to provide in the Teaching Notes of the Teacher Edition, a more detailed description for each goal is described below.

Eliciting Prior Knowledge

Anticipation Guide
Concept Map

Processing Information

Frayer Model
Venn Diagram
Word Sort

Reading Comprehension

Directed Activity Related to Text (DART)
Read, Think, and Take Note
Word Wall

Oral Discussion and Debate

Developing Communication Skills
Walking Debate

Writing Support

Science Notebook
Writing Frame

ANTICIPATION GUIDE

What It Is

An Anticipation Guide is a pre-reading exercise to help students activate their background knowledge about a topic and generate curiosity about the material they will learn. Students answer a set of prompts before reading; after reading, students discuss how their predictions compare with the information in the reading.

Why Use It?

The value of an Anticipation Guide is in the discussion that occurs before and after the reading. Before reading, students discuss their predictions and the reasons for them. During this discussion, the teacher gleans information about the depth of students' existing knowledge and their misconceptions about a topic. The post-reading discussion on how students' answers have changed allows teachers to formatively assess what students gained from the reading.

How To Use It

Students begin by individually responding to a series of statements related to the text they will read. They state whether they agree or disagree with a statement by marking it with a + (agree) or a – (disagree). The statements give students a sense of the key ideas in the reading and elicit their current ideas about and knowledge of the material. Students then discuss their predictions as a class. After completing the reading and participating in another discussion, students revisit the statements and record whether they now agree or disagree with each one. Their final task is to cite information from the reading to explain how the text either supported or changed their initial ideas.

Where It Is

The Anticipation Guide Student Sheet can be found in the Teacher Edition for the activities in which it is used. Sample student responses are also located in the Teacher Edition.

CONCEPT MAP

What It Is

A concept map is a visual representation of the relationship between ideas and concepts. Concept maps ask students to make and describe relationships between main ideas and subtopics and among the subtopics themselves.

Why Use It?

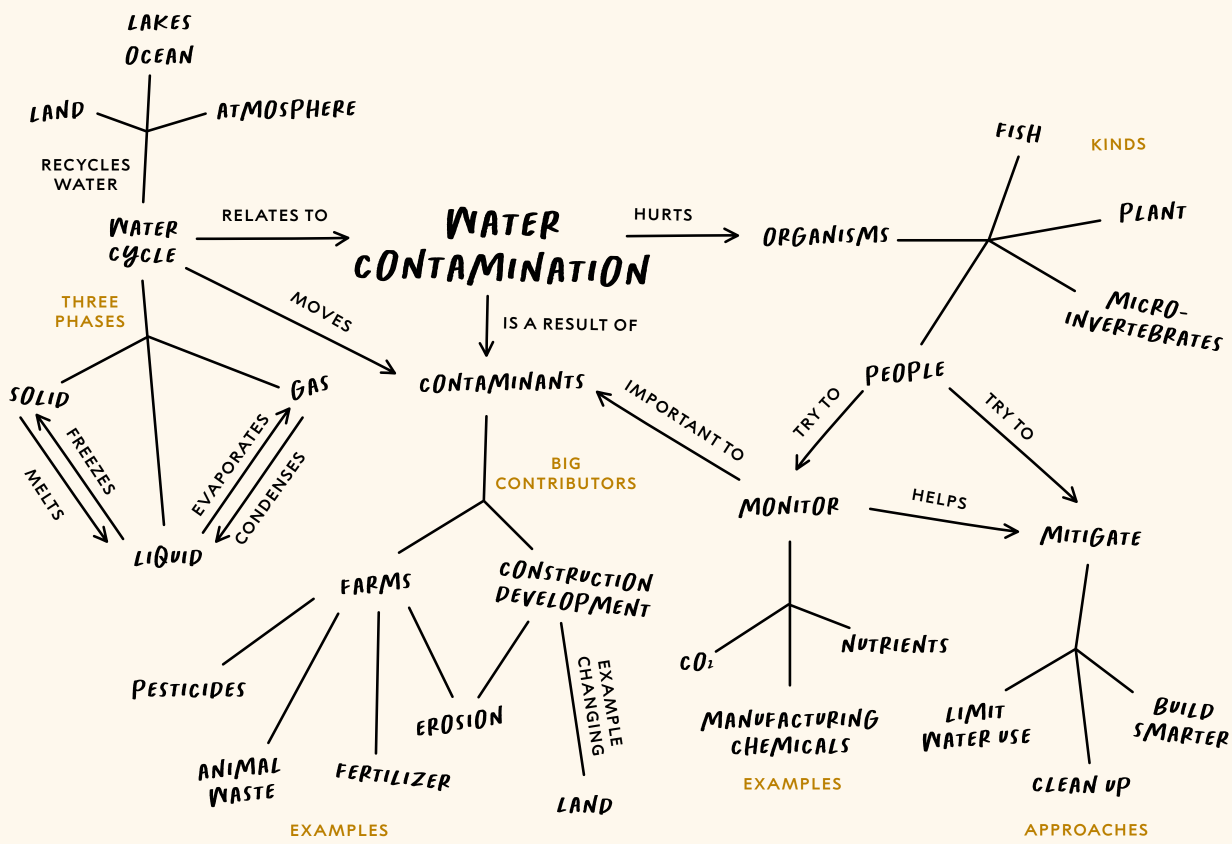
Concept maps demonstrate students' understanding of the connections between topics in a spatial manner. They also allow students to expand their knowledge related to a topic.

