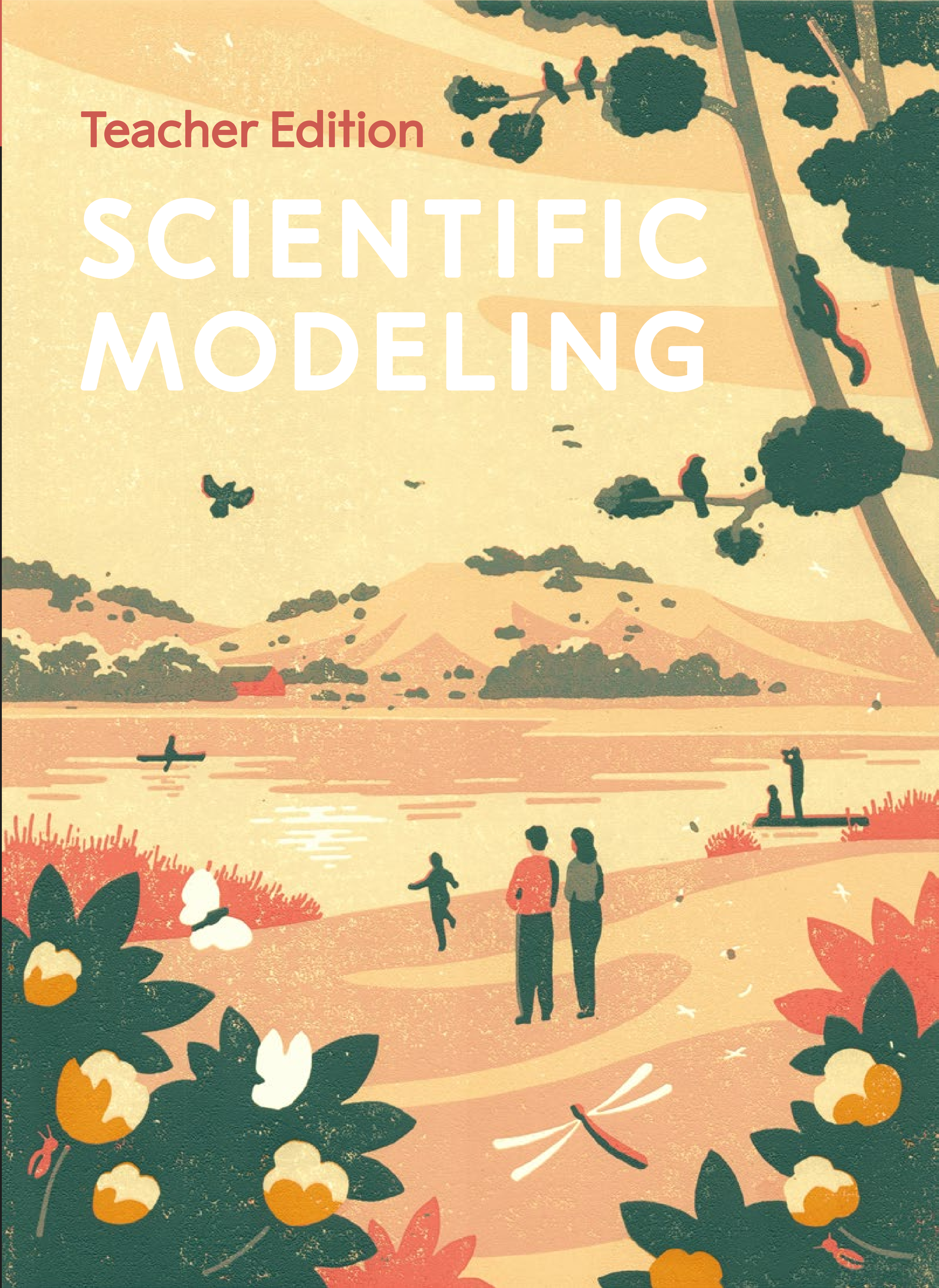
UNIT 2

v 1.0

SCIENTIFIC THINKING FOR ALL : A TOOLKIT

Teacher Edition

SCIENTIFIC MODELING



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.

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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?

UNIT 2: SCIENTIFIC MODELING

TABLE OF CONTENTS

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SCIENTIFIC MODELING

UNIT SUMMARY

INTRODUCTION

In this unit, students use, compare, and develop **scientific models** to investigate scientific questions, such as where a species is likely to be found in the future. They explore how data on ecological change is gathered and how scientists use different methods of population estimation, such as **Fermi estimates**, to simplify complex problems and guide research. They apply their new skills in deciding on a scientific question, constructing a model, and determining the most important factors to include in a model (known as **orders of understanding**). Throughout the unit, students apply these conceptual tools to local and global ecological issues.

UNIT DRIVING QUESTION

How can scientific models be used to investigate changes in the distribution of species?

PRIMARY CONCEPTUAL TOOL

Scientific Modeling

UNIT 2

SCIENTIFIC MODELING

KEY CONCEPTS & PROCESS SKILLS

SCIENTIFIC MODELING

- Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.
- Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.
- Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.
- Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.

ORDERS OF UNDERSTANDING

When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*

FERMI ESTIMATIONS

One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a Fermi estimate—can be used to approximate unknown quantities that are difficult to measure.

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.

	ACTIVITY									
KEY CONCEPTS & PROCESS SKILLS	1	2	3	4	5	6	7	8	9	10
Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.	●	●	●	●	●	●			●	●
Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.		●		●	●	●			●	●
Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.			●		●				●	●
Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.			●		●			●	●	
When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*.				●	●	●			●	●
One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a Fermi estimate—can be used to approximate unknown quantities that are difficult to measure.							●		●	●

UNIT 2

SCIENTIFIC MODELING

UNIT OVERVIEW

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
1. Using Models CARD-BASED INVESTIGATION Students examine two scientific models that inform a decision about which of two creeks to daylight (a process of bringing underground creeks back to the surface) to boost a local frog population. Students compare the models to local frog data in order to determine which model is more applicable and use the models to predict the effect of different factors on the local operation. Based on their analysis, students decide which creek to daylight.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How can models be used to inform a decision?**
2. Scientific Models and Scientific Questions DATA ANALYSIS Students examine additional types of models and further explore the role of models in science. They identify how multiple scientific questions can be investigated with a single scientific model and how a single question can be investigated with more than one model. Students discuss the role that models play in answering questions and how different types of models are best utilized for addressing different types of questions.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • NGSS Connection: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.	**How are scientific models used to answer scientific questions?**

UNIT OVERVIEW

CONTINUED

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
3. Constructing a Model FIELD TRIP Students draw on prior knowledge to construct a food web model of a local ecosystem. The class takes a field trip to a local nature area to make and record observations. Students revise their models based on their real-world observations. The class uses the models to make predictions about how feeding relationships affect population size. Students revise their models a final time based on additional researched information. The class discusses the role of data, including firsthand observations, to inform scientific models.	• Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated. • Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors. • Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How are firsthand observations used in scientific modeling?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
4. Modeling Factors Affecting a Population COMPUTER SIMULATION Using computer models, students investigate the inclusion of factors in a model based on their relative impact, known as *orders of understanding.* The first model explores the changing distribution of two fictional butterfly species. Students use this model to determine how each of four environmental factors appears to affect each species. A second model provides a clearer picture of the orders of understanding of factors on each species. Students make predictions about the likely future population size and distribution. They then apply their findings to make a decision about possible actions to address the changing butterfly populations.	• When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*. • Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • NGSS Connection: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.	**What factors should be included in a scientific model?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
5. The Role of Models in Science READING A reading summarizes important unit concepts about scientific modeling and the role of systems, assumptions, limitations, orders of understanding, and revision in constructing a model. The use of models to study the changing distribution of lobsters off the east coast of Canada and the United States provides real-world examples of ecological research. The potential use of conservation strategies in addressing species change is highlighted.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated. • Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors. • When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How do scientific models represent a system?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
6. Modeling Migration GAME Students investigate the similarities and differences between deterministic models and probabilistic models. They begin by constructing a simple deterministic model by graphing the population of a school of bluefin tuna during migration. Students explore a probabilistic model of the same migrating species as they play a board game. The class combines their probabilistic data and compares the outcome with the deterministic model. Students compare the two models while investigating each model's factors and their orders of understanding.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How can models include uncertainty?**

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
7. Fermi Estimations DATA ANALYSIS Students are introduced to Fermi estimates and powers of 10 as approaches to mathematical modeling. They begin as a class to estimate the number of trees lost in Arizona's 2020 Bighorn Fire. They discuss the available information and the assumptions that can be made and use this information to make an informed estimate. Students discuss the likely accuracy of their estimate based on the powers of 10 and discuss how refining their assumptions could affect their estimate. They then make their own Fermi estimates of the population size of house sparrows in their local community and compare and evaluate the powers of 10 of their estimates as a class. Students use the Bighorn Fire estimate to inform a decision about the replanting of trees for ecosystem restoration.	• One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a *Fermi estimate*—can be used to approximate unknown quantities that are difficult to measure. • NGSS Connection: Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.	**How can you use mathematical modeling to make an estimate?**
8. Modeling a Method INVESTIGATION Students explore a model of the method of mark and recapture for estimating population size. They identify the assumptions and limitations of the model and suggest changes to the model based on their analysis. They then conduct their revised models and compare the resulting estimates. Students identify ways in which the model represents or excludes elements of real-world systems.	• Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How can you revise a model for estimating population size?**

UNIT OVERVIEW

CONTINUED

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
9. Constructing Predictive Models PRESENTATION Students brainstorm factors that affect the size of a population. They then develop a scientific question about a local species and its future interactions, population size, or population range within their community. By identifying and selecting factors relevant to their question, they construct models. Students use their models to make Fermi estimates for the present and to predict the future. They then discuss the strengths and limitations of their models.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated. • Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors. • When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*. • One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a *Fermi estimate*—can be used to approximate unknown quantities that are difficult to measure. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**How can a model be used to predict changes to the distribution of a population?**

UNIT OVERVIEW

CONTINUED

ACTIVITY TITLE AND SUMMARY	KEY CONCEPTS & PROCESS SKILLS	GUIDING QUESTION
10. Applying Models to Decisions CARD-BASED INVESTIGATION Students revisit the fictional frog population of Menanda as they construct models of a frog population. Students apply their knowledge of orders of understanding to build their models. They use their models to construct a Fermi estimate and to inform a decision about which local site would best support the future frog population. The class discusses the role of models in decision-making.	• Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. • Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions. • Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated. • When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*. • One approach to mathematical modeling is estimation. Rough estimates based on limited information–known as a *Fermi estimate*–can be used to approximate unknown quantities that are difficult to measure. • NGSS Connection: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	**What role can models play in making a conservation decision?**

ACTIVITY 1

Using Models

CARD-BASED INVESTIGATION

ACTIVITY 1

Using Models

ACTIVITY SUMMARY

Students examine two scientific models that inform a decision about which of two creeks to daylight (a process of bringing underground creeks back to the surface) to boost a local frog population. Students compare the models to local frog data in order to determine which model is more applicable and use the models to predict the effect of different factors on the local operation. Based on their analysis, students decide which creek to daylight.

ACTIVITY TYPE
CARD-BASED INVESTIGATION

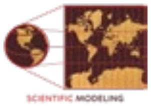
NUMBER OF 40–50 MINUTE CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1. Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

`NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:`
`Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.` (*Science and Engineering Practice: Developing and Using Models*)

CONCEPTUAL TOOLS



VOCABULARY DEVELOPMENT

factor

something that actively contributes to the production of a result. In scientific modeling, a factor is a variable that has an effect on another variable within the model

scientific model

a representation of an idea, object, process, or system

trade-off

a desirable outcome given up to gain another desirable outcome

TEACHER BACKGROUND INFORMATION

Scientific Modeling

Scientists use models to represent and investigate the natural world. Depending on the quality and purpose of the model, models can be used to explain and/or predict natural processes. A predictive model is limited by the accuracy and precision of the data that goes into it, as well as the accuracy with which it represents the relationships of the system under investigation.

There are many types of scientific models including physical models, conceptual models, mathematical models, and computer models. A physical model is a concrete representation of an object where the scale of the model tells how big it is in relation to the real thing. For example, if a model car were at a 1:10 scale, it would be one-tenth the size of an actual car. Not all physical models are smaller than the thing they represent. A scientist might use three foam balls to make a physical model of a carbon dioxide molecule—two balls representing oxygen atoms and one ball representing a carbon atom—in order to illustrate the shape of the molecule. Not all physical models look like the thing they represent. A set of plastic disks might represent the number of organisms in a population.

Scientists also use conceptual models. Conceptual models are often used to describe relationships among different parts of a system and to define patterns governing those relationships. A food web diagram is a conceptual model that describes the way in which populations of organisms in an ecosystem are interrelated through feeding relationships, such as predator and prey. A more complicated model might try to show the flow of biomass through levels of the food web; in that case, the model might consist of a series of mathematical equations resulting in a mathematical model. When trying to model more complex mathematical relationships, scientists might enter the equations into a computer program, creating a computer model. A computer model takes advantage of the computer's ability to do rapid calculations. Computer models can quickly show how a situation might change as time goes by or as conditions change.

Feedback Loops

Feedback loops are essential processes in ecology in which the output of a system circles back to become an input, thus influencing its future behavior. Negative feedback loops are self-regulating and help to maintain equilibrium by counteracting an initial change; a classic example is the predator–prey relationship in which an increase in prey leads to an increase in predators, which then reduces the prey population. Conversely, positive feedback loops amplify or reinforce an initial change, which can drive a system away from its original state, such as in the accelerating melting of Arctic sea ice due to the albedo effect (how much sunlight a surface reflects versus absorbs). Understanding these loops is crucial for predicting how ecosystems will respond to environmental disturbances.

Feedback loops are often shown as a diagram where arrows connect the variables to show the direction of influence. The output of one variable becomes the input for the next, forming a closed circuit or loop. A sign is placed next to each arrow to indicate the type of influence. A positive sign indicates a direct relationship between the two variables. An increase in one variable causes an increase in another, and vice versa. A negative sign indicates an inverse relationship between the two variables. An increase in one variable causes a decrease in another, and vice versa.

Amphibians

Amphibians are the class of vertebrates that includes frogs, toads, salamanders, and newts. Amphibians are ectothermic (cold-blooded) and anamniotic (must lay their eggs in water). Most amphibians have three distinct life stages: an egg stage, an aquatic larval stage that breathes underwater using gills (such as tadpoles), and an adult stage that can breathe both water and air. Their skins are permeable, which makes them particularly vulnerable to waterborne toxins.

In 2023, the second Global Amphibian Assessment found that of all the vertebrate classes, amphibians are the most endangered, with 41% of 8,000 species surveyed meeting the criteria for an endangered species. Declines from 1980 to 2004 were driven primarily by disease and habitat loss. Since 2004, climate-change effects are estimated to be the most serious driver, followed by habitat loss.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 1.1
  “Interpreting Graphs”
  (OPTIONAL)
- VISUAL AID 1.2
  “Understanding Conceptual Tools”
  (OPTIONAL)

FOR EACH GROUP OF FOUR STUDENTS

- SET OF 2 FROG MODEL CARDS
- SET OF 2 FROG DATA CARDS

FOR EACH STUDENT

- STUDENT SHEET 1.1
  “Daylighting Decision”
- STUDENT SHEET 1.2
  “Writing Frame: Evidence and Trade-Offs”
  (OPTIONAL)
- STUDENT SHEET 1.3
  “Unit Concepts and Skills”
  (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Elicit students' prior knowledge about scientific models.**

- This activity introduces scientific modeling, and the focus of the unit will be the use of models to represent systems. Begin by eliciting prior knowledge about scientific models. Ask, What is a scientific model you are familiar with and what does it represent? While there are many possible answers, research indicates that most students tend to describe physical models such as model airplanes that represent real historical airplanes; foam-and-stick models of atoms, such as those that are sometimes built in middle school; a diorama as a model of a scene or place; a map as a model of a geographic area; and/or a globe as a model of Earth. Some students may also suggest computer models and/or mathematical models.

- Students may have personal experience with and prior knowledge of issues related to scientific models. 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.

- If needed, review with the class the formal definition of a *scientific model:* a representation of an idea, object, process, or system. The general purpose of such a model is to represent a real system in a simpler way so that aspects of it can be investigated. A scientific model does not have to look like the object being modeled; it should represent it in some important way.

2 **Review ecological vocabulary and amphibian life cycle as needed (optional).**

- If needed, review basic ecological concepts and vocabulary from Science Review: Populations of Organisms in Ecosystems found at the end of Activity 1 in the Student Book.

- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by reviewing the terms from the Science Review and supporting the construction of a word wall. For this activity, record the terms *organism*, *species*, *habitat*, *ecosystem*, *population*, and *range*. Students are expected to be familiar with these terms based on middle school science standards. Provide additional examples for each term as needed. For more information on a Word Wall, see Appendix 1: Literacy Strategies.

- In this activity, students make a decision affecting a fictional frog species. If needed, review information about frog life history (eggs to tadpoles to adults, which then lay eggs) and simple predator–prey relationships. You may want to explain that because most amphibians breathe through their skin, their skin is not a strong barrier against potential toxins such as pesticides and fungal infections.

3 **Present the fictional scenario from 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.

- Depending on your student population, use oral storytelling to support diverse learners in decoding scientific ideas and constructing meaning. Ask questions about the main points of the scenario to ensure comprehension. Students can refer to the text in the Student Book as needed.

- Review the map included in the scenario as needed. Point out that daylighting a creek will allow the frogs to travel between Chimbly Marsh and one of the other two marshes (Geyser or Umpawa).

- You may wish to research if there is a daylighted creek in your area or (more likely) a paved-over creek. If so, ask students if they are aware of it and point it out to connect the issue in this activity to their local context.

PROCEDURE SUPPORT (25 MIN)

4 **Hand out the Frog Model cards to each group and support students as needed.**

- 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 like 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.

- Students who have difficulty interpreting graphs (such as students with dyscalculia) can be provided with a copy of the graphs and optional Visual Aid 1.1, “Interpreting Graphs” in advance.