How To Use It

The main concept is written in the center of a page (or on the board), and students place subtopics around it, connecting lines between each subtopic and the main concept. On or near each line they've drawn, students add a brief description of the relationship between the two words.

The following example is from a prompt in a unit in which students are asked to draw a concept map about water contamination.

Initially, students may find it helpful to have a list of words that must be included in the map or an incomplete concept map to fill in. Later, students might brainstorm words that should be included and make a list before beginning their concept maps. It may also be helpful to write each subtopic on an index card or sticky note so students can physically manipulate them and lay out the map.



If your students are unfamiliar with concept maps, model the process by using a familiar central idea, such as school. Write "school" on the board and with the class, brainstorm subtopics to place around it (i.e., What are words and ideas associated with school?). Off to the side, organize these subtopics in a hierarchy, listing the more general ideas first and the more specific ones toward the bottom. Arrange the ideas spatially on the map, with the more general ideas closer to the central topic and the more specific ideas radiating out from the general ideas. Link the general ideas to the central concept with specific ideas, words, or short sentences defining the connection between the concepts. Then add links explaining the connection between the general and more specific ideas.

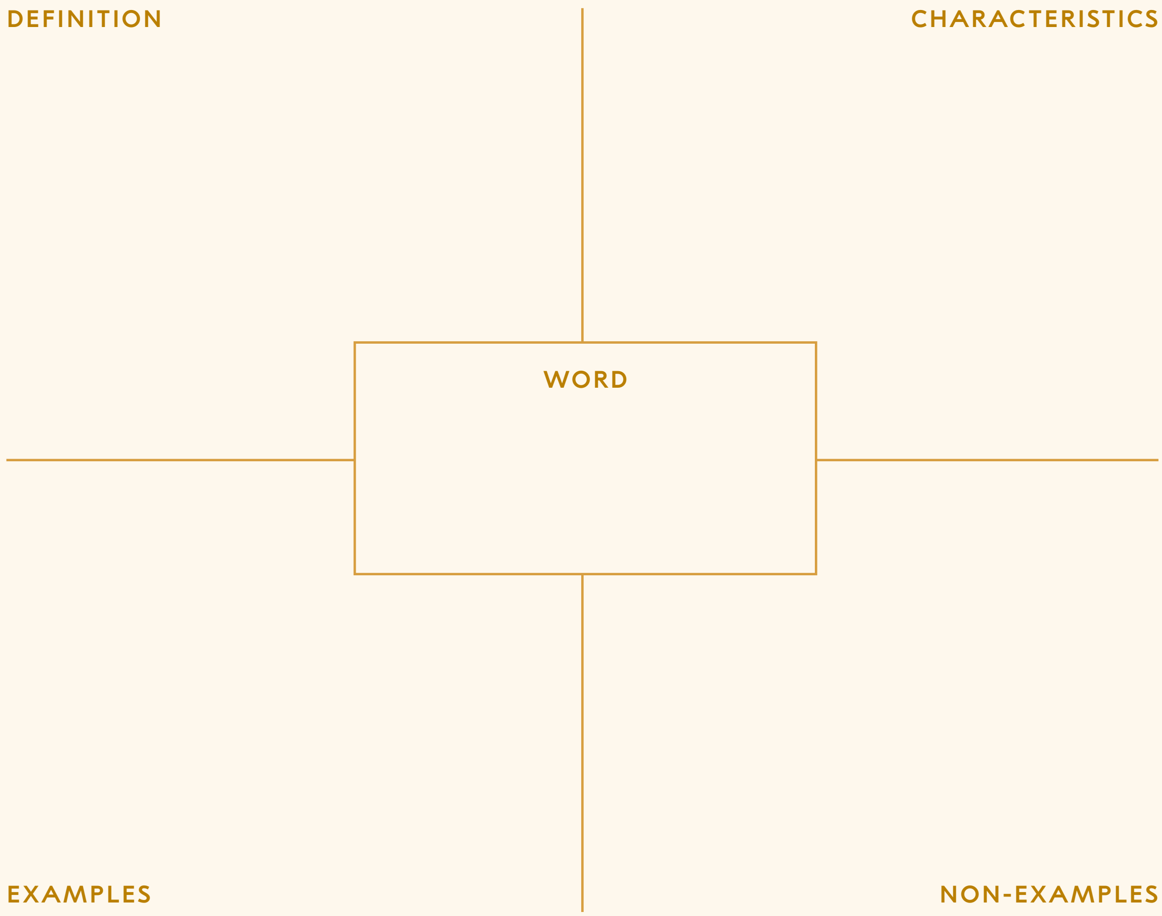
Where It Is

Concept maps are most often part of the Teaching Notes in the Teacher Edition; they may also be Build Understanding items in the Student Book. Instructions for constructing a concept map can be found in the Teacher Edition.

FRAYER MODEL

What It Is

The Frayer Model is a graphic organizer used in direct instruction of discipline-specific vocabulary. In a Frayer Model, students define a word and examine its characteristics and then offer examples and non-examples to build a deep conceptual understanding of the word.



Why Use It?

The Frayer Model offers support as students examine the conceptual meaning of discipline-specific vocabulary. The Frayer Model supports the conceptual development of terms and concepts as they are introduced. Students can return to the Frayer Model as they continue to use the word throughout a course of learning to revise the model, based on their deepening understanding of the word.

Where It Is

Frayer Models can be found in the Teaching Steps in the Teacher Edition and as Build Understanding items in the Student Book.

VENN DIAGRAM

What It Is

A Venn diagram is a strategy for comparing the relationship between two ideas or concepts in a simple visual format. Students visually map the characteristics that are unique to a set of ideas or concepts and the characteristics that are shared.

Why Use It?

By placing words on a page in relation to each other and then explaining their placement, students show that they understand the meaning of each word and the relationship between them. A Venn diagram can be used as a focus for a discussion or for a writing assignment that asks students to compare and contrast ideas. It can also be used as a formative assessment that probes students' understanding of a set of concepts. The simplicity and flexibility of setting up a Venn diagram makes it easily adaptable to many classroom situations.