- Hand out a set of Frog Model cards to each group and Student Sheets 1.1, “Daylighting Decision,” to each student. (Note: Do not provide the Frog Data cards at this time.) Each pair in a group will analyze one of the two Frog Models cards, using Student Sheet 1.1. Students who are examining Model 1 first will complete Table 1, and students who are examining Model 2 first will complete Table 2. Students complete each table by analyzing their assigned model, comparing data about the two marshes, and then making a recommendation. Sample student responses are located at the end of this activity

- If students have trouble interpreting their model, have each pair share their work with another pair who examined the same model and discuss their ideas.

- Have pairs share their findings with the other half of their group so all group members can complete Tables 1 and 2.

- Group members then discuss whether data from the two models suggested the same creek to daylight. Students should recognize that Model 1 predicts daylighting Geyser Creek will be better because Geyser Marsh has a slightly lower temperature and more insect prey. Model 2 predicts that daylighting Umpawa Creek will be better for the frogs because Umpawa Marsh has lower levels of pesticides and slightly lower rates of Bd fungal infection.

5 Hand out the Frog Data cards and have students update their recommendations.

- Hand out a set of Frog Data cards to each group. These cards provide data on the apparent effect of temperature, insects, and pesticides on the *Anura menanda* frog population.

- In Procedure Step 9, students evaluate which of the four factors (temperature, insect population, pesticides, Bd fungus) appear to have the greatest effect on the frog populations:

  > Table 2 on Student Sheet 1.1 shows that the amount of Bd fungus in each marsh is very similar and so is unlikely to make a difference for this decision. In the real world, evidence is often ambiguous, and more investigations and data may be needed to better determine a relationship.
  >
  > Frog Data 1 shows a declining frog population but a steady population of insects and a steady average temperature. This indicates that some other factor, besides insects and temperature, is the reason for the decline. It does not show how insects and temperature may affect frog population size if these factors were to change.

Frog Data 2 shows an unusual pattern in the decline of the frog population—it is decreasing but irregularly. The periods of sharp frog decline correspond with periods of higher pesticide levels.

The data from the two models and the two data cards indicate that pesticides appear to have the greatest effect on the size of the frog population.

Given this data, students should conclude that Umpawa Marsh is a better habitat than Geyser Marsh because it has a lower pesticide level. It would be better to daylight Umpawa Creek so that frogs can travel between Chimbly Marsh and Umpawa Marsh.

SYNTHESIS OF IDEAS (15 MIN)

6 Introduce the idea that models can explain, predict, raise new questions, and be revised.

- Ask, Can you brainstorm the features of a model useful for making decisions, in light of the model-based decision you just made? A useful model:
  - is clear and comprehensible.
  - includes factors that relate to the question being investigated.
  - offers relevant explanations.
  - is testable.
  - produces accurate predictions.

  The models that students use in this activity address some, though not all, of these features.

- Point out that the models do not make numeric predictions. Ask, How can a model be useful for decision-making even when it does not generate precise numerical results? Models that do not generate precise numerical results provide an explanation of relationships among factors and inform the decision, such as which of several marshes would be a better environment for the frog population.

- Highlight the concept that scientific models can be used to both explain phenomena and make predictions. Some models are better for explanations, others better for predictions, and some do both. The Frog Model cards help explain factors affecting two different frog populations.

- Introduce the idea that models can raise new research questions and be revised based on new findings. Have students reconsider Model 2, which showed the relationships between frogs, pesticides, and Bd fungus. Models are constructed based on past data and present understandings. The data that informed this model would have shown that an increase in pesticides resulted in an increase in Bd fungus. Pesticides might be assumed to have a negative effect on the living fungus since it has a negative effect on frogs. This aspect of the model could be the basis of new research questions to further explore this relationship. This, in turn, could eventually result in a more complex or revised model.

7 Introduce the conceptual tool of scientific modeling.

- Introduce the role of scientific modeling 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. Use optional Visual Aid 1.2, "Understanding Conceptual Tools," to support the multiple contexts that are used with 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. In this course, students consider conceptual tools, such as probabilistic reasoning, as a way of exploring the application of science to everyday life.

8 Introduce the concept of trade-offs and how it applies to the scenario of daylighting creeks.

- Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs. In this activity, students use trade-offs when they respond to Build Understanding item 3. 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 of this course, 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 1.2, “Writing Frame: Evidence and Trade-offs” provides additional support for students responding to Build Understanding item 1. 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.

9 **Highlight opportunities for metacognition here and throughout the unit through the use of optional Student Sheet 1.3, “Unit Concepts and Skills.”**

- As students build understanding about the importance of scientific modeling, 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 course organizer is designed to help students reflect on their understanding of the conceptual tool, consider how they will use it to analyze problems throughout the unit, and how it may influence their decisions about unit topics.
- While a sample completed course organizer is provided for the teacher’s reference in this activity, students will not be able to complete the student sheet at this time; the ideas in the sample response will be built over the course of the unit. At the end of this activity, students can add their initial ideas about scientific modeling.

- Optional Student Sheet 1.3 provides an opportunity for students to practice metacognition—thinking about one’s own thought processes. Research has found that students show greater improvement in their learning when they are given opportunities to examine and evaluate their own learning.

- Highlight metacognition opportunities here and throughout the unit. Ask, In what ways could thinking 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 be more aware of mistakes or limitations in their thinking or make them more likely to change their minds. They may also enhance their skills at communicating their ideas and asking questions.

- Finish the activity by revisiting the Guiding Question, *How can models be used to inform a decision?* Use this as a chance to revisit and summarize the key concepts and process skills of the activity.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

The Build Understanding and Connections to Everyday Life items are intended to guide student understanding. You may decide to assign some or all of them, depending on the needs of your students. However, some of the items are recommended in particular activities for use as assessments or to review key concepts.

① **In this activity, you used models to investigate an ecosystem.**

`TEACHER'S NOTE:` `Students may select either model and either creek for daylighting. Evaluate their responses based on their explanations and reasoning for their selections and the logic of their predictions based on their selections.`

a **Which creek do you recommend for daylighting: Geyser or Umpawa?**

I recommend that Umpawa Creek be daylighted to reconnect Chimbly Marsh with Umpawa Marsh.

b **Explain which model—Model 1 or Model 2—was the most useful for deciding which creek to daylight and why.**

Model 2 because the data on the Menanda frogs showed that they were most affected by pesticide vs. the other factors. Model 2 predicted how pesticides might affect a frog population.

c **Provide at least two reasons why the model you chose supports your recommendation.**

Data from Menanda shows that when pesticide levels are higher, frog populations have decreased. Umpawa Marsh has much lower levels of pesticides (0.06 µg/L vs 0.28 µg/L in Geyser Marsh). Model 2 shows a negative relationship between frogs and pesticides. Model 2 also shows that Bd fungus decreases in frogs when pesticides are present, but the amount of Bd fungus in Umpawa Marsh and Geyser Marsh is about the same (11% vs 12%).

d **Make a prediction for what will happen to the *Anura menanda* frog population if your recommendation is followed.**

I predict that if Umpawa Creek is daylighted, the frog population in both Chimbly and Umpawa marshes will increase. When that creek was open, frogs were seen traveling between the marshes. Because pollution is low in Umpawa, and there are plenty of insects for the frogs to eat, if more frogs can get between these two marshes, they should be able to reproduce and increase the population.

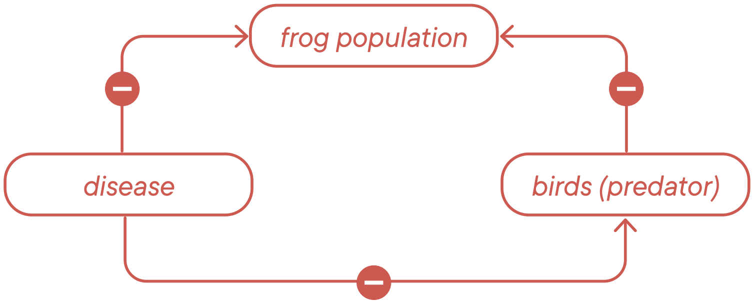
② **Simple diagrams modeled the interactions between frogs and the factors affecting its population. Identify at least two additional factors that could affect the size of a frog population.**

a **Using the following symbols, draw a model to show how these factors will likely affect a frog population.**

→ **a relationship between factors**

⊕ **a positive effect, such as an increase in population size**

⊖ **a negative effect, such as a decrease in population size**



b **What data could you collect to test the accuracy of your model?**

I could sample the frog and bird populations to assess their health and if they have a disease. I could collect data on the size of frog and bird populations over time to see if the bird population has a negative effect on the number of frogs.

③ **Time has passed. A group of residents has been working on habitat restoration of Menanda marshes. Their work has improved water quality and reduced pollution levels, including pesticides, to levels that cannot be measured. While some residents would like to daylight the other creek, it is currently buried under a pedestrian bridge. Other people do not want to daylight it because it would cost a significant amount to move the crossing.**

Would you recommend daylighting the other creek? Support your answer with evidence from Student Sheet 1.1 and identify the trade-offs of your decision. A trade-off is a desirable outcome that is given up to gain another desirable outcome.

I would not daylight the other creek. Model 2 showed pesticides decreased frog populations and increased Bd fungus. With no measurable pesticides and less Bd fungus, the frog population is likely doing better without daylighting another creek. There is already a high insect population at the site, which has a positive effect on the frogs. The trade-off is that there may be fewer frogs at Geyser Marsh than at the other marsh.

CONNECTIONS TO EVERYDAY LIFE

④ **Your smartphone uses a model to show you the estimated minutes or hours remaining on your phone's battery.**

a What are some of the factors this model must incorporate to calculate an accurate time estimate?

Factors affecting a phone's battery power include whether the phone is being used (or asleep), screen brightness, which apps are being used (for example, location services use more power), and how long apps are being used for.

b How could you test your ideas about the factors included in this model?

I could observe my battery percentage and what I am doing on my phone. I could look for relationships and record how quickly the battery percentage changed as I used my phone for different activities.

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Luedtke, J. A., Chanson, J., Neam, K., et al. (2023). Ongoing declines for the world's amphibians in the face of emerging threats. *Nature, 622,* 308–314. https://www.nature.com/articles/s41586-023-06578-4

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STUDENT SHEET 1.1 | DAYLIGHTING DECISION | NAME

Table 1: Analyzing Model 1

	MODEL 1	
Frog species and its location		
Factors included in the model		
How each factor affects the frog population		
Change in average temperature in Menanda	+1.1°C (+2°F) in Geyser Marsh	+1.7°C (+3°F) in Umpawa Marsh
Insect population of Menanda *(insects per square meter)*	233 insects/m^2 in Geyser Marsh	199 insects/m^2 in Umpawa Marsh
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why		
Recommended creek to daylight: Geyser or Umpawa		

Table 2: Analyzing Model 2

	MODEL 2	
Frog species and its location		
Factors included in the model		
How each factor affects the frog population		
Pesticide Index in Menanda *(micrograms per liter)*	0.28 μg/L in Geyser Marsh	0.06 μg/L in Umpawa Marsh
Percentage of frogs with Bd fungus in Menanda	12% in Geyser Marsh	11% in Umpawa Marsh
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why		
Recommended creek to daylight: Geyser or Umpawa		

CONTINUED

Table 3: Analyzing Data on *Anura menanda* Frog Population	**Possible effect on *Anura menanda* frog population**
Average temperature	
Insect population	
Pesticide	
Bd fungus	
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why	
Recommended creek to daylight: Geyser or Umpawa	

STUDENT SHEET 1.1 | **DAYLIGHTING DECISION** | **NAME** SAMPLE STUDENT RESPONSE

Table 1: Analyzing Model 1

	MODEL 1	
Frog species and its location	*Gold frog of Yarata*	
Factors included in the model	*temperature, insects, frogs*	
How each factor affects the frog population	*temperature reduces frog population,* *insects increase frog population*	
Change in average temperature in Menanda	+1.1°C (+2°F) in Geyser Marsh	+1.7°C (+3°F) in Umpawa Marsh
Insect population of Menanda *(insects per square meter)*	233 insects/m^2 in Geyser Marsh	199 insects/m^2 in Umpawa Marsh
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why	*Geyser Marsh will be better because it has a lower temperature and more insects. The gold frog model showed that temperature decreases population, and insects increase population.*	
Recommended creek to daylight: Geyser or Umpawa	*Geyser Creek*	

Table 2: Analyzing Model 2

	MODEL 2	
Frog species and its location	*Clawed frog of Raya*	
Factors included in the model	*pesticide, fungus, frogs*	
How each factor affects the frog population	*pesticide reduces frog population,* *fungus reduces frog population*	
Pesticide Index in Menanda *(micrograms per liter)*	0.28 µg/L in Geyser Marsh	0.06 µg/L in Umpawa Marsh
Percentage of frogs with Bd fungus in Menanda	12% in Geyser Marsh	11% in Umpawa Marsh
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why	*Umpawa Marsh will be better because it has lower concentration of pesticides and fewer frogs with fungal infections. The clawed frog model showed that pesticides and fungus both decrease population .*	
Recommended creek to daylight: Geyser or Umpawa	*Umpawa Creek*	

SAMPLE STUDENT RESPONSE

CONTINUED

Table 3: Analyzing Data on *Anura menanda* Frog Population	Possible effect on *Anura menanda* frog population
Average temperature	*no apparent effect based on Frog Data Card 1*
Insect population	*no apparent effect based on Frog Data Card 1*
Pesticide	*significant decline based on Frog Data Card 2*
Bd fungus	*no distinguishable effect, given 12% vs. 11% infection rates*
Prediction of which marsh—Geyser or Umpawa—will be a better habitat for *Anura menanda* and why	*Umpawa Marsh because it has a lower concentration of pesticides. Frog Data Card 2 shows a strong negative relationship between the* Anura menanda *population and pesticides.*
Recommended creek to daylight: Geyser or Umpawa	*Umpawa Creek*

STUDENT SHEET 1.2 | **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 1.2 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

daylighting creeks to support frog populations.

My decision is that

the second creek should also be daylighted.

My decision is based on the following evidence:

First,

based on Model 2, pesticides have a negative impact on frogs.

Second,

the data on Menanda frogs appeared to show a negative relationship between frogs and pesticides. There was a higher level of pesticides (0.28 µg/L) at Geyser Marsh than at the other area.

Third,

the marsh now has no measurable pesticides.

The trade-off(s)

A pedestrian bridge will be taken down, and it will cost a lot.

People who disagree with my decision might say that

the safety of people is more important than the frog population.

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)
Scientific Model	Simplified representation of an idea, object, process, or system Answers scientific questions: many models can answer one question, one model can answer many questions Contains components, assumptions, limitations Can be made more accurate through revision	Anura menanda frog models, polar bear model, monarch butterfly model, Canada jay model, European common frog model, food web models, butterfly computer models, lobster research models, tuna game models, estimation models, population models
Systems	Collection of parts that interact with each other to work together as a whole Investigated through observations	Making models of local system; butterfly ecosystem, lobster ecosystem; tuna migration; Menanada ecosystems
Orders of Understanding	Factors included in a model based on which factors have a greater impact on the system than others	Rating factors in: computer butterfly models, Dr. Wahle's model on lobster distribution, tuna game model, constructing local species, Anura menanda frog sites
Fermi Estimate	A method of calculating an approximate value of a difficult-to-know quantity Uses relative scale (for example, powers of 10)	Estimates of the number of: people in line, snacks for a school dance, shoes thrown away in the world every year, trees lost to Bighorn Fire, house sparrows, local species now and 50 years in future, Anura menanda frogs at each site

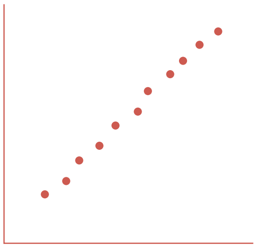
WHAT DECISION(S) WERE MADE OR ACTION(S) TAKEN?

Daylighting of creek in Mendana, Butterfly Bluff Park actions, tuna fishing locations, Bighorn tree replanting, Anura menanda *frog conservation site*

VISUAL AID 1.1 | INTERPRETING GRAPHS

Determine the path that describes the data.

IS THERE A RELATIONSHIP?

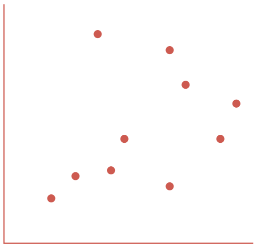


THERE IS A PATTERN.

↓

RELATIONSHIP

↓

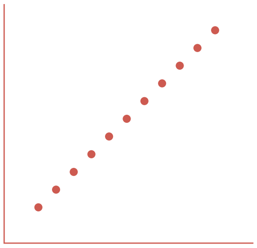


THERE IS NO PATTERN.

↓

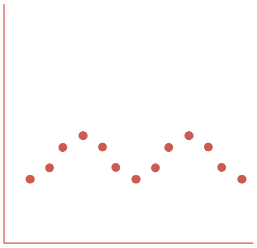
NO RELATIONSHIP

WHAT IS THE GENERAL TREND OF DATA?



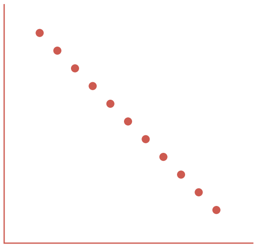
POSITIVE

as x increases, y increases



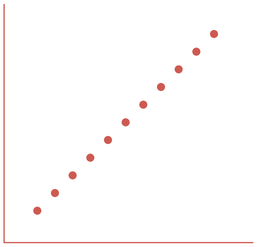
CYCLICAL

as x increases, y repetitively increases and decreases



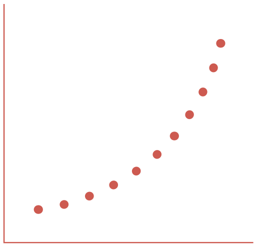
NEGATIVE

as x increases, y decreases



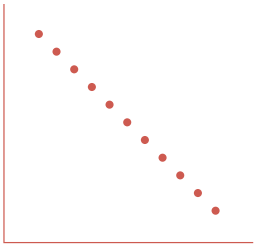
LINEAR

as x increases, y consistently increases *(sometimes called "direct")*



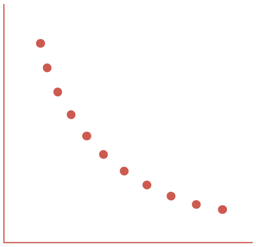
NONLINEAR

as x increases, y increases at a changing rate



LINEAR

as x increases, y consistently decreases

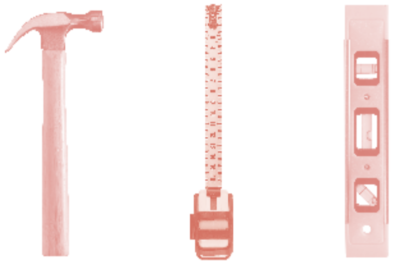


NONLINEAR

as x increases, y decreases at a changing rate *(sometimes called "inverse")*

VISUAL AID 1.2 | UNDERSTANDING CONCEPTUAL TOOLS

CONSTRUCTION TOOLS



SCIENTIFIC TOOLS

SCIENTIFIC TOOLS + TECHNOLOGY

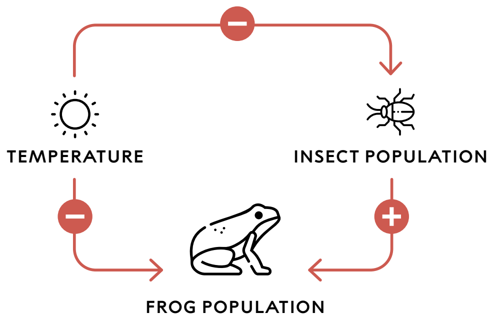
CONCEPTUAL TOOLS

ACTIVITY 1 | FROG MODEL CARDS

FROG MODEL 1

GOLD FROG OF YARATA

Scientists have collected data on the gold frog found in the marshes of Yarata. Over the last 100 years, the average temperature in the Yarata marshes has increased. This has negatively affected the size of the gold frog population. Lots of insects, a primary food source for gold frogs, results in increases in the frog population. Scientists developed this model to show how these factors are affecting the gold frog population.



KEY

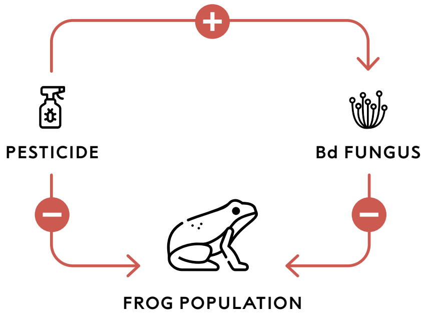
- → a relationship between factors
- ⊕ a positive effect, such as an increase in population size
- ⊖ a negative effect, such as a decrease in population size

`SCIENTIFIC THINKING FOR ALL: A TOOLKIT`
`UNIT 2: Scientific Modeling, Activity 1: Frog Model Cards`

FROG MODEL 2

CLAWED FROG OF RAYA

Scientists have collected data on the clawed frog found in the marshes in Raya. Scientists found that pesticide runoff from nearby agricultural fields negatively affected the population size of clawed frogs. When Bd fungus is present in the population, it causes disease and death in the frog population. Scientists developed this model to show how these factors are affecting the clawed frog population.



KEY

- → a relationship between factors
- ⊕ a positive effect, such as an increase in population size
- ⊖ a negative effect, such as a decrease in population size

`SCIENTIFIC THINKING FOR ALL: A TOOLKIT`
`UNIT 2: Scientific Modeling, Activity 1: Frog Model Cards`

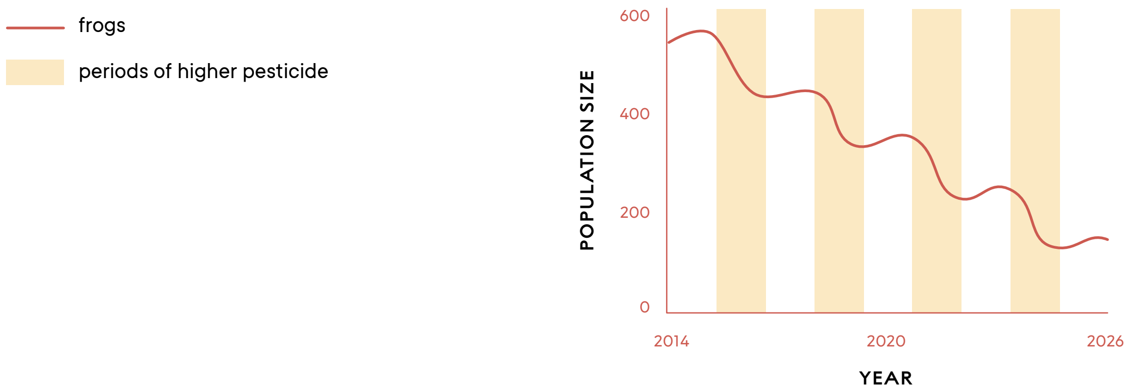
FROG DATA 1

Insects, Temperature, and *Anura Menanda* Frog Populations Over Time

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 1: Frog Data Cards

FROG DATA 2

Effect of Pesticides on *Anura Menanda* Frog Populations



SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 1: Frog Data Cards

ACTIVITY 2

Scientific Models and Scientific Questions

DATA ANALYSIS

ACTIVITY 2

Scientific Models and Scientific Questions

ACTIVITY SUMMARY

Students examine additional types of models and further explore the role of models in science. They identify how multiple scientific questions can be investigated with a single scientific model and how a single scientific question can be investigated with more than one model. Students discuss the role that models play in answering questions and how different types of models are best utilized for addressing different types of questions.

ACTIVITY TYPE
DATA ANALYSIS

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2-3

KEY CONCEPTS & PROCESS SKILLS

1 Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

2 Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (*Science and Engineering Practice: Developing and Using Models*)

CONCEPTUAL
TOOLS

VOCABULARY DEVELOPMENT

species distribution

the pattern of occurrence of a species within a geographic range

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 1.1 “Interpreting Graphs” (OPTIONAL)
- VISUAL AID 2.1 “Developing Communication Skills” (OPTIONAL)
- STUDENT SHEET 9.3 “Developing Scientific Questions” (OPTIONAL)

FOR EACH GROUP OF FOUR STUDENTS

- SET OF SCIENTIFIC QUESTION CARDS (4 CARDS)
- SET OF SCIENTIFIC MODEL CARDS (4 CARDS)

FOR EACH STUDENT

- STUDENT SHEET 2.1 “Investigating Scientific Models”
- STUDENT SHEET 1.3 “Unit Concepts and Skills” (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Introduce the idea of a scientific question.**

- This activity introduces scientific models and scientific questions. Ask, What do you think the difference is between a question and a scientific question? Help students develop the idea that a scientific question should be testable and answered with observable natural phenomena, while a general question is broader (for example, it may be about opinions, beliefs, or topics that cannot be measured or observed through an investigation). Scientific questions are more focused and objective. Ask, Can you brainstorm a list of scientific questions vs. general questions?

EXAMPLES OF SCIENTIFIC QUESTIONS	EXAMPLES OF GENERAL QUESTIONS
What causes cells to age?	Which is the best sports team in the league?
How do plants convert light into chemical energy?	What are you doing for lunch tomorrow?
What determines a molecule’s boiling point?	Who is your favorite singer?
How fast is the universe expanding?	Is this room hot?
What causes coral bleaching?	What is the meaning of life?

- If you need to further support students’ understanding of scientific questions, you may also want to refer to Student Sheet 9.3, “Developing Scientific Questions,” found in Activity 9.

2 **Review the term *species distribution.***

- The Introduction in the Student Book describes a change in the climate classification of New York City. Specifically, it is referring to a macroclimate—long-term atmospheric conditions over a large geographic area. You may wish to have students investigate the macroclimate of your local area to find out if there have been changes over time.

- Use the Introduction to introduce the term *species distribution*—the pattern of occurrence of a species within a geographic range. Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the term *species distribution* to a word wall and providing an example as needed. For more information on a word wall, see Appendix 1: Literacy Strategies.

PROCEDURE SUPPORT (30 MIN)

3 In Procedure Part A, students examine and summarize four scientific models.

- There are four Scientific Models presented in the Student Book. In Procedure Part A, students generate multiple scientific questions that could be investigated by a single model. In Procedure Part B, students develop the idea that a single question can be investigated by multiple models.
- Each student will read and analyze one model and share their understanding with their group members. The models vary in their difficulty, and you may wish to assign models accordingly. Scientific Models 1 and 3 require interpreting a visual graphic, Scientific Model 2 requires interpreting a map, and Scientific Model 4 requires interpreting a graph (and may be the most challenging). Note that in Scientific Model 1, the reference to positive and negative impacts on the population of other species refers to mathematical effects and is not intended to imply good or bad effects.
- Depending on your student population, you may wish to review how to interpret graphs using optional Visual Aid 1.1, "Interpreting Graphs."
- Provide each student with a copy of Student Sheets 2.1,"Investigating Scientific Models."
- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding a few more words to the word wall. Students, particularly those examining Scientific Model 2, may have questions about a species distribution and its relationship to migration. If needed, clarify that the term *migration* is the movement of animals from one region to another, often seasonal. For example, many bird species have a long-distance migration pattern from breeding ranges in the United States and Canada to wintering grounds in Central and South America. All the areas that have the living (biotic) and nonliving (abiotic) conditions for the species to survive would be a part of its potential range. *Range shifts* are defined as changes in the distribution limits of a species, generally along altitude or latitudinal lines. *Species distribution* refers to how a species is spread throughout its range, for example, in tight groupings in one area or evenly throughout. For more information on a word wall, see Appendix 1: Literacy Strategies.

TEACHER'S NOTE: Some language in this unit may require particular care and sensitivity, depending on students' individual experiences. For example, the concept of migration may be familiar to students from other contexts, such as history (e.g., migration during the Dust Bowl or during wars) or from current global human migration.

- Have groups work together to share their understanding of each model and to develop a scientific question that could be answered by each model. To support students' discussion, you may wish to use optional Visual Aid 2.1, "Developing Communication Skills," to help guide student interactions. Visual Aid 2.1 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. For more information about Developing Communication Skills, see Appendix 1: Literacy Strategies.

- After group members discuss their thinking, each student can record their own ideas to complete Table 1 on Student Sheet 2.1. There does not need to be agreement among group members. Sample student responses are located at the end of this activity.

- After group members identify at least one scientific question that can be investigated for each model, each student can record the questions in the last row of Table 1 on the student sheet.

4 **Have groups share their scientific questions with the class.**

- Remind students that the scientific questions they generate should be questions that could be investigated using each model (and are not questions about the model itself).

- For each of the four models, make a list of scientific questions that students generated. For example, for Scientific Model 1, students might generate scientific questions such as: *If the polar bear population continues to decline due to climate change, is it possible that the population of subarctic seals and common eiders will begin to increase? Will reduced sea ice reduce the arctic seal population? Is there competition between the two seal species?*

- To figure out if a model can answer a scientific question, students can compare the question to the model's purpose and scope (e.g., the factors it includes). You may want to review ways in which a model can be used to address a scientific question, such as by explaining a phenomenon or predicting a future outcome.

- Ask, Can one scientific model be used to answer different scientific questions? Students should recognize that the list of scientific questions generated by the class for a single model means that the answer is yes.

5 **In Procedure Part B, hand out both sets of cards to each group.**

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

- There are 4 Scientific Question cards and 4 Scientific Model cards. Students are asked to identify which models could be used to answer the scientific question on each card and record their responses in Table 2 of the student sheet. It is important that students understand that more than one model can be used to investigate a particular question—there is not a one-to-one correspondence between the cards.

- Highlight the idea that a scientific question may be addressed by more than one scientific model.

6 **Have students share their own scientific questions about species distribution.**

- Have students share with the class the scientific questions they would like to have answered about species distribution. For example, students may be interested in how bird migration is affected by increasing numbers of people living in urban (vs. rural) areas.
- While student responses will vary, possible questions may include:

What will happen to our local oak trees in the future? What effect do invasive species such as silver carp have on local fish populations such as largemouth bass? Do large-scale wildfires have a permanent effect on global air quality?

- Have students share the models they brainstormed that could help address a scientific question about species distribution, such as a computer model that could incorporate changing patterns of urbanization and its effect on the migration of birds.
- While student responses will vary, one possible response is:

The future of our local oak trees could be modeled by creating a computer model that includes historic data on temperature, water availability, tree diseases, and soil quality. The model could exclude factors such as competition and predation, since people have planted these trees and they are also the ones who could remove them. Assuming that people are not going to plant more trees or remove the trees, the model could predict how the identified factors will change in the future and affect the future population and health of oak trees.

SYNTHESIS OF IDEAS (10 MIN)

7 **Review the relationship between scientific models and scientific questions.**

- Summarize the key takeaways: a single scientific model can be used to answer different scientific questions, and a scientific question may be addressed by more than one scientific model.
- Highlight the idea that the relationship between scientific models and scientific questions is cyclical: scientific questions are used to construct models to help explain, predict, and test ideas. Models can then generate new scientific questions as a result of simplifying complex phenomena, refining existing models, and producing data.
- Review the idea that models may be represented as drawings, graphs, equations, three-dimensional structures, or words. Other familiar examples of models include weather maps and planetary globes. Different types of models are best utilized for different types of questions.
- As needed, review student responses to Student Sheet 2.1.

- Depending on your student population, you may wish to review the model in Build Understanding item 2. It is an expanded version of the models first presented in Activity 1. It is a type of model that is sometimes referred to as a feedback loop, where change in one part of a system triggers a specific response in another part of the system. As needed, explain the meaning of arrows as well as +/– signs in this type of model. You may need to explain that an increase in deaths is a negative effect.

8 **Use optional Student Sheet 1.3, "Unit Concepts and Skills," to help track important concepts of the unit.**

- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about scientific questions and their relationship to scientific models.
- Highlight how the activity helped students address the Guiding Question: *How are scientific models used to answer scientific questions?* Develop the idea that different scientific questions about a single system may be best addressed by different scientific models. A single system, such as a forest or a human body, is too complex to capture perfectly in one model.

EXTENSION (10 MIN)

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

- Students can look online to further investigate scientific models and ways in which they are being used to investigate scientific questions. Note that this unit provides examples of conceptual, mathematical, and computer models (seen later in the unit) but does not utilize physical models with which students are typically more familiar and which they may have described in the Getting Started discussion in Activity 1. You may wish to use this Extension as an opportunity to provide additional examples of physical models if needed.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **A team is developing a population model for bass fish in a local freshwater lake ecosystem. The team decides to focus only on two key factors: the population size of bass fish and water temperature.**

- a **Identify at least two factors of the real-world lake system that the team is leaving out of their model.**

  Possible responses include:
  water quality, predators, food availability, competition, and disease.

- b **Explain how excluding these factors might lead to an inaccurate prediction about the bass population.**

  One or more of these factors may be having a greater impact on the bass population than water temperature. Not including them in the model could result in attributing population change to the wrong factor.

- c **If the team's scientific question is *How does the bass population size change in response to changes in water temperature?*, do you agree with the focus of their model? Why or why not?**

  Yes, because then the model is looking specifically at the effect of water temperature on the population. The model can help determine if there is a relationship and, if so, what that relationship is (positive or negative).

② **The following diagram is another type of model that shows that a change in one part of a system causes a specific response in another part of the system.**

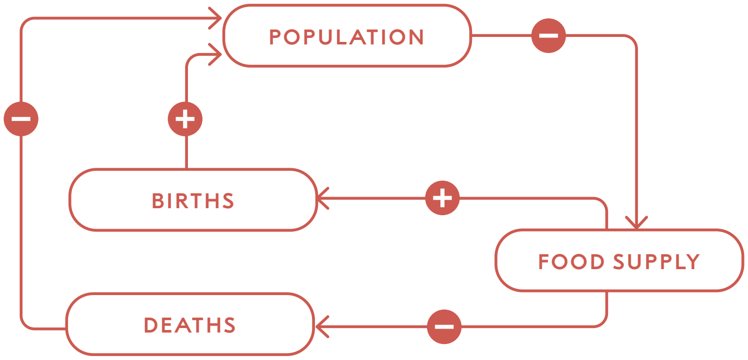


FIGURE 2.5
Population model diagram showing relationship between population, births, deaths, and food supply