How To Use It

A Venn diagram involves drawing two to four overlapping circles, each labeled according to the subject being compared. In the outer part of each circle, students write the information that is unique to the subject of the circle. In the overlapping spaces, they write the elements common to all subjects. Students may complete Venn diagrams as a class, in groups, or individually

Where It Is

Venn diagrams can be found in the Teaching Steps in the Teacher Edition and as Build Understanding items in the Student Book.

WORD SORT

What It Is

A word sort is a categorization activity that helps students synthesize science concepts and vocabulary. Students classify words and phrases into categories based on the relationship between them.

Why Use It?

Word sorts encourage students to accurately draw on what they've learned and to use logic to determine how different words and phrases are related. Teachers can use students' explanations as a formative assessment of how well they understand the overall concepts.

How To Use It

Students are first asked to look for a relationship among a list of four or five words or phrases related to a topic and to cross out the one word or phrase that does not belong. Next, they are asked to circle or highlight any word or phrase that includes all the other words. (There may be more than one correct answer to a single word sort.) Finally, students must explain how the circled word or phrase is related to all the other words or phrases in the list.

Where It Is

Word sorts can appear in the Teaching Steps in the Teacher Edition or as Build Understanding items in the Student Book.

DIRECTED ACTIVITY RELATED TO TEXT (DART)

What It Is

A Directed Activity Related to Text (DART) supports reading comprehension and critical thinking by having students interact with and manipulate the information they are reading. Examples of DARTs are matching and labeling exercises, sequencing, grouping, predicting, and completing a diagram or table. DARTs that require higher-order processing include extracting information and placing it in tables and flowcharts.

How To Use It

A DART must be prepared before students begin so that it can be tailored to a particular text. Students usually complete the DART after they finish the reading. To help students further engage with the content, they may discuss the DART in groups before completing it or complete it as a group.

Where It Is

DARTs are usually found as Build Understanding items or as Student Sheets in the Teacher Edition for the activity in which they are used.

READ, THINK, AND TAKE NOTE

What It Is

Read, Think, and Take Note is a strategy that helps students externalize their thinking by recording their thoughts, reactions, or questions on sticky notes as they read. The notes serve to make concrete the thoughts arising in students' minds and then serve as prompts to generate conversation or write explanations.

Why Use It?

Asking students to record thoughts on sticky notes as they read helps with literacy development by providing a structure for students to record the thinking process. Students may later return to that record to clarify misconceptions or to add depth to their thoughts. The notes also provide a way for the teacher to see how students think as they read, enabling the teacher to select appropriate supports. For example, a student who is unsure of the meaning of a word benefits from the teacher's suggestion to look up the definition. Or, if a student has noted how a reading reminds them of an event from their own life, the teacher can note how making those connections helps with comprehension.

How To Use It

Teachers can explain to students that as they follow this strategy, they are learning some ways that proficient readers think while reading. After reviewing the Read, Think, and Take Note Guidelines in the Student Book, teachers can then model the strategy, using a section of text from the Student Book. There are many ways to respond to text, and each student will create a unique set of comments. Teachers should emphasize that everyone is learning and has questions and that they should all be respectful of one another's ideas. One option is to conduct small-group discussions or a class discussion during which students can clarify any points of confusion, and the teacher can see how students are interpreting the reading.

Where It Is

The Read, Think, and Take Note Guidelines can be found in the Student Book and the Teacher Edition.

WORD WALL

What It Is

A word wall is a collection of words displayed in a classroom for students to use during reading and other classroom activities.

Why Use It?

Word walls are interactive tools that can help students build vocabulary, support reading, and make connections between ideas. The prominently displayed words provide a visual point of reference when students are reading, writing, and discussing their ideas.

How To Use It

Consider the instructional goals of the activity or unit and select vocabulary terms that are important for the topic. Display the words prominently on a wall, bulletin board, or other surface. The words should be visible at all times during class and can be organized alphabetically or grouped, based on the topic.