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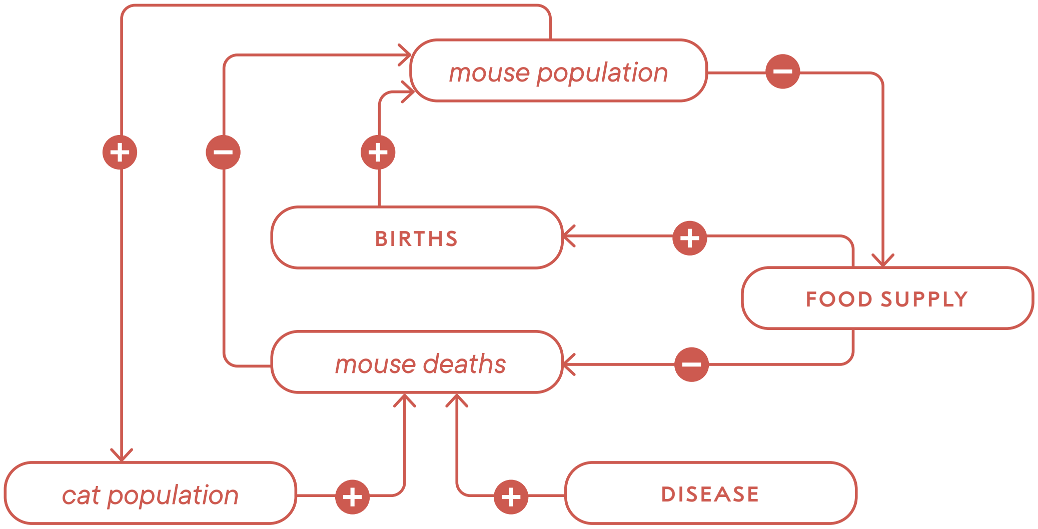
Factors such as birth rate, death rate, and food supply can af-
fect the size of a population. For example, when there is more
food (+), there can be an increase in births, which increases (+)
the population.
```

a **According to the model, how would an increase in population affect the food supply?**

An increase in population would cause a decrease in the food supply.

b **Revise this model to show the possible effect of at least two additional factors on a population of mice.**



c **List at least one scientific question that could be investigated by your revised model.**

Sample questions include:
If the mouse population increases, does the cat population increase at the same time? Does the density of the mouse population affect the birth rate? When the mouse population is high, does competition for food cause an increase in deaths?

CONNECTIONS TO EVERYDAY LIFE

③ **Different mapping apps provide different models of the geographic layout of Earth's surface. For example, one model, used for navigation, can tell you the best way to get from one place to another by car, foot, or public transportation as well as an estimate of how long each will take. Another model shows satellite photographs with labels to identify cities and country boundaries. Take a moment to go online to explore both of these mapping models.**

a **What factors are included in a satellite map model but not in a navigation map model?**

A satellite model includes geographic features such as mountains and what Earth really looks like from above.

b **What factors do both models include?**

Rivers, towns, large roads.

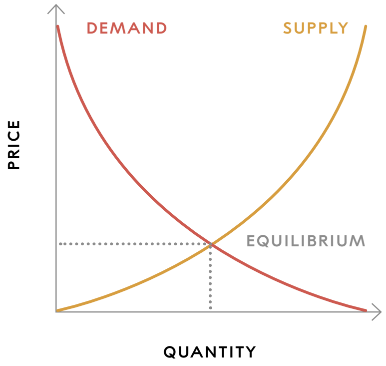
c **Given these differences, what is one question that a satellite map model can help address but a navigation map model cannot?**

Sample responses include:
Which regions have more green plants vs. dry earth? How widespread are forests in this area? How does the color of deserts vary in different states?

d **What is one question that both models address equally well?**

What is the direct distance from London, England, to Cairo, Egypt?

④ **Other fields of study also use models. The graph to the right is one that is commonly used in economics to model the relationship between the price of goods and services based on the supply and demand for them. A clothing retailer uses it as a model to set the price for a popular vintage T-shirt.**



a **When the supplier sets the price exactly at the equilibrium point, what is the model predicting will happen to the number of T-shirts sold?**

The number of T-shirts sold will exactly match the supply of available T-shirts.

b **Identify one limitation of this model.**

`HINT: Consider what might happen if the T-shirt became a viral trend on social media.`

One limit of this model is that it does not address changing demand. For example, a T-shirt that goes viral online suddenly has a high demand and sells out (there is not enough supply).

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STUDENT SHEET 2.1	INVESTIGATING SCIENTIFIC MODELS	NAME

Table 1: Describing Four Scientific Models

	MODEL 1	MODEL 2	MODEL 3	MODEL 4
Species				
Location				
Factors included in the model				
Model prediction(s)				
Scientific question				

CONTINUED

Table 2: Asking Scientific Questions

Scientific Question	**This scientific question could be investigated by which model(s)?** Explain your reasoning.
CARD A How will the distribution of a species change over time?	
CARD B What role does food availability play in the population size of a species?	
CARD C What effect does temperature have on the suitability of a habitat for a species?	
CARD D How are changes in global climate likely to affect predator–prey relationships?	

STUDENT SHEET 2.1 | INVESTIGATING SCIENTIFIC MODELS | NAME SAMPLE STUDENT RESPONSE

Table 1: Describing Four Scientific Models

	MODEL 1	MODEL 2	MODEL 3	MODEL 4
Species	*Polar bear*	*Monarch butterfly*	*Canada Jay*	*European common frog*
Location	*Arctic*	*North America*	*Northern Canada*	*Finland*
Factors included in the model	*Populations of polar bears, arctic seals, common eiders, subarctic seals, climate*	*Butterfly distribution, climate, food availability for larvae*	*Canada jay distribution, climate, wildfire patterns, vegetation*	*Habitat suitability, breeding sites, climate*
Model prediction(s)	*Less polar bear predation on Arctic seals; more predation on subarctic seals, common eiders as climate changes*	*Geographic range moves northward as average temperatures increase over time*	*Distribution directly affected by climate, distribution indirectly affected by wildfire patterns and vegetation*	*Increased suitable habitat as average temperatures increase over time*
Scientific question	*Will the arctic seal population stay the same with decreased polar bear predation and less sea ice habitat?*	*Why is there a greater likelihood of monarch butterflies in Canada with severe climate change vs moderate change?*	*Will an increase in wildfires reduce the population of Canada jays in Northern Canada?*	*How large can the population of European common frogs get if all sites are available for breeding?*

NAME SAMPLE STUDENT RESPONSE

CONTINUED

Table 2: Asking Scientific Questions

Scientific Question	**This scientific question could be investigated by which model(s)?** Explain your reasoning.
CARD A How will the distribution of a species change over time?	• *Model 2 predicts the change in the monarch butterfly distribution over time.* • *Model 3 predicts the change in Canada jay distribution over time.* • *Model 4 predicts the change in European common frog habitat suitability over time, which is likely to affect its distribution.*
CARD B What role does food availability play in the population size of a species?	• *Model 1 predicts changes in predator–prey relationships and polar bear population size.* • *Model 2 incorporates the food availability for butterfly larvae in its model.*
CARD C What effect does temperature have on the suitability of a habitat for a species?	• *Model 1 predicts the effect of climate change, which includes temperature, on polar bears.* • *Model 2 predicts the effect of climate change, which includes temperature, on monarch butterflies.* • *Model 3 predicts the effect of climate change, which includes temperature, on Canada jays.* • *Model 4 predicts the effect of climate change, which includes temperature, on European common frogs.*
CARD D How are changes in global climate likely to affect predator–prey relationships?	• *Model 1 predicts changes to polar bear predation.*

DEVELOPING COMMUNICATION SKILLS

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...?

SCIENTIFIC MODEL 1

POLAR BEARS

Model of Predicted Climate Change Effects on Polar Bear Predation in the Arctic

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Model Cards

SCIENTIFIC MODEL 2

MONARCH BUTTERFLIES

Species Distribution Modeling (SDM) of monarch butterflies across North America in June under three different climate scenarios

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Model Cards

SCIENTIFIC MODEL 3

CANADA JAYS

Model of Predicted Climate Change Effects on Canada Jay Distribution in Northern Canada

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Model Cards

SCIENTIFIC MODEL 4

EUROPEAN COMMON FROGS

Species Distribution Modeling (SDM) of habitat changes for the European common frog in subarctic Finland

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Model Cards

SCIENTIFIC QUESTION A

How will the distribution of a species change over time?

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Question Cards

SCIENTIFIC QUESTION B

What role does food availability play in the population size of a species?

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Question Cards

SCIENTIFIC QUESTION C

What effect does temperature have on the suitability of a habitat for a species?

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Question Cards

SCIENTIFIC QUESTION D

How are changes in global climate likely to affect predator–prey relationships??

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling
Activity 2: Scientific Question Cards

ACTIVITY 3

Constructing a Model

FIELD TRIP

ACTIVITY 3

Constructing a Model

ACTIVITY SUMMARY

Students draw on prior knowledge to construct a food web model of a local ecosystem. The class takes a field trip to a local nature area to make and record observations. Students revise their models based on their real-world observations. The class uses the models to make predictions about how feeding relationships affect population size. Students revise their models a final time based on additional researched information. The class discusses the role of data, including firsthand observations, to inform scientific models.

ACTIVITY TYPE
FIELD TRIP

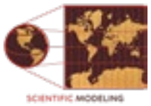
NUMBER OF
40–50 MINUTE
CLASS PERIODS
2-3

KEY CONCEPTS & PROCESS SKILLS

1. Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.
2. Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.
3. Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (*Science and Engineering Practice: Developing and Using Models*)

CONCEPTUAL
TOOLS



VOCABULARY DEVELOPMENT

system

`a collection of parts that interact with each other to work together as a whole`

TEACHER BACKGROUND INFORMATION

Population Dynamics

Population dynamics is the study of how and why the size, structure, and distribution of a population change over time. Mathematical models are used to understand the biological and environmental processes that drive these changes. The core factors studied are the four demographic events: birth, death, immigration, and emigration. By analyzing how these rates are influenced by factors such as resource availability, predation, disease, and climate, ecologists can predict future population trends, assess species health, and inform conservation and management strategies.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- MAP OF THE FIELD TRIP AREA
- RESEARCH ON LOCAL FOOD SPECIES INTERACTIONS (OPTIONAL)
- VISUAL AID 3.1 "Scoring Guide: Developing and Using Models (MOD)"
- ITEM-SPECIFIC SCORING GUIDE: Activity 3, Build Understanding Item 4

FOR EACH STUDENT

- STUDENT SHEET 3.1 "Making Local Observations"
- STUDENT SHEET 3.2 "An Ecological Relationship Model" (OPTIONAL)
- STUDENT SHEET 1.3 "Unit Concepts and Skills" (OPTIONAL)
- SCORING GUIDE: Developing and Using Models (MOD) (OPTIONAL)
- SPECIES IDENTIFICATION PHONE APP (such as *Merlin* and/or *Seek by iNaturalist*)
- UNLINED PAPER
- CLIPBOARD (OPTIONAL)

Prior to the activity, you will need to identify one or more suitable sites in which to conduct the activity. The site(s) should have at least some biotic (living) components. Consider a school garden, a grassy median, or a playground.

It is helpful to be able to identify common species in the local area. Several apps exist for aiding species identification, although these often work best for organisms that move slowly or are stationary, such as plants or snails. You may wish to download one of these apps onto your own phone and learn to identify some of the most common plant and animal species in your area.

In Procedure Part C, students are asked to do research on their local ecosystem and use that information to revise their models for the final time. Depending on the time available and your student population, you may wish to do this research in advance and provide students with this information in Part C.

Safety Note

Prepare students with guidelines and expectations for participating in a field trip.

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Explain that models represent systems.**

- Use the Introduction in the Student Book to connect the activity to the issue of changing animal distribution, modeling, and systems. If you have begun a word wall, add the term *system*.

2 **Discuss organisms that students have seen in their area.**

- Have students brainstorm a list of common local organisms. Ask, What kinds of animals, birds, insects, and plants (including trees and bushes) have you seen in the area, around the school, or around your homes? What do they look like? Even in cities, there are many organisms such as pigeons, sparrows, crows, starlings, hawks, squirrels, rats, mice, ants, spiders, flies, etc. You may have some students who can identify organisms at a finer grain size, such as a white-crowned sparrow. Since most students will not be able to do this, list more specific species after the broader category—for example, Sparrow: house sparrow, white-crowned sparrow, etc.
- If students do not know names of species, encourage them to describe animals they've seen and help them identify those animals. You can invite the class to come up with shorthand descriptions for internal reference, such as fried-egg flowers. If students know very little about your area and have difficulty generating likely organisms, you may wish to prepare a set of pictures of common local organisms. Or you can use the Explore function in the *iNaturalist* app to find out what species have been observed recently in your area; this will pull up a map with observations tagged and color-coded by kingdom (animal, plant, fungus). Tapping on a tag will pull up the species, date of observation, and a photograph. You can use this information to highlight common local species.

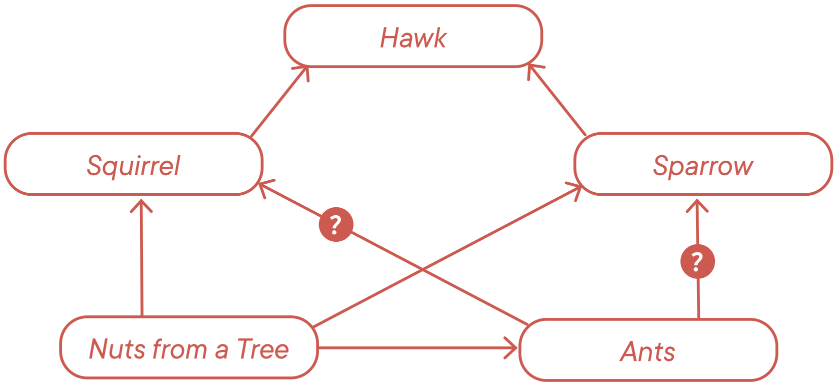
PROCEDURE SUPPORT (20 MIN)

3 In Part A, students construct food web models based on prior knowledge.

`TEACHER'S NOTE:` This activity has students iterate on a food web model. Depending on your student population and your content objectives, this activity can also be done using a model of ecological relationships. Optional Student Sheet 3.2,"An Ecological Relationship Model," describes these relationships and includes suggestions for constructing the model. If you use Student Sheet 3.2, you will need to use a different version of Build Understanding item 4. A different version of this question is provided at the end of this activity, along with a sample student response.

- This activity assumes that students have some prior knowledge of simple food web models and local organisms. A food web model is shown in Procedure Part A, and a brief Science Review on food webs can be found at the end of the activity in the Student Book.
- In Procedure Step 2, hand out a sheet of unlined paper to each student. Explain that models are constructed through a process of revision and that students are not expected to construct complete and correct models. They should construct models to the best of their knowledge and place a question mark on their models anywhere they are unsure of an organism or a relationship.
- If students are having difficulty with this task, you may want to have them work together in pairs or small groups to construct their models.
- A sample response is provided.

Sample Response to Procedure Step 2



4 The class participates in a field trip to a natural area to make observations.

- Explain that students will have the opportunity to make real-world observations to inform and, if need be, revise their food web models. Present a map of the outdoor area you are going to visit. As a class, discuss how well the field trip site represents (or differs from) common local ecosystems and/or the local organisms that students have been including in their food web models.
- Prior to visiting the site, communicate any safety considerations and behavioral expectations.
- At the site, hand out Student Sheet 3.1, "Making Local Observations," and ask students to arrange themselves as far apart as possible within your range. Remind them that the quieter they are, the more organisms they will see. Encourage students to observe not only in trees or on the grass but also under leaves or stones, in cracks in the pavement, in soil, and in the sky.
- Remind students to use the phone app to help identify any unfamiliar species.
- Have students make their observations in silence and record observations on Student Sheet 3.1. Remind them to:
  - include at least five different observed species.
  - describe any possible feeding relationships based on observations and prior knowledge.
  - add a drawing or a map to their observations and label parts of their drawing or map as needed. (This can be done on the back of Student Sheet 3.1). They may want to sketch the entire scene or mark a particular organism's place within the environment.
- After a minimum of 10 minutes of observation, invite students to share what they've seen with the class. Ask, In general, in which parts of the environment do you observe more animals? Which organisms did you observe in proximity to each other? Did you observe any organisms interacting (including animals and plants)? What observations could inform your ideas about the relationships among the organisms? Useful types of observations include noticing proximity between organisms; animals carrying or eating plants or seeds; organisms feeding on scraps of food discarded by people; cats and dogs in the area that play a role in the local ecology; animals pulling fruit or nuts off trees or the ground, digging in the ground, chasing insects, etc.
- After this initial sharing, you may want to provide students with a few more minutes to observe. Having their peers notice something that they didn't may guide students to enhance their observations, either by observing the same thing or by making additional observations.
- After students have completed their observations, provide them with time to use a phone app or other type of key to identify the organisms in the ecosystem. They can edit their observations on Student Sheet 3.1 as necessary.

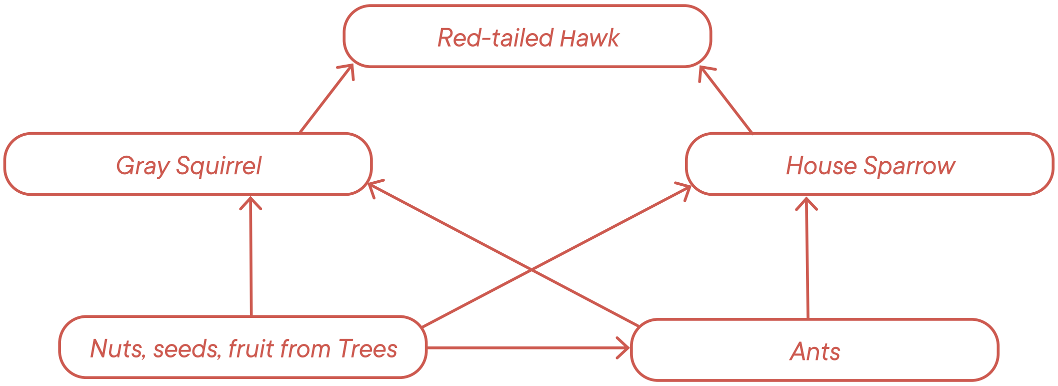
5 **Students make additional observations through the process of nature journaling (optional).**

- If you have more time and/or there are very few animals to be seen, invite students to nature journal—a process that is designed to engage students in closer observation of their environment. Have students respond to one or more of the following prompts:
  - *What do you notice? What does it remind you of? What do you wonder about?*
  - *Draw what you see. You may decide to draw an animal, a tree, sketch the scene as a whole, or draw animals in the scene.*
  - *Write five or more sentences describing what you see in as much detail as possible.*

6 **Students share their observations and revise their food web models.**

- After returning to the classroom, have students share their observations. In a food web model, organisms provide food to other organisms. As a class, discuss potential feeding relationships between the different organisms that students may have observed. Work together to brainstorm possible feeding relationships.
- Students should use the class' observations to revise their food web models as needed. Students are asked to label their food web models with a word or phrase that describes the system they are modeling. A sample response is provided here.

Sample Food Web: The Wooded Park at Town's Edge



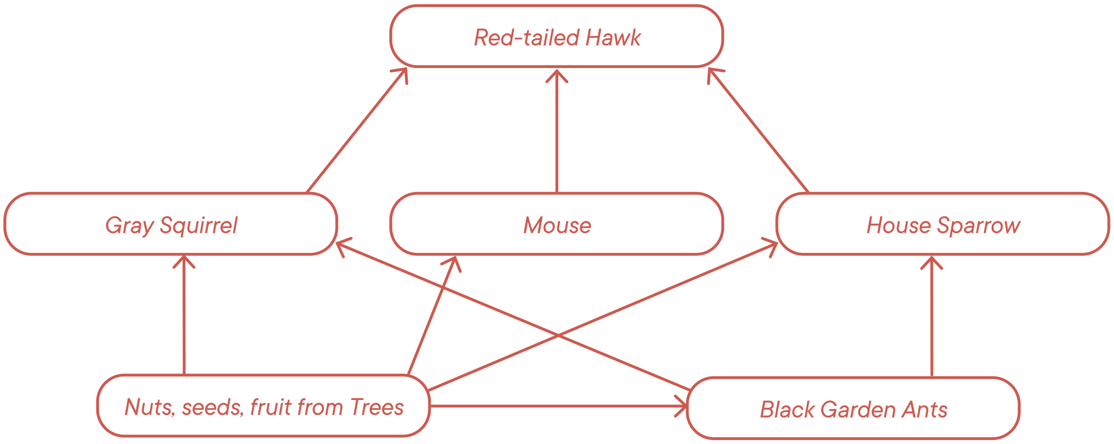
- As a class, discuss how to make predictions about the interactions among species. For example, ask, What would happen to the population of sparrows if herbicide was sprayed and most of the insects died? Students should be able to conclude that the sparrow population would likely decline without any other source of food. Provide additional examples as needed.
- Point out that the food web model is useful in explaining feeding relationships within an ecosystem and can be used to predict what might happen to other species when there is a change in the population of a particular species.

- Ask, What scientific questions could this model be used to investigate? Possible responses include: *What happens to the hawk population when the grass dies due to drought? What effect do large spider populations have on sparrow populations? What effect do outdoor house cats have on bird populations?*

7 Students research their local ecosystem and revise their food web models.

- Have students research or provide information to them about the species and feeding relationships common in the type of local ecosystem they visited. Students should use this information to revise their food web models as needed. A sample response is provided.

Revision of Sample Food Web: The Wooded Park at Town's Edge



- Have students share their final food web models with the class. You may want to create a gallery wall for students to observe one another's work.

SYNTHESIS OF IDEAS (20 MIN)

8 **Discuss how observations of a system inform scientific models and model revisions.**

- A scientific model can represent a system and can be used to help understand and predict its structure, behavior, and interactions. By breaking down complex phenomena into manageable parts and illustrating their connections, scientific models of systems enable people to understand, analyze, and predict how systems function. Review the idea that scientific models are developed based on observations of a system and the relationship between its components. Point out that this is exactly what students did by drawing from their prior knowledge (often based on previous observations), field trip observations, and research (based on observations and studies produced by others).
- Ask, What additional observations could you make to inform your model and how? Students could spend more time making observations, make observations under more varied conditions (i.e., different times of the day, different weather conditions), and make observations in different areas with similar ecosystems.
- Ask, How do you think additional observations would cause you to revise your model? Possible responses include adding additional organisms to the model and revising interactions between organisms.
- Highlight the process of revision that goes into model making and the role that real-world data plays in making those revisions.

9 **Use optional Student Sheet 1.3, "Unit Concepts and Skills," to help track important concepts of the unit.**

- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about models representing systems, as well as the use of new information to revise models.

10 **Introduce the assessment for Build Understanding item 4.**

- Build Understanding item 4 is a modeling assessment item. This first opportunity should be used to introduce your students to the Scoring Guide: Developing and Using Models (MOD). 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 Guide for more guidance and information on using the Scoring Guides and assessment system with your students.
- Do not share the item-specific version of the Scoring Guide (Item-Specific Scoring Guide: Activity 3, Build Understanding Item 4) 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 3.1, "Scoring Guide: Developing and Using Models (MOD)," can be used to assess Build Understanding item 4. 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 4 would include. You may develop a Level 4 exemplar as a class or share with students the Level 4 response 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. You may wish to project a copy of the Scoring Guide for your students to review each level and clarify your expectations.

- 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.

EXTENSION (50+ MIN)

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

- **Extension 1:** Have students collect observations over time and record them on a map of your school district. Compare the results of the data collection with the observations from the field trip. Discuss whether the new data support the design of the food web model and what new scientific questions are raised.

- **Extension 2:** You may wish to have students construct a physical model of an ecosystem by establishing an ecosystem in a bottle, often referred to as "bottle biology." In this sample model, two plastic bottles are cut into two, and the ecosystem is established in the first bottle. The top half of the second bottle is used to seal the system. Many such models utilize soil, water, plants, and, in some cases, invertebrates. The first step in establishing such a system is deciding on what ecosystem to model and what question to investigate.

TEACHER'S NOTE: The use of vertebrates (such as fish or lizards) in the classroom is often governed by local or state guidelines and laws and may not be allowed or may require additional authorizations or approvals.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **An ecosystem consists of both living (biotic) parts, such as wildlife, and nonliving (abiotic) parts, such as water.**

a **Which parts are included in a food web model?**

Living (biotic) parts.

b **What are three examples of nonliving parts that are not included in a food web model?**

Rainfall, temperature, and population density.

c **If you wanted to construct a more complete and accurate model of an ecosystem, what would you do differently?**

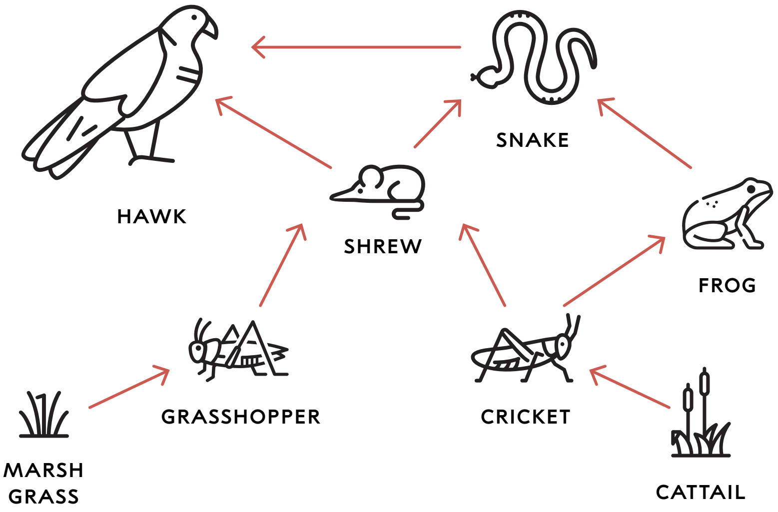
I could add lines connecting nonliving factors to the organisms and use +/– signs to indicate positive or negative relationships. For example, I could add a line pointing to the grass that says "rainfall" and mark it with a "+" sign.

② **Reflect on the ways in which your initial food web model changed to incorporate new information. Design a more scientific approach to gathering firsthand observations to inform your food web model.**

I would choose a time when there were fewer people, observe for a longer period of time, and go back on different days. I would record the time of year and the weather (since that might affect my observations).

③ **Scientific models are constructed to explain phenomena and make predictions. Look at the following food web model.**

FIGURE 3.2
Food Web Model



a **What do you predict would happen to the population of other species if the cricket population declined? Explain your reasoning.**

I predict that the frog species would decline significantly because it only eats crickets. The shrew and the snake would only decline a bit because they have other sources of food. The hawk would also decline because it eats snakes and shrews. The grasshopper population might go up because it would have less competition.

b **An owl species that eats snakes, frogs, and grasshoppers moves into the area. What do you predict will happen to the populations of the different species?**

The snake, frog, and grasshopper populations would decline, possibly causing the shrew and hawk populations to decline as well.

④ MOD Scoring Guide

Imagine you visited a park with a small pond and recorded the following observations about the organisms there.

ORGANISM	NUMBER	OBSERVATIONS
Turtles	3	One turtle sat on a log in the sun. The other two were eating plants and beetles, and one of them caught a small fish and ate it.
Aquatic beetles	Lots	Beetle larvae eat aquatic plant roots, and adult beetles eat leaves of aquatic plants.
Leafy aquatic plants	Lots	The plants are growing under water in the shallow area of the pond.
Aquatic beetles	At least 50	There are different-sized fish, but they all look similar. The smaller fish are eating the leafy aquatic plants, and the larger fish are eating aquatic beetles.

a **Develop a food web model that shows the pond organisms and their interactions. Be sure to do the following:**

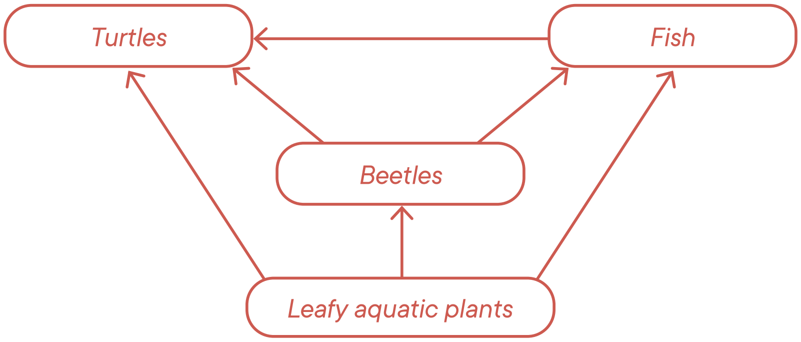
- label each organism in your model,
- show the interactions between organisms in your model,
- identify the system your model represents, and
- describe the feeding relationships shown in your model by explaining at least three species interactions.

b **Use your model to predict what would happen to the population of other species if all the beetles died. Explain your reasoning.**

c **Imagine wanting to investigate the possible effect that the arrival of the nine-banded armadillo, which eats insects found in or near the water, could have on your local ecosystem. Use your food web model to predict what might happen. Be as specific as possible.**

`NOTE: The interactions students show may vary.`

Level 4 response

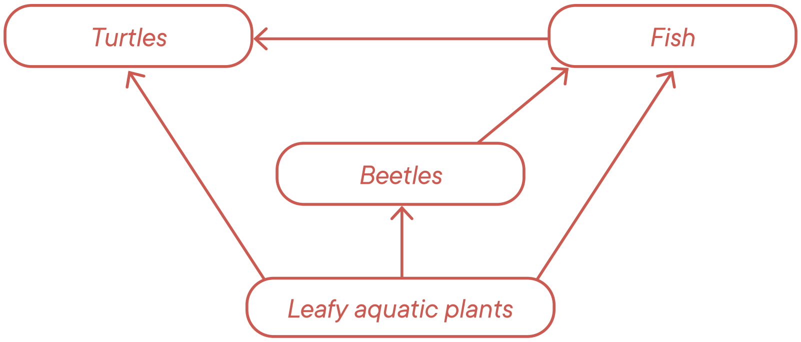


a *My model represents a food web of a pond. Turtles eat fish, beetles, and fish. Fish eat beetles and plants. Beetles eat aquatic plants.*

b *If all the beetles died, the populations of fish and turtles might also go down because they would lose a food source.*

c *If an armadillo ate the beetles, it would compete with the turtles and fish for this food source. This could first result in a decline in the beetle population and then maybe also reduce the population of turtles and fish over time.*

Level 3 response

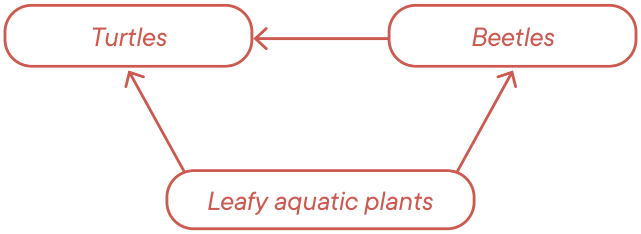


a *This is a pond ecosystem model. It shows which species eat each other. Fish, beetles, and turtles eat leafy plants, fish also eat beetles, and turtles also eat fish.*

b *Without beetles, fish would have one less food source.*

c *If armadillos came and ate beetles, fish would eat more plants. There would be less plants.*

Level 2 response

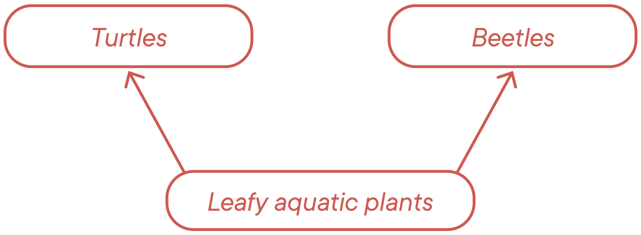


a *In the pond, the turtles and beetles eat the plants.*

b *Without beetles, turtles would only have plants to eat.*

c *With armadillos, turtles would have less food. There might be less turtles.*

Level 1 response



a *Leafy plants provide food for turtles and beetles.*

b *If there were no beetles, turtles would have lots more plant food.*

CONNECTIONS TO EVERYDAY LIFE

⑤ **Think about the physical layout of the building and grounds of your school. You have a mental model of the size, shape, and location of classrooms, offices, and other facilities.**

- a **What observations helped you to develop this model?**

  Seeing the school layout as I walked around helped develop my mental model.

- b **Does your mental model include any elements of the buildings that you have not observed (for example, a room that you have not been inside)? If so, how were you able to include them in your mental model?**

  Yes, I know where some closets are because I've seen the doors, but they're locked. I was able to include them because of my prior knowledge of similar spaces.

⑥ **A GPS navigation app uses a model to predict the fastest route and arrival time. Think about your own experience with such apps and their relative accuracy.**

- a **Think about a situation from your own experience where the model did not correctly predict the fastest route and/or correct arrival time. What happened to affect the model's accuracy?**

  An accident happened on my route around the time I left home. The app did not update that quickly.

- b **Could the model be revised to address this type of situation? Why or why not?**

  It could be revised if there were millions of sensors everywhere to relay this data in real time.

REFERENCES

Blackwood, J. S., Dresner, M. Luh, H.-K. (April 2006, posting date). Using student generated qualitative ecological models. *Teaching Issues and Experiments in Ecology, Vol. 4:* Experiment #4. https://www.esa.org/tiee/vol/v4/experiments/ecological_models/synopsis.html

STUDENT SHEET 3.1

MAKING LOCAL OBSERVATIONS

NAME

Organism What is it?	**Observations** How many? Where is it? What is it doing? You can add sketches.	**Possible feeding relationships within the ecosystem**	**Questions you have about organisms and their interactions**

STUDENT SHEET 3.1

MAKING LOCAL OBSERVATIONS

NAME SAMPLE STUDENT RESPONSE

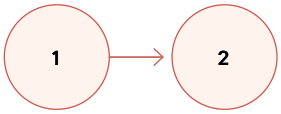
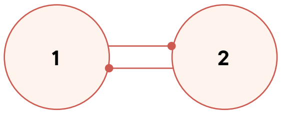
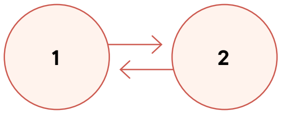
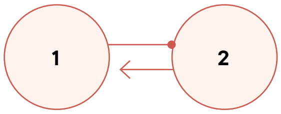
Organism What is it?	**Observations** How many? Where is it? What is it doing? You can add sketches.	**Possible feeding relationships within the ecosystem**	**Questions you have about organisms and their interactions**
Crows	*Two crows on different tree branches making sounds, bobbing heads*	*Eating insects, scavenging food from people/dead animals*	*What do crows eat?* *How many crows in an average flock?*
Small bird	*One flying overhead*	*Eating insects*	*What bird is it?* *Where do these small birds nest?*
Black ants	*Four ants along the path near the grass border, moving around in different ways*	*May gather nectar from flowers, may be food for other organisms*	*What do ants eat?* *Do birds eat ants?* *Where is the ant hill?*
Marigold flowers	*Patch of seven yellow-orange flowers that smell a little lemony*	*May be food for other animals or insects*	*Do bees pollinate marigolds?* *Are these flowers native to our area?*
Trees	*Three large trees*	*Makes its own food using sunlight, provides food to other organisms such as squirrels*	*What type of tree is it?* *Is it native, or has it been planted?*

STUDENT SHEET 3.2 | AN ECOLOGICAL RELATIONSHIP MODEL | NAME

Table 1: Common Ecological Relationships

Commensalism	An interaction where one organism or species benefits while the other is unaffected. For example, birds benefit from nesting in trees, but most trees are unaffected by the presence of nests.
Competition	An interaction between organisms or species in which both require a resource that is in limited supply. For example, two different bird species may compete for the same food source.
Mutualism	An interaction where both organisms or species benefit. For example, bees gather food (nectar or pollen) from flowering plants, and flowering plants disperse pollen to other plants of the same species to aid in reproduction.
Parasitism	An animal or plant that gets nutrients by living on or in an organism of another species. For example, black-legged ticks are common parasites of deer, and they live on their skin while feeding on their blood.
Predation	An interaction where one organism (the predator) eats another organism (the prey). For example, predators such as wolves eat prey such as caribou. (Herbivory is a type of predation where an animal eats parts of plants.)

Table 2: Representing Ecological Relationships in a Model

Commensalism	Organism 1 has a positive effect on Organism 2 without any effect on itself.	
Competition	Two organisms negatively affect each other.	
Mutualism	Two organisms positively affect each other.	
Parasitism, Predation	Organism 1 has a negative effect on Organism 2, while Organism 2 has a positive effect on Organism 1.	

CONTINUED

BUILD UNDERSTANDING ITEM 4 ALTERNATIVE:

Imagine you visited a park with a small pond and recorded the following observations about the organisms there.

ORGANISM	NUMBER	OBSERVATIONS
Turtles	3	One turtle sat on a log in the sun. The other two were eating plants and beetles, and one of them caught a small fish and ate it.
Algae	Lots	Algae is growing at the edges of the pond and on the sides of the log in the pond.
Leafy aquatic plants	Lots	The plants are growing under water in the shallow area of the pond.
Fish	At least 50	There are different-sized fish, but they all look similar. The smaller fish are eating the algae, and the larger fish are eating the leafy aquatic plants.

a **Develop an ecosystem model that shows the pond organisms and their interactions. Be sure to do the following:**

- label each organism in your model,
- show the interactions between organisms in your model, and
- label your model with a title.

b **Describe the ecological processes shown in your model by identifying at least three ecological interactions and explaining how the organisms interact.**

CONTINUED

BUILD UNDERSTANDING ITEM 4 ALTERNATIVE:

Imagine you visited a park with a small pond and recorded the following observations about the organisms there.

ORGANISM	NUMBER	OBSERVATIONS
Turtles	3	One turtle sat on a log in the sun. The other two were eating plants and beetles, and one of them caught a small fish and ate it.
Algae	Lots	Algae is growing at the edges of the pond and on the sides of the log in the pond.
Leafy aquatic plants	Lots	The plants are growing under water in the shallow area of the pond.
Fish	At least 50	There are different-sized fish, but they all look similar. The smaller fish are eating the algae, and the larger fish are eating the leafy aquatic plants.