Where It Is

Suggestions for when to use or add terms to a word wall can be found in the Teacher Edition for the activities in which it is used.

DEVELOPING COMMUNICATION SKILLS

What It Is

The Developing Communication Skills Visual Aid is a tool to help students effectively participate in class discussions. It promotes positive classroom discourse by suggesting how students might appropriately express disagreement, seek clarification, or build on one another's ideas.

How To Use It

Suggestions are presented in the form of sentence starters that students can use to initiate a conversation and express their ideas. Teachers can gradually incorporate this strategy into group work by introducing one sentence starter at a time to elicit students' ideas.

Where It Is

The Developing Communication Skills Visual Aid can be found in the Teacher Edition for the activities in which it is used.

DEVELOPING COMMUNICATION SKILLS

COMMUNICATION	SENTENCE STARTERS
to better understand	One point that was not clear to me was . . . Are you saying that . . . ? Can you please clarify . . . ?
to share an idea	Another idea is to . . . What if we tried . . . ? I have an idea—we could try . . .
to disagree	I see your point, but what about . . . ? Another way of looking at it is . . . I'm still not convinced that . . .
to challenge	How did you reach the conclusion that . . . ? Why do you think that . . . ? How does it explain . . . ?
to look for feedback	What would help me improve is . . . Does it make sense, what I said about . . . ?
to provide positive feedback	One strength of your idea is . . . Your idea is good because . . .
to provide constructive feedback	The argument would be stronger if . . . Another way to do it would be . . . What if you said it like this . . . ?
to discuss information presented in text and graphics	I'm not sure I completely understand this, but I think it may mean . . . I know something about this from . . . A question I have about this is . . . If we look at the graphic, it shows . . .

WALKING DEBATE

What It Is

A Walking Debate allows students to practice oral argumentation. The teacher designates specific locations around the classroom that represent differing perspectives on an issue. Students stand in the location that best represents their opinion regarding the issue. In turns, students argue for the merits of their perspectives and support their arguments with evidence. As they hear others' arguments and evidence, students can opt to change their opinions and physically move to the area of the room that best represents what they now believe.

Why Use It?

Walking Debates require students to physically engage in oral discourse in the classroom. By committing to a position, both literally and figuratively, Walking Debates support oral discourse that uses claims, evidence, and reasoning. Students' engagement in scientific argumentation is motivated by seeing the distribution of perspectives among their classmates. Research also suggests that the inclusion of movement in the activity provides sensory input to the brain that enhances learning.

How To Use It

Begin by identifying the question or issue to be debated and designate different parts of the classroom as representing certain points of view. For example, for the question *Which vehicle do you think is safer, Vehicle 1 or Vehicle 2?*, one corner of the room could be designated as Vehicle 1 and a different corner designated as Vehicle 2.

Students walk to the corner that best represents their point of view and then talk within that group to come up with a convincing argument to bring people from the other area(s) to their own area. It is helpful to have students keep a record of the evidence they will consider for the Walking Debate, especially when they are new to the strategy. Teachers might also have students work in pairs to generate the evidence.

Each group makes its presentation, and students from the other group(s) may ask questions. When all groups have presented, students who change their minds move to the area that represents their final position.

Where It Is

Walking Debates are usually identified in the Procedure steps in the Student Book. The corresponding Teacher Edition provides instructions on how to run the specific debate.

SCIENCE NOTEBOOK

What It Is

The science notebook is an informal place for students to record their ideas and develop new constructs that aid in their sensemaking. In their notebooks, students bring together their ideas as they make sense of the unit issue and key concepts.

Why Use It?

A science notebook allows students to authentically engage in the practices of science. It supports students' efforts to process ideas, ask questions, keep track of data during investigations, and build their scientific-observation skills and writing skills. Students can also use the science notebook to keep complete records of their data and investigations.