a **Develop an ecosystem model that shows the pond organisms and their interactions. Be sure to do the following:**

- label each organism in your model,
- show the interactions between organisms in your model, and
- label your model with a title.

b **Describe the ecological processes shown in your model by identifying at least three ecological interactions and explaining how the organisms interact.**

VISUAL AID 3.1 | SCORING GUIDE: DEVELOPING AND USING MODELS (MOD)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION
Level 0 **Missing or off task**	The student's response is missing, illegible, or irrelevant.
X	The student had no opportunity to respond.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.	The student response: • includes all four organisms. • correctly shows and explains at least one interaction between all four organisms. • correctly and thoroughly predicts what would happen to other species in two different scenarios.
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.	The student response: • includes all four organisms. • correctly shows at least one type of interaction between all four organisms. • correctly predicts what would happen to other species in two different scenarios, BUT explanations are minimal.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.	The student response: • includes at least three organisms. • correctly shows interactions between some organisms BUT does not include all organisms. • predicts what would happen to other species in different scenarios, BUT predictions are partially incorrect or incomplete.
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.	The student response: • may not include all four organisms. • shows interactions between a few organisms, BUT the model is mostly incorrect or incomplete. • includes predictions that are vague, incomplete, or incorrect.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 0 **Missing or off task**	The student's response is missing, illegible, or irrelevant.	
X	The student had no opportunity to respond.	

v 1.0

ACTIVITY 4

Modeling Factors Affecting a Population

COMPUTER SIMULATION

ACTIVITY 4

Modeling Factors Affecting a Population

ACTIVITY SUMMARY

Using computer models, students investigate the inclusion of factors in a model based on their relative impact, known as *orders of understanding*. The first model explores the changing distribution of two fictional butterfly species. Students use this model to determine how each of four environmental factors appears to affect each species. A second model provides a clearer picture of the orders of understanding of factors on each species. Students make predictions about the likely future population size and distribution. They then apply their findings to make a decision about possible actions to address the changing butterfly populations.

ACTIVITY TYPE
COMPUTER SIMULATION

NUMBER OF 40–50 MINUTE CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1. When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding*.
2. Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.
3. Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

CONCEPTUAL TOOLS

SCIENTIFIC MODELING

ORDERS OF UNDERSTANDING

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTIONS:

Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (*Science and Engineering Practice: Analyzing and Interpreting Data*)

Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. *(Science and Engineering Practice: Developing and Using Models)*

VOCABULARY DEVELOPMENT

orders of understanding

the factors included in a model based on which factors have a greater impact on the system than others

TEACHER BACKGROUND INFORMATION

Orders of Understanding

Since complex systems are affected by many factors, it is often useful to distinguish between those factors having the greatest impact and those factors that have a lesser impact. For example, the factors most affecting a student's success in outdoor basketball shots may be regular practice and distance from the hoop, while a less important factor may be weather. A qualitative distinction can be made between the cause(s) with the greatest impact on a given variable (known as the first-order factor), the causes with somewhat lesser impact (second-order factor), and the much less influential causes (third-order factor and higher).

In Activity 4, students are introduced to orders of understanding as they explore the effects of various factors on two butterfly populations. Students use a rating scale from 1–3 to distinguish between those factors that have the greatest impact on the population size (rated as 1) and those that have a smaller impact (rated as 3). Because this rating is a scale and not a ranking, two or more factors may have the same rating.

Later in the unit, students apply the concept of orders of understanding to construct models. When constructing a model, it is important to consider the scientific question being investigated and the effect size of different factors in the system. Constructing a model usually requires identifying and including first-order factors—factors with a greater impact on other parts of the system. A more detailed model will also include factors with a lesser impact (i.e., second-order factors and higher). Differentiating orders of understanding is useful in deciding what factors to include in a model.

Orders of understanding can be thought of as the level of detail included in a model. A first-order understanding includes only first-order factors (those with a big impact), a second-order understanding includes first-order and second-order factors (those with a medium impact), and a third-order understanding also includes factors with a small impact.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 4.1 “Population Factors”
- TOPOGRAPHIC MAP OF LOCAL AREA (OPTIONAL)

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 4.1 “Butterfly Bluff Simulation: Model 1 Data”
- STUDENT SHEET 4.2 “Butterfly Bluff Simulation: Model 2 Data”
- STUDENT SHEET 4.3 “Butterfly Bluff Park: 2050”
- STUDENT SHEET 4.4 “Writing Frame: Evidence and Trade-offs” (OPTIONAL)
- STUDENT SHEET 1.3 “Unit Concepts and Skills (OPTIONAL)

Review the Butterfly Bluff Simulation before class so you are familiar with how it functions and are prepared to answer questions.

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

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

- Remind students they looked at a model of the distribution of monarch butterflies in Activity 2. Ask, Have you observed any butterflies in this area? Ask students to share their observations and what they deduced about the role of butterflies in the local ecosystem. Butterflies are pollinators (transferring pollen between flowering plants to enable plants to produce seeds and fruits) and a part of the food chain. The presence of butterflies can indicate environmental health, while a lack of butterfly populations can signal ecosystem stress. Explain to students that they will investigate factors that affect butterflies, utilizing a fictional scenario based on real-world data.
- The fictional scenario presented in Procedure Step 1 can be shared with the class in multiple ways. Read it 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. Depending on your student population, use oral storytelling to support diverse learners in decoding scientific ideas and constructing meaning and ask questions about the main points of the scenario to ensure comprehension. Students can refer to the text in the Student Book as needed.
- 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.
- Let students know that the two butterfly species described in the scenario are not a real species. The Alpine Crystal butterfly is loosely based on an Alpine butterfly that depends on a specific host plant, while the Indigo Longwing is more of a generalist species that has a broader number of resources in its diet.

PROCEDURE (20 MIN)

2 **Brainstorm factors that could affect the distribution of a species.**

- In Procedure Step 2, have students brainstorm factors that could affect the population size and range of a butterfly species. Generate a list that can be revisited at the end of the activity. If appropriate for your student population, such as with emerging multilingual learners, consider having students initially respond in pairs and then share their ideas with the larger class.

Sample Student Response, Procedure Step 2

- availability of food

- humans moving into area/new construction

- changes in predator population

- looking for water

- changes in temperature

- natural hazard, such as a hurricane (moving organisms into new areas)

3 **In Part A, students use Model 1 to observe how factors affect the distribution of two fictional butterfly species over time.**

- Model 1 provides data on a map and utilizes a key to distinguish butterfly species, geographic features, and regional factors. Note that the key changes based on which elements of the simulation are selected. There is also a compass rose on the bottom-right corner of the map indicating the four cardinal directions: north, south, east, and west. Depending on your student population, you may wish to review the use of the key, a compass rose, and the meaning of the term *mean temperature* (i.e., average).

- Note that the simulation relies on color to identify changes to a factor over time and to distinguish among factors. If you have a student with limited visual acuity or color blindness, you may need to provide additional guidance or pair the student with someone who can help interpret the simulation.

- Model 1 allows students to toggle the topographic map on and off, as described in Procedure Step 4. To check for student understanding, ask, Where are the highest and lowest points on the topographic map of the Butterfly Bluff area? Students should be able to tell that the highest point is the top of the bluff, which is 1,600 meters (5,249 feet) and that the lowest point is Bluff Lake and the shoreline of the ocean, both below 200 meters (656 feet). For students who need more support with the use of a topographic map, use a few online topographic maps to show how elevation is presented. It may be helpful to provide a topographical map of your local area with a familiar landform.

- In Procedure Step 5, hand out Student Sheet 4.1, “Butterfly Bluff Simulation: Model 1 Data,” and assign each pair to a butterfly species. Have students explore changes to their assigned butterfly population over the three time periods presented on the map: 1975, 2000, and 2025. In this step, they do not select any of the factors, though the river width on the map does visually change over time; when the River Width factor is selected, data on the exact width of the river can be seen on the map. As students work, have them record their observations of Model 1 on the student sheet. A sample student response can be found at the end of this activity.

- In Procedure Steps 6 and 7, students look at how each factor changes over time and how each factor affects a butterfly population. Students may deduce that river width is the one factor that does not affect either species. If students do not notice this at this point in the activity, you need not explain it as it will become apparent in Model 2.

- In Procedure Step 8, students should have observed that the population distribution of both species changed over time. When pairs compare notes with another pair, they should share that the Indigo Longwing range has moved along the river and shrunk slightly and that its population size has been slightly declining. The Crystal Alpine butterfly range has shrunk significantly and moved up in elevation, and its population size has been declining significantly.

  Sample Student Response, Procedure Step 8

  Similarities:
  Both species' ranges moved, and their populations declined.

  Differences:
  The Crystal Alpine moved up in elevation and lost more land area than the Indigo Longwing.
  The Indigo Longwing moved along waterways such as the river and lake.

- At the end of Part A, you may want to ask students to hypothesize why the butterfly distribution is changing. Responses may vary, depending on students' awareness of changing regional temperatures and its relationship to climate change. Students who understand the impact of a warming climate may point out that a higher temperature could change the location of the food source. Or, in the case of the Indigo Longwing, the species could be found by a water source. If students do not yet see that the Crystal Alpine range is shifting to a higher elevation as a result of climate change, do not share this as it will become evident as they progress through the activity.

4 **In Part B, students use Model 2 to further investigate how factors affect the population size of both fictional butterfly species.**

- Model 2 shows the impact of 6 different factors on the population of a butterfly species. Students can move each factor independently to see its impact on a population.

- Before students begin Part B, remind them that in Model 1, they were able to see that the changes over time indicated that there are some relationships between the factors and butterfly distribution. Ask, Did Model 1 allow you to know which factors have a greater or lesser impact on the species distribution? No, Model 1 provided data about potential relationships between the distribution of a species and several factors, but it did not provide enough information to conclude exact effects or the relative impact of one factor over another. Let students know that in Part B, they will explore a second model to further explore the effects of each factor on each species, as well as two additional factors: disease and predation.

- In Procedure Step 10, hand out Student Sheet 4.2, "Butterfly Bluff Simulation: Model 2 Data." Students collect data to help determine which factors are having an impact on their butterfly species. Students should find that, while food availability is critical to both species, each species has different relative factors that impact them. For example, the Crystal Alpine is more affected by disease compared to the Indigo Longwing. The Indigo Longwing is more sensitive to precipitation than to predation. A complete sample student response for Student Sheet 4.2 is shown at the end of this activity.

- Use Visual Aid 4.1, "Population Factors," to help describe the relationship between the species and the six factors in the model.

5 Students determine the orders of understandings for the factors in Model 2.

- The factors affecting the two species are different and have different relative impacts. As students rate the factors by applying orders of understanding, point out that the factors having the greatest impact are rated as "1" and factors having less impact are rated as either "2" or "3." Be clear that this rating is not a ranking. They may choose to use the same rating number for factors that appear to have similar impacts. They can label two factors as a 3, and/or they may not end up using every rating number. For example, for the Crystal Alpine, disease, food availability, and temperature appear to have a significant impact on its population size and, therefore, all could be rated a 1 for having a greater impact than other factors.
- If your student population needs additional support, create a list of word cues associated with each rating. For example, factors that have "serious impact/significantly reduce/primary impact" could be rated 1 (largest impact), factors that are "constant/steady" rated 2 (medium impact), and factors that are "little/no impact" rated 3 (lowest impact).
- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition by adding the term *orders of understanding* to the word wall and providing an example as needed. For more information on a word wall, see Appendix 1: Literacy Strategies.
- In Procedure Step 13, when pairs compare their conclusions from their butterfly species to the conclusions of another pair who were assigned a different species, they should see that the two species have different orders of understanding for the various factors. Without having distinguished orders of understanding in Model 1, these differences may have been missed. Identifying the factors that have the greatest impact on a species and knowing how that factor is likely changing over time can be used to make more accurate future predictions. Students use this information to make a prediction about population distribution of both species in the year 2050.
- Students should notice that some factors have a positive impact on populations, and some have a negative impact. In Model 2, food availability had a positive effect on population size, and other factors had a negative effect. Challenge students to think about the direction of the effect (positive or negative) and how it relates to orders of understanding. Point out that in the context of orders of understanding, it doesn't matter if the factors have a positive or negative effect. It is the quantity, or absolute value, of the factor that determines its orders of understanding.

6 **Students use Model 1 and Model 2 to predict the future of the species.**

- Ask students to consider how information from both models can be used together to help explain observed changing population distribution of the species. For example, Model 1 showed that the Crystal Alpine butterflies are now found in a narrower range of higher elevation. Model 2 provides data that indicates that the Crystal Alpine are sensitive to temperature and likely moving to a cooler climate at a higher elevation. The fact that there is less food availability in this smaller geographical area helps explain its population decline.

- In Procedure Step 14, students have to combine their understanding of how the distributions are changing over time (Model 1) with the relative impact of the factors on population (Model 2). On Student Sheet 4.3, "Butterfly Bluff Park: 2050," students predict a possible species distribution for both species in the year 2050. Responses may vary, but one possible sample student response is shown at the end of this activity.

- In Procedure Step 15, lead a discussion in which students share and compare their predictions. While students explain their predictions, encourage them to cite which model they used for each aspect of their prediction.

SYNTHESIS OF IDEAS (20 MIN)

7 **Discuss the similarities and differences between Model 1 and Model 2.**

- Both models provide information about butterfly populations. Model 1 shows a changing range and population density with a potential correspondence to different factors, while Model 2 shows relationships between individual factors and butterfly population size.

- Discuss the kinds of questions each model can answer. Through the experiences with both models, students should be able to brainstorm questions related to the characteristics of each model, as shown in the following table:

MODEL	CHARACTERISTICS OF EACH MODEL	POSSIBLE FUTURE QUESTIONS
1	• Population density • Species range • Food availability, precipitation, river width, temperature over time • Map (visual data)	• How many butterflies can be found within the park boundary? • Where can the greatest number of Indigo Longwing be found? • What mean temperature range appears to provide the most suitable habitat for the species?
2	• Population size • Relative impact of each factor on population size (orders of understanding) • Impact of food availability, precipitation, river width, temperature, disease, and predation on population • Numerical data • Potential relationships between factors	• Is the Crystal Alpine species more likely to be affected by changes in predation or temperature? • Which species will be more affected if average precipitation levels increase? • What factor is most likely to result in an increase in population?

- Use the characteristics of the two models to emphasize the key concept that different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

8 Discuss the role of orders of understanding in designing a model.

- To reinforce the concept of orders of understanding, ask, If you could only model one factor in the butterfly simulation, which one would it be? Students are likely to say food availability or temperature since these factors had the greatest impact on both species. These factors had higher orders of understanding for the model. Follow up by asking, If the butterfly model only used a factor with a lower orders of understanding, how useful would the model be? The predictions made with such a model would not be very useful; for example, a model based on river width alone would not show any effect on butterfly distribution. For the Indigo Longwing, if the factor that was modeled was disease, which was a lower order relative to the others, or predation for the Crystal Alpine, then the model would provide little insight into changes in species distribution. In the class discussion, reinforce the idea that any model reflects the information that is used to build that model.

9 Students make a decision about the Butterfly Bluff scenario in Build Understanding item 2.

- Build Understanding item 2 applies the concepts of evidence and trade-offs to decision-making. For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 4.4, “Writing Frame: Evidence and Trade-Offs,” to compose their responses. Students could also use Student Sheet 4.4 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

10 Use optional Student Sheet 1.3, “Unit Concepts and Skills,” to help track important concepts of the unit.

- You may wish to have students revisit optional Student Sheet 1.3, “Unit Concepts and Skills,” and add information about orders of understanding.
- Finish the activity by revisiting the Guiding Question, *What factors should be included in a scientific model?* Use responses to this question to formatively assess students’ understanding of the key concepts and process skills. Students’ responses should indicate their understanding that models should include factors that have the greatest impact (higher orders of understanding), as determined by the scientific questions that are being investigated.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **When constructing a model, it is important to know which aspects of the real world to include and which to leave out. Imagine you were asked to construct a model to investigate a previously unstudied population of butterflies in Butterfly Bluff Park. The model should answer the scientific question *Why is the population of this species increasing at lower altitudes?* What factors would you include in the model and why?**

I would include food availability, elevation, and temperature because these factors address the scientific question being asked and because the models used in this activity showed that food availability was the only included factor that increased population.

② **Butterfly enthusiasts who visit Butterfly Bluff Park are concerned about the changes in the populations of Indigo Longwing and Crystal Alpine butterflies. They are discussing the following four options with local park managers.**

- **A Expand the boundary of Butterfly Bluff Park to the east and north so Bluff Lake and the surrounding areas are maintained as a protected food source for the Indigo Longwing.**
- **B Actively plant the host plant at the top of Butterfly Bluff, which is the primary food for the Crystal Alpine.**
- **C Increase the treatment of disease for both butterfly species.**
- **D Do nothing.**

Which option(s) would you recommend as the highest priority? Support your answer with evidence from the models and identify the trade-offs of your decision.

Answers will vary. One sample response follows:

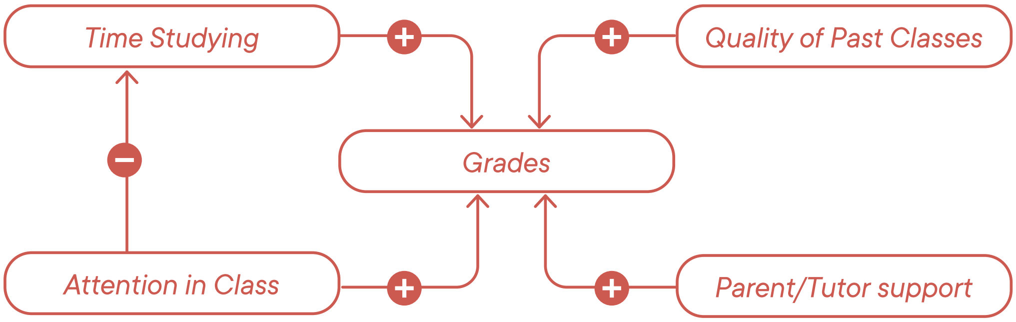
I support Option B, planting food. My decision is based on three pieces of evidence. First, Crystal Alpine butterflies have been moving up in elevation based on Model 1. Second, they are running out of food availability as they move up in elevation. Third, food availability is one of the factors most affecting Crystal Alpine population size based on Model 2. The trade-off is that it costs time and money, and the plants might not survive. People who disagree with my decision might say that planting food interferes with nature and may have consequences for other species.

CONNECTIONS TO EVERYDAY LIFE

③ **You may spend a lot of time on social media apps. The apps' feeds seem to know what videos you want to watch next. What are three factors you think are incorporated into the apps' models to predict what videos you may like? List these factors according to their impact, considering orders of understanding, and explain your reasoning.**

Previous watch history, viewing time, and shares. Whenever I watch a new show, my feed changes. It seems less affected by my viewing time and shares.

④ **Think about how your actions affect your grade in your favorite class. Construct a model to represent the factors that you control that most affect your grade and whether each factor has a positive or negative effect. Be sure to include arrows showing any relationships between factors.**



STUDENT SHEET 4.1

BUTTERFLY BLUFF
SIMULATION: MODEL 1 DATA

NAME

Butterfly Species: ____________________

Table 1: Butterfly Distribution, 1975–2025

Range	
Population Size	

Table 2: Factors Possibly Affecting Species Distribution

FACTOR	TREND OVER TIME	POSSIBLE CORRELATION BETWEEN FACTOR AND SPECIES DISTRIBUTION
Food availability		
Precipitation		
River width		
Temperature		

STUDENT SHEET 4.1 | BUTTERFLY BLUFF SIMULATION: MODEL 1 DATA | NAME SAMPLE STUDENT RESPONSE 1

Butterfly Species: *Indigo Longwing*

Table 1: Butterfly Distribution, 1975–2025

Range	*Moved east and north along river toward Bluff Lake and got a little smaller, species range has moved out of park over time*
Population Size	*Decreased a little from 2000 to 2025*

Table 2: Factors Possibly Affecting Species Distribution

FACTOR	TREND OVER TIME	POSSIBLE CORRELATION BETWEEN FACTOR AND SPECIES DISTRIBUTION
Food availability	*Food area has decreased, shrinking into the eastern and northern areas.*	*Food availability appears to correspond to changes in the Longwing's distribution over time.*
Precipitation	*Highest levels of precipitation have moved from the coast eastward, lowest levels of precipitation moved westward.*	*No clear correlation: Longwing's initial range was in areas of high and middle precipitation. Over time, its population remained within the middle precipitation level (25-35 cm).*
River width	*Decreased from 200 meters to 175 meters in area with butterflies.*	*Longwing's range moved north and closer to Bluff Lake where river width appears narrow. No clear correlation.*
Temperature	*Area of highest mean temperature has greatly increased, moving northwest; shrinking band of coolest mean temperature in mountain area.*	*Longwing's range remained within middle mean temperature (18°C/64.5°F). Its distribution appears to correspond to changes in temperature over time.*

STUDENT SHEET 4.1 | **BUTTERFLY BLUFF SIMULATION: MODEL 1 DATA** | **NAME** SAMPLE STUDENT RESPONSE 2

Butterfly Species: *Crystal Alpine*

Table 1: Butterfly Distribution, 1975–2025

Range	*Stayed within a much narrower area of the mountains over time, stayed half in and half out of the park over time*
Population Size	*Decreased a lot (maybe by 50%)*

Table 2: Factors Possibly Affecting Species Distribution

FACTOR	TREND OVER TIME	POSSIBLE CORRELATION BETWEEN FACTOR AND SPECIES DISTRIBUTION
Food availability	*Higher density of food is now available higher up the mountains, and the area of food availability has shrunk slightly.*	*Food density and food area appear to correspond to changes in the Crystal Alpine's distribution over time.*
Precipitation	*Highest levels of precipitation have moved from the coast eastward, lowest levels of precipitation moved westward.*	*Alpine's range remained mostly within the middle precipitation level (25–35 cm) over time. No clear correlation.*
River width	*Has decreased 10–25 meters in different areas.*	*Alpine's range over time does not overlap with the location of the river. No clear correlation.*
Temperature	*Area of highest mean temperature has greatly increased, moving northwest; shrinking band of coolest mean temperature in mountain area.*	*Alpine's range remained within the coolest mean temperature (17°C/63°F). Its distribution appears to correspond to changes in temperature over time.*

STUDENT SHEET 4.2 | BUTTERFLY BLUFF SIMULATION: MODEL 2 DATA | NAME

Butterfly Species: ______________________

POPULATION DATA

FACTOR	INITIAL POPULATION	FINAL POPULATION	CHANGE IN POPULATION	RELATIVE IMPACT ON POPULATION 1 = GREATEST IMPACT 3 = LEAST IMPACT
Disease				
Food availability				
Precipitation				
Predation				
River width				
Temperature				

STUDENT SHEET 4.2 | BUTTERFLY BLUFF SIMULATION: MODEL 2 DATA | NAME SAMPLE STUDENT RESPONSE 1

Butterfly Species: Indigo Longwing

POPULATION DATA

FACTOR	INITIAL POPULATION	FINAL POPULATION	CHANGE IN POPULATION	RELATIVE IMPACT ON POPULATION 1 = GREATEST IMPACT 3 = LEAST IMPACT
~~**Disease**~~	1,000	975	–25	3
Food availability	1,000	1,183	+183	1
Precipitation	1,000	805	–195	1
~~**Predation**~~	1,000	862	–138	2
~~**River width**~~	1,000	1,000	0	3
Temperature	1,000	838	–162	1

STUDENT SHEET 4.2 | BUTTERFLY BLUFF SIMULATION: MODEL 2 DATA | NAME SAMPLE STUDENT RESPONSE 2

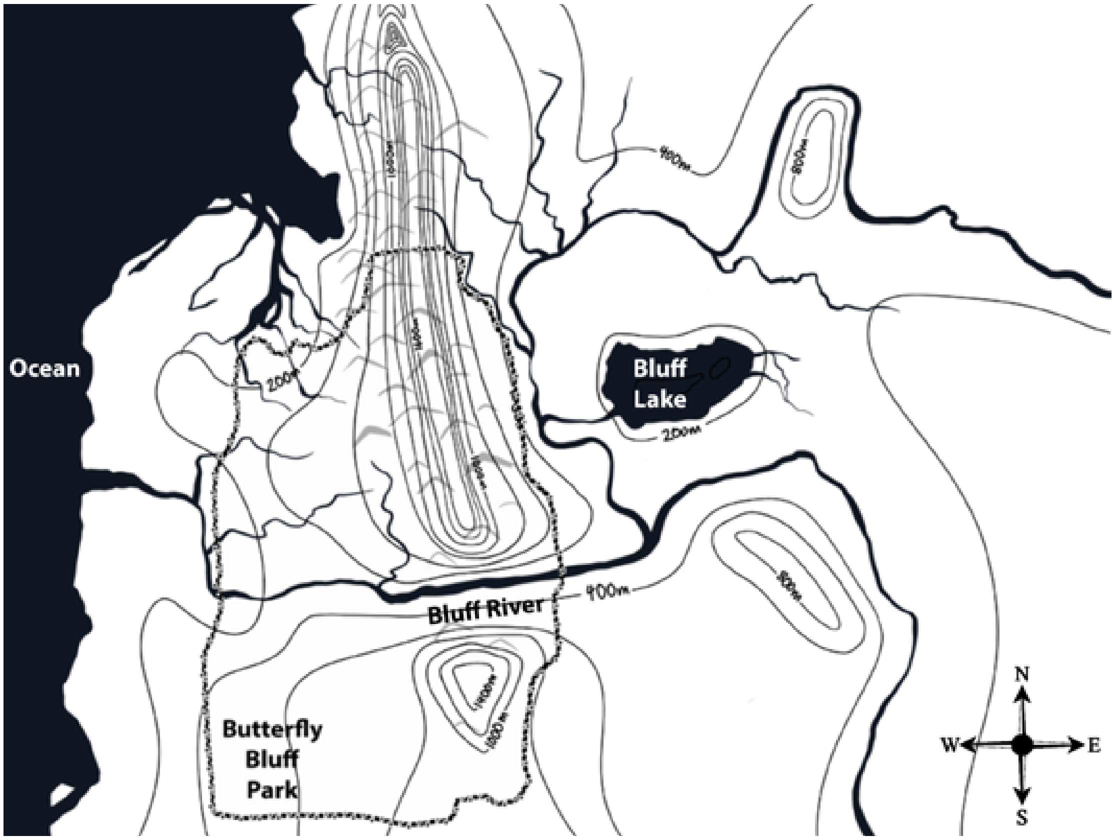
Butterfly Species: *Crystal Alpine*

POPULATION DATA

FACTOR	INITIAL POPULATION	FINAL POPULATION	CHANGE IN POPULATION	RELATIVE IMPACT ON POPULATION 1 = GREATEST IMPACT 3 = LEAST IMPACT
Disease	*1,000*	*773*	*–227*	*1*
Food availability	*1,000*	*1,173*	*+173*	*1*
~~**Precipitation**~~	*1,000*	*880*	*–120*	*2*
~~**Predation**~~	*1,000*	*967*	*–33*	*3*
~~**River width**~~	*1,000*	*1,000*	*0*	*3*
Temperature	*1,000*	*825*	*–175*	*1*

STUDENT SHEET 4.3 | BUTTERFLY BLUFF PARK: 2050 | NAME

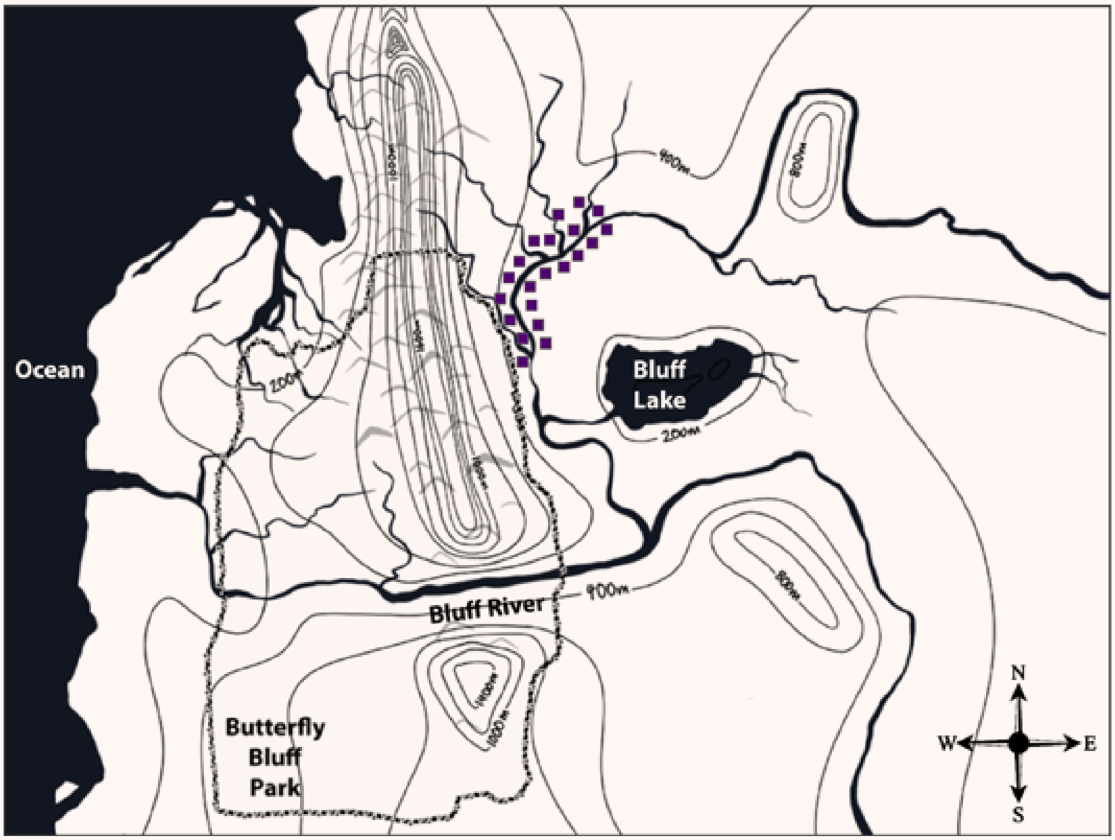
Draw your predictions of the species distribution for the Indigo Longwing and the Crystal Alpine in 2050.



Describe your predictions, making sure to explain your reasoning and how each model informed your prediction.

STUDENT SHEET 4.3 | **BUTTERFLY BLUFF PARK: 2050** | **NAME** SAMPLE STUDENT RESPONSE

Draw your predictions of the species distribution for the Indigo Longwing and the Crystal Alpine in 2050.



Describe your predictions, making sure to explain your reasoning and how each model informed your prediction.

Model 2 showed that the factors most affecting the Crystal Alpine population size are food availability, disease, and temperature. I predict that the Crystal Alpine will disappear from the park and the area altogether because they will run out of places to get food at the top of the bluff as it gets warmer and wetter with climate change. Model 1 showed these trends on the map over time, so my conclusions are based on that trend continuing.

The Indigo Longwing has already disappeared from the park because it is now only found outside its boundary, and I don't think it will come back. Model 2 showed that precipitation, food availability, and temperature had the greatest impact on its population size. Model 1 showed warming temperatures moving northward and the species moving northward along the river over time. I think that the Indigo Longwing will survive, but with a smaller population size and a range that is farther north.

STUDENT SHEET 4.4

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 4.4

WRITING FRAME:
EVIDENCE & TRADE-OFFS

NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

butterfly populations declining in Bluff Park.

My decision is that

the boundary of the park should be expanded north and east.

My decision is based on the following evidence:

First,

the Indigo Longwing range has moved north and east over time and is no longer found within the park.

Second,

its food availability appears to be shrinking over time based on Model 1.

Third,

food is very important to its population based on Model 2.

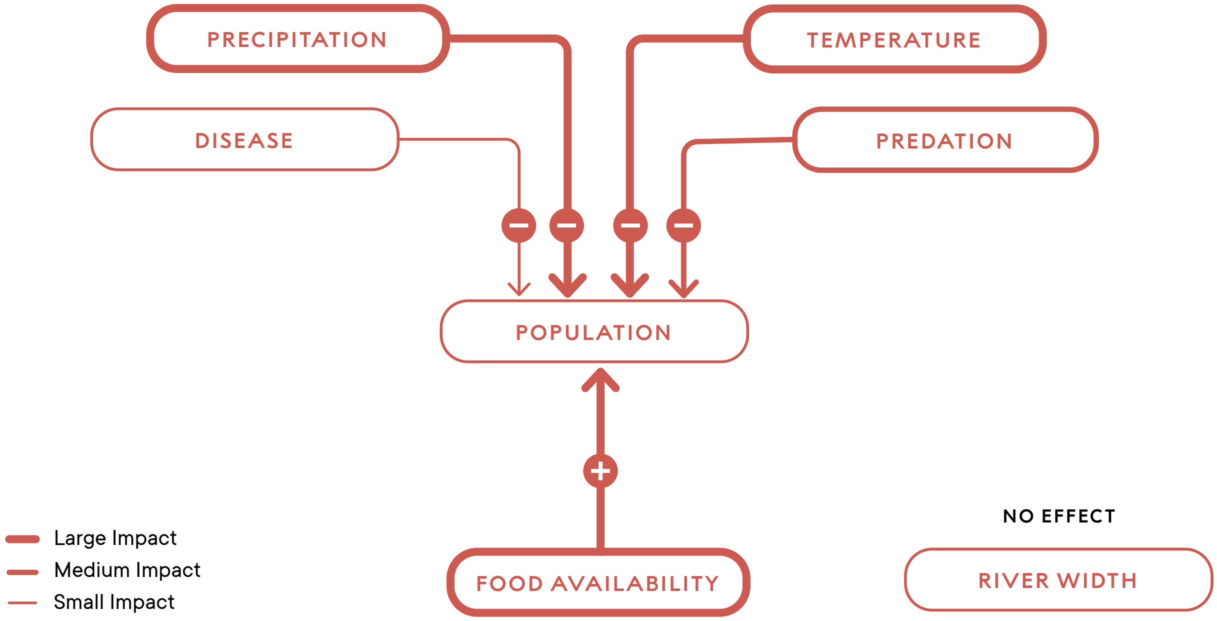
The trade-off(s)

is that expanding the boundary and protecting its food source may not be enough. Changes to temperature and precipitation may cause its population to continue to decline.

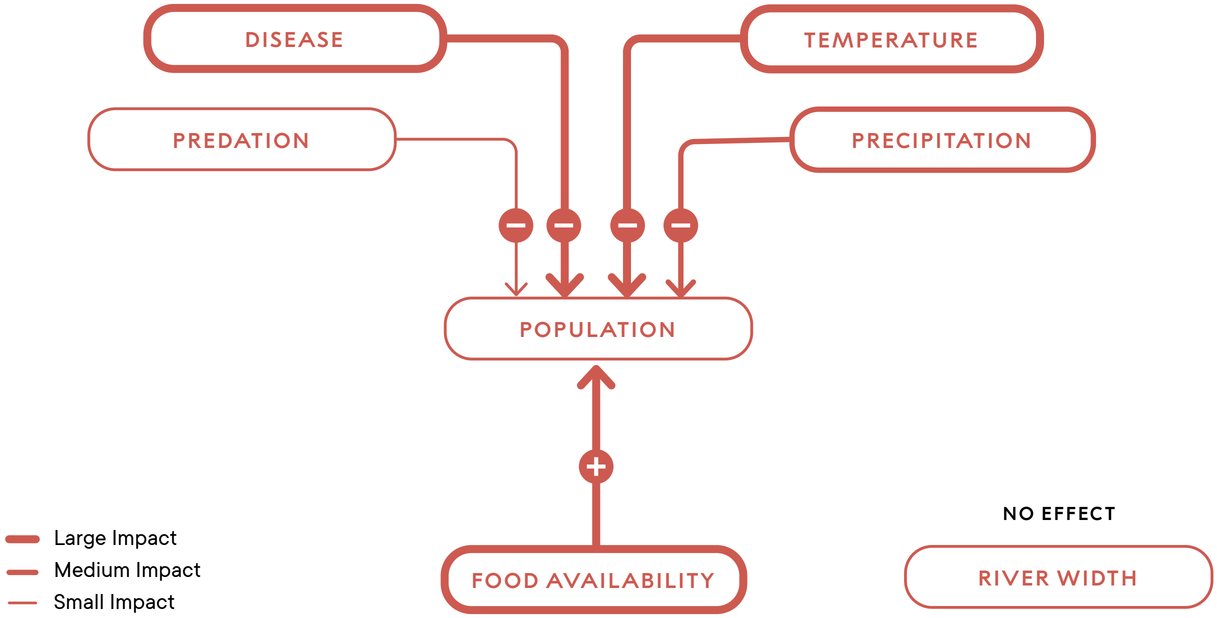
People who disagree with my decision might say that

nature changes over time, so people don't need to do anything.

INDIGO LONGWING



CRYSTAL ALPINE



ACTIVITY 5

The Role of Models in Science

READING

v 1.0

ACTIVITY 5

The Role of Models in Science

ACTIVITY SUMMARY

A reading summarizes important unit concepts about scientific modeling and the role of systems, assumptions, limitations, orders of understanding, and revision in constructing a model. The use of models to study the changing distribution of lobsters off the east coast of Canada and the United States provides real-world examples of ecological research. The potential use of conservation strategies in addressing species change is highlighted.

ACTIVITY TYPE
READING

NUMBER OF
40–50 MINUTE
CLASS PERIODS
1

KEY CONCEPTS & PROCESS SKILLS

1 Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

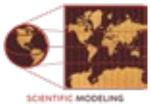
2 Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

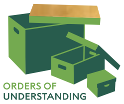
3 Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.

4 Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.

5 When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*

CONCEPTUAL
TOOLS





NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. *(Science and Engineering Practice: Developing and Using Models)*

VOCABULARY DEVELOPMENT

assisted migration

when humans deliberately move species from one location to another

components

factors, relationships, and processes of a system that are being represented in a model

predictive model

a tool to forecast the future

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 5.1 “Read, Think, and Take Note Guidelines”
- VISUAL AID 5.2 “Scoring Guide: Developing and Using Models (MOD)”
- ITEM-SPECIFIC SCORING GUIDE: Activity 5, Build Understanding Item 4

FOR EACH STUDENT

- 3-5 STICKY NOTES
- STUDENT SHEET 1.3 “Unit Concepts and Skills (OPTIONAL)
- SCORING GUIDE: Developing and Using Models (MOD) (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (5 MIN)

1 **Use the Introduction in the Student Book to set the context for the activity.**

- Let students know that, in the Student Book Introduction, they will be reading about how modeling is being used in the seafood industry.

PROCEDURE SUPPORT (30-40 MIN)

2 **Review the Read, Think, and Take Note Guidelines to support students in completing the reading.**

- This reading summarizes key concepts of the unit and provides additional examples of modeling in current ecological research. The Read, Think, and Take Note strategy provides an opportunity for students to record their thoughts, reactions, and questions on sticky notes as they read. The notes serve to make concrete the thoughts arising in their minds and then serve as prompts to generate conversation or write explanations. You can use Visual Aid 5.1, "Read, Think, and Take Note Guidelines," to review this literacy strategy. If your students are unfamiliar with the strategy, it can be helpful to demonstrate with a short passage of simple text, such as the Introduction to the activity. For more information about the Read, Think, and Take Note strategy, see Appendix 1: Literacy Strategies.
- Support students, particularly emerging multilingual learners, in sensemaking and language acquisition as they read the text. For example, students may need help in interpreting the last sentence of the first paragraph in the "Models and Decision-Making" section ("The models estimated that even with changing ocean temperatures, using this strategy would have reduced population decline in southern New England from 78% to 57%."). Circulate around the room and check in with students as they decode scientific ideas and construct meaning as they read.