How To Use It

When introducing science notebooks, introduce guidelines for how to keep good records and model how students should record information. Include the purpose, background, hypothesis, experimental design, data, and conclusion for an investigation.

Where It Is

The Student Book regularly prompts students to use their science notebooks, particularly during Procedures.

WRITING FRAME

What It Is

A Writing Frame creates an outline to guide student composition. It can be geared to a particular type of explanatory writing, such as arguments that depend on evidence. Through prompts that students briefly respond to in writing, the Writing Frame leads students to develop headings, sentences, and main content points.

Why Use It?

Writing Frames are an excellent strategy to help students develop and organize their ideas prior to writing extended analysis-item responses or completing a writing assignment. Writing Frames also support assessment of student work.

How To Use It

Teachers first provide direct instruction on the appropriate type of Writing Frame and the components it includes. When introducing the Writing Frame, teachers instruct students on the components essential to the structure of the essay, including an opening sentence that states the decision or conclusion each student has come to, evidence that supports the decision or conclusion, and a discussion of the trade-offs associated with their conclusion.

Where It Is

The Writing Frame Student Sheet can be found in the Teacher Edition for the activities in which it is used. Sample student responses are also located in the Teacher Edition.

APPENDIX 2

ASSESSMENT RESOURCE

The assessments provided in ***Scientific Thinking for All: A Toolkit*** are designed to be used as formative and summative assessment of students' progress. Assessments support classroom instruction while ensuring that students are provided with adequate opportunities to demonstrate their developing understanding of the content and receive feedback to further this learning process. Teachers can use this research-based approach for interpreting students' work to monitor and facilitate their progress. The assessment approach for the course shifts the assessment of knowledge from **what students know to how they are able to apply what they know**. As such, students engage in the key concepts and process skills of the course as they analyze evidence and make decisions related to everyday issues.

Assessment tasks are embedded in the curriculum and are an integral part of the learning activities. Teachers can use these assessments to inform future instruction, with the aim of helping to enhance students' learning. This is done through the use of purposefully designed assessment variables, assessment items, and Scoring Guides, as shown in the following diagram and description of each component.

ASSESSMENT VARIABLES concepts and practices	ASSESSMENT ITEMS	SCORING GUIDES general and item-specific rubrics
Analyzing and Interpreting Data (AID) Decision-Making (DM) Developing and Using Models (MOD) Engaging in Argument from Evidence (ARG) Evidence & Trade-Offs (E&T)	→ embedded in activities for each variable	→ describe competency levels for each variable

ASSESSMENT VARIABLES

The assessment variables listed in the second column of the following table are the key areas across which students are expected to progress throughout a unit or sequence of units. Each unit focuses on one of these variables as shown here.

UNIT	ASSESSMENT VARIABLE	DESCRIPTION
1 **Evidence & Iteration in Science**	Evidence and Trade-Offs (E&T)	This Scoring Guide is used when students are making a choice or developing an argument about a socioscientific issue where arguments may include judgments based on nonscientific factors.
2 **Scientific Modeling**	Developing and Using Models (MOD)	This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about scientific phenomena.
3 **Scientific Uncertainty and Probabilistic Reasonings**	Analyzing and Interpreting Data (AID)	This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.
4 **Investigating Evidence for Causation**	Analyzing and Interpreting Data (AID)	This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.
5 **Human Bias in Science**	Engaging in Argument from Evidence (ARG)	This Scoring Guide is used when students are developing arguments about alternative explanations of scientific phenomena.
6 **Group Decision-Making**	Decision-Making (DM)	This Scoring Guide is used when students are making a decision by integrating evidence, facts, and values.

Within each unit, the focus should be on progress, and each student's goal should be to improve with each subsequent assessment in a unit. Across the units, the variables build on one another as the curriculum progresses. Over time, the progression of variables supports students' increasing sophistication in using the conceptual thinking tools of the curriculum for decision-making in their everyday lives. For example, in Unit 1, students are assessed on their ability to use evidence to make a decision and identify simple trade-offs based on that decision. By Unit 5, students' understanding of how evidence is used in claims has increased, and they are expected to articulate their decision using more complex claims, evidence, and reasoning.

ASSESSMENT ITEMS

Assessment items are questions, tasks, or prompts related to the assessment variables that are designed to gather evidence about students' progress. Assessment items may take the form of a procedural step, a Build Understanding or Connections to Everyday Life prompt that asks students to communicate about a new idea, analyze data from an experiment, model concepts and relationships, transfer their understanding to a novel context, or make predictions. For example, in Unit 6, students make a recommendation for a fictional community's energy generation system. After their group collectively comes up with a recommendation, each student is assessed on their individual response to a Build Understanding item that prompts students to describe in detail how they used facts and values to make a decision.

SCORING GUIDES

Scientific Thinking for All: A Toolkit Scoring Guides directly correspond with each assessment variable and are used to interpret students' responses. Scoring Guides allow teachers and students to monitor students' growth and encourage their progression from novice to expert on each variable. The general Scoring Guides are formatted as holistic scoring guides. Additionally, all items designated as assessments within the curriculum also have detailed Item-Specific Scoring Guides with criteria specific to each assessment item. These Item-Specific Scoring Guides can be found in the Teacher Edition for the activity in which a summative assessment appears.

Students' responses are categorized into the following scoring levels:

Level 4	**Complete and correct**
Level 3	**Almost there**
Level 2	**On the way**
Level 1	**Getting started**
Level 0	**Missing or off task**

To achieve a particular scoring level, a student's response must fulfill all the requirements of that level. A Level 4 response indicates that the student has mastered the practice or concept. The Teacher Edition includes Level 1–4 student exemplar responses in the Teaching Steps or sample responses for each designated assessment item.

Note that while the Scoring Guides involve assigning numerical values to student work from 0 to 4, these scores are not equivalent to a grading system. Rather, scores on assessment items are indicative of the level of performance demonstrated by the student on a specific task, evaluated through a clearly defined lens. They are meant to reflect levels of performance on individual tasks, whereas a grading system inevitably reflects the goals and desired outcomes of a district, school, and/or teacher.

USING A SCORING GUIDE

Initially, it is not reasonable to expect students to perform at Levels 3 and 4. The targets for a scoring level may vary over the course of a unit and a school year. Likewise, it is not always useful to use students' work to set the standards for each scoring level. For example, the best student response should not automatically be given a score of 4. The important thing is that both teacher and student understand what each various scoring level represents and that it can identify growth over multiple uses of the Scoring Guide. For most students, achieving consistent improvement of one level or more in an assessment variable over the course of a unit is an indicator of academic progress.

Before using a Scoring Guide, teachers must make sure that the criteria for each scoring level are clear to themselves and their students and that everyone understands the distinctions between levels. While the Item-Specific Scoring Guide is provided only for teacher use, as it can reveal an appropriate response, students should be provided the general Scoring Guide in advance of an assessment item. They should be encouraged to refer to the Scoring Guide as they develop their responses. This helps them develop the ability to evaluate their own work and take on more ownership of their learning.

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38 Centers for Disease Control and Prevention, 2024;

39 State of Washington, 2018;

50 National Interagency Coordination Center, 2024;

93 United States Environmental Protection Agency, 2023;

106 Joan Casey et al./Proceedings of the National Academy of Sciences of the United States of America, 2024;

131 The Regents of the University of California, 2025;

140 Celeste McFarlane et al./ Aerosol and Air Quality Research, 2021;

143 Centers for Disease Control and Prevention, 2023;

169 Marshall Burke et al./Nature, 2023;

206 John R. Weir, Sam D. Fuhlendorf, Angela M. Reid/ Oklahoma State University, 2017;

219 John R. Weir, Sam D. Fuhlendorf, Angela M. Reid/ Oklahoma State University, 2017;