- Add the terms *assisted migration*, *components*, and *predictive models* to the word wall and provide examples as needed. For more information on a word wall, see Appendix 1: Literacy Strategies

SYNTHESIS OF IDEAS (20 MIN)

3 **Review important ideas about models and their use in science.**

- You may wish to use questions (such as *In general, what do scientific models represent? How are models used in science? What are some ways of revising a scientific model? Why do scientific models have limitations?)* to do a quick post-reading assessment of student understanding and elicit the following main ideas:
  - In science, models are used to represent systems, or parts of systems, in order to study and communicate ideas about those systems.
  - In science, models help scientists make predictions about how systems will behave under given conditions.
  - A scientific model can be refined and revised based on testing it by comparing it to real-world systems, refining it based on new data, adding or deleting factors, and modifying the relationships between factors.
  - All models have limitations because they are simplified representations. As a result, they cannot include every aspect of the real world. While models help explain how things work together, they may oversimplify complex systems or fail to predict unexpected outcomes.
- Highlight the idea that in scientific study, the size and scope of a system is defined by the question being investigated. For example, an astronomer studying black holes may investigate the structure of the galaxy, while an ecologist gathering data on local tick populations may be focused on a local forest ecosystem. Systems thinking is the ability to recognize, describe, and model a complex phenomenon in its structure, behavior, and function (as a system). Systems-thinking skills include identifying system organization, analyzing system behavior, and system modeling. Students build these skills over the course of this unit.

4 **Use optional Student Sheet 1.3, "Unit Concepts and Skills," to highlight the important aspects of scientific models.**

- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about assumptions, limitations, and components. Again, help students think metacognitively by asking questions. For example, ask, What determines which factors are worth including in a model? Students should recognize that the question being investigated helps determine the model and the key elements to be included in the model.

5 **Assess student growth using the Item-Specific Scoring Guide for Build Understanding item 4.**

- Remind students of the Developing and Using Models (MOD) Scoring Guide. You may wish to project Visual Aid 5.2, "Scoring Guide: Developing and Using Models (MOD)" 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 5, Build Understanding Item 4) with students as it provides specific information on how to respond to the item prompt.
- Remind students that you expect to see them demonstrate growth in their development, use, and analysis of models, and they may want to review their responses to the assessment in Activity 3 (Build Understanding item 4). 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 1).
- 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 the 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 do scientific models represent a system?* Use this as a chance to revisit and summarize the key concepts and process skills of the activity.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **Dr. Wahle and his team are modeling how warming waters near the Arctic will affect lobster populations in the Northwest Atlantic. What are two sources of uncertainty in the model's predictions?**

The rate of global environmental change is one source of uncertainty. Another source of uncertainty is the impact that factors that are not included in the model might have on the results.

② **Look back at Figure 3.1: Gulf of Maine Food Web Model in Activity 3.**

a **What factor is missing from this food web model?**

Lobsters.

b **What do you think is the effect of not having this factor in the model? Explain your reasoning.**

The feeding relationships in the food web model are less accurate and can result in incorrect outcomes when using the model to make predictions.

③ **Imagine that the "bottle biology" model shown in Figure 5.4 represents a pond ecosystem.**

a **Identify which parts of the real-world system are included and which parts are excluded from the model.**

The included parts are plants, water, soil, air, snails, and the pond bottom (rocks and leaves). The model does not include larger species such as fish or frogs, the physical space of a pond ecosystem, and weather and other environment changes.

b **Now imagine that the same model is intended to represent planet Earth. Identify which parts of the real-world system are included and which parts are excluded from the model.**

It includes air, water, land, and some of the living parts of Earth (plants and animals). It does not include weather, climate, long-term geological change, and other species (including people).

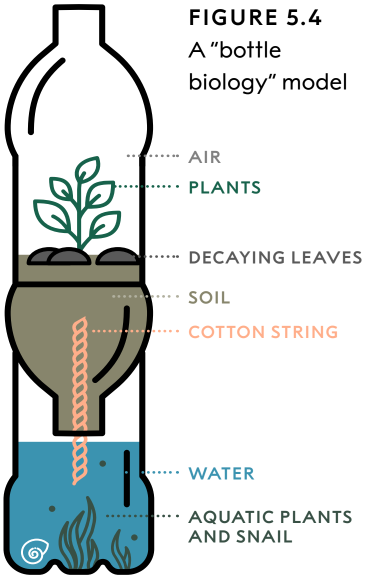


FIGURE 5.4
A "bottle biology" model

c **Which system—a pond ecosystem or planet Earth—is better represented by this bottle biology model? Explain your reasoning.**

Student responses can vary. The focus of a response should be on an explanation supporting their system selection.

I think that the bottle biology model better represents the pond ecosystem because it is missing fewer factors. When the bottle represents Earth, it is missing global processes, which are an important part of Earth's system.

④ **MOD Scoring Guide**

Climate conditions in the upper Midwestern United States have moved about over 300 kilometers (200 miles) north in 2 decades. The climate typical of southern Minnesota from 20 years ago is now in northern Minnesota. In 2016, the United States Forest Service conducted an experiment in assisted migration at Minnesota's Cutfoot Experimental Forest. They planted seedlings of 8 tree species from seeds collected up to several hundred kilometers farther south. There were 4 native species, while the other 4 species were not native. In 7 of the 8 species, the survival rate was 85%–90%. How would you construct a model to investigate the potential impacts of assisted migration for a species of tree?

a **Describe your model in detail and the key factors that you would include.**

b **Choose one key factor. Predict what your model would show if you changed that factor and your model was accurate.**

c **Predict what your model might show if the model was inaccurate.**

Level 4 response

a *I would use a computer model that would include temperature, rainfall, and location of new (assisted migration) tree plantings. My model would have a map that showed the trees' current range and areas where new trees might be planted. It would also show tree growth, with color-coding to show more growth or less growth. My model would include past data, current data, and predicted data based on different factors changing.*

b *One key factor is rainfall. If the model was accurate, it would show that with more rain in areas where the trees were newly planted, there would be more tree growth, and the opposite with less rain.*

c *If the model was inaccurate, the model might show less growth or no growth in areas with more rain, or it might show more growth in areas with less rain.*

Level 3 response

a *I would create a computer model with temperature, rainfall, and location of assisted migration tree plantings. A map would show the area where the trees grow and areas around it. It would also show the amount of tree growth.*

b *If I changed the amount of rainfall in the model and the model was accurate, it would show more tree growth with more rain.*

c *If the model was inaccurate, it might show less tree growth.*

Level 2 response

a *I would use a computer model, like the butterfly one, so I could change things. I would have a map that showed where the trees are. The key factor I would include is rain.*

b *If the model is good, it will show more trees growing.*

c *If it's not good, it won't.*

Level 1 response

a *I would use a computer model with a map. The key factor I would include is trees.*

b *If the model is good, it will show correct predictions.*

CONNECTIONS TO EVERYDAY LIFE

⑤ **A major online clothing retailer wants to use a predictive model to decide how many of a new style of hoodie to order for the upcoming season. If they overpredict, they waste money; if they underpredict, they lose sales. What key factors would they need to input into their model to forecast demand, especially given how fast trends change?**

Key factors may include weather, trend indicators (social media callouts, engagement with the website), and the general state of the economy.

⑥ **Imagine your school district wants to use a predictive model to help improve student success. The model uses data to predict which current freshman students are most likely to not graduate on time four years later.**

a **Identify three different types of data about a freshman student that the school might input into this predictive model.**

Attendance, grades, and number of credits taken per semester.

b **If the model predicts that a specific student has a very high chance of not graduating, this is a prediction, not a certainty. Explain why the model's prediction contains uncertainty.**

Past behavior is not predictive of future behavior. A student's grades or attendance can improve or decline for many reasons. This creates uncertainty in the model.

c **How could the prediction from this model create a useful feedback loop for school administrators to help improve the system and help the student succeed?**

If the model is even slightly accurate, it can help identify at-risk students so they can get additional support services to address attendance, grades, or course credits. This will reduce the likelihood that they will not graduate on time.

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Read, Think, and Take Note Guidelines

Stop at least three times during each section of the reading to mark on a sticky note your thoughts or questions about the reading.

As you read, use a sticky note from time to time to:

- explain a thought or reaction to something you read.
- note something in the reading that is confusing or unfamiliar.
- list a word from the reading that you do not know.
- describe a connection to something you've learned or read previously.
- make a statement about the reading.
- pose a question about the reading.
- draw a diagram or picture of an idea or connection.

After writing a thought or question on a sticky note, place it next to the word, phrase, sentence, diagram, drawing, or paragraph in the reading that prompted your note.

After reading, discuss with your partner the thoughts and questions you had while reading.

VISUAL AID 5.2 | SCORING GUIDE: DEVELOPING AND USING MODELS (MOD)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION
Level 0 **Missing or off task**	The student’s response is missing, illegible, or irrelevant.
X	The student had no opportunity to respond.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.	The student response: • includes a detailed description of the model and multiple relevant key factors. • provides a thorough, logical prediction of model outcomes for an accurate and inaccurate model.
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.	The student response: • includes a description of the model and multiple relevant key factors. • predicts logical model outcomes for an accurate and inaccurate model.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.	The student response: • includes a limited description of the model and at least one relevant key factor. • predicts logical model outcomes BUT may be vague AND/OR may not describe both accurate and inaccurate model outcomes.
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.	The student response: • includes a minimal description and at least one key factor, which may or may not be relevant or appropriate. • includes a prediction of outcomes that is vague, illogical, or not provided.

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* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
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 6

Modeling Migration

GAME

ACTIVITY 6

Modeling Migration

ACTIVITY SUMMARY

Students investigate the similarities and differences between deterministic models and probabilistic models. They begin by constructing a simple deterministic model by graphing the population of a school of bluefin tuna during migration. Students explore a probabilistic model of the same migrating species as they play a board game. The class combines their probabilistic data and compares the outcome with the deterministic model. Students compare the two models while investigating each model's factors and their orders of understanding.

ACTIVITY TYPE
GAME

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2-3

KEY CONCEPTS & PROCESS SKILLS

1. Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.
2. Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.
3. When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. *(Science and Engineering Practice: Developing and Using Models)*

CONCEPTUAL
TOOLS

SCIENTIFIC MODELING

ORDERS OF
UNDERSTANDING

VOCABULARY DEVELOPMENT

deterministic model	a tool that produces a single predictable outcome for a given set of initial conditions
probabilistic model	a tool that uses patterns in data to predict the likelihood of different outcomes. It produces a range of possible outcomes for a given set of conditions

TEACHER BACKGROUND INFORMATION

Bluefin Tuna

There are three recognized species of bluefin tuna: the Atlantic Bluefin *(Thunnus thynnus)*, the Pacific Bluefin *(Thunnus orientalis)*, and the Southern Bluefin *(Thunnus maccoyii)*. Tuna is one of the most important fish in the global food business. Roughly 40,000–68,000 metric tons of all bluefin species combined are caught annually. The global market value is estimated at $2–$2.5 billion.

Bluefin tuna were in rapid decline from the 1970s until around 2010. Since 2009, the population of some species have begun to recover as a result of collaborative fishing rules across the globe. Some populations have recovered by about 50% in 20 years and are no longer considered overfished. The range of the bluefin tuna continues to be impacted by changes in the climate.

Deterministic Models

A deterministic model is one that produces a single, predictable outcome for a given set of inputs. It has no random or uncertain variables. A simple example is a model in the form of an equation that describes a physical system, such as speed = distance/time. This mathematical model will always give the same quantity when calculated, given the same inputs. Deterministic models are useful when future events can be calculated exactly. It is most used when a system is fully understood and the external influences on the system are not significant or negligible.

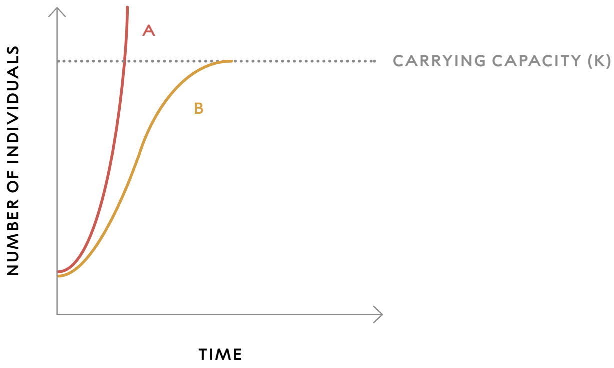
Probabilistic Models

A probabilistic model (sometimes referred to as stochastic model) is one that does not provide a definitive output for a given input, but a probability distribution of possible outputs. A probabilistic model is useful when dealing with uncertainty and randomness in data or phenomena. Probabilistic models are powerful tools for prediction in a complex or incompletely understood system because they can evaluate the potential results of different actions. As new data emerges and processes are better understood, a probabilistic model can update its estimates and become more accurate. An everyday example of a probabilistic model is weather forecasting. For example, a model predicting tomorrow's weather may conclude there is a 70% chance of rain, 20% chance of clouds, and 10% chance of sun based on current conditions and historical data.

Population Growth Curve

In an ecosystem, a population growth curve can vary based on the specific characteristics of the organism or population being studied. These growth curves can vary based on factors such as the initial population size, the rate of growth, and the carrying capacity of the environment. The carrying capacity of an ecosystem is the maximum population size of a species that can be sustained by the environment under study, given the resources available. It corresponds to a population equilibrium, when the number of deaths in a population equals the number of births.

In the following diagram, Curve A shows exponential growth in the absence of a carrying capacity, and Curve B shows logistic growth where the environment has a carrying capacity.



MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 6.1 "Bluefin Tuna: Deterministic Model"
- VISUAL AID 6.2 "Bluefin Tuna: Deterministic and Probabilistic Models"
- VISUAL AID 1.1 "Interpreting Graphs" (OPTIONAL)

FOR THE CLASS

- CHART PAPER (or a visual aid)
- MARKERS

FOR EACH GROUP OF FOUR STUDENTS

- BLUEFIN TUNA MIGRATION GAME BOARD
- NUMBER CUBE
- COIN
- 4 SMALL GAME PIECES (4 different-colored disks)
- SET OF EVENT CARDS (20 cards, 4 for each of 5 weeks)

FOR EACH STUDENT

- STUDENT SHEET 6.1 "Bluefin Tuna Game Tracker"
- STUDENT SHEET 6.2 "Writing Frame: Evidence and Trade-Offs" (OPTIONAL)

Bluefin Tuna Migration Game

- For each group, make a copy of the two-page game board and tape it together. Check that the game pieces are appropriately sized to fit on the spaces of the game board.
- For each group, print a set of 20 Event cards. Each card needs a front (content of the card) and a back (WEEK # EVENT). The backs of the cards will be face up on the table when students create the 5 piles of cards. These should be printed double-sided. Alternatively, you can write "WEEK # EVENT" on the back of each card.
- The game is designed for groups of four. If played with fewer than four, some trends may not be revealed to group members. In that case, the class data should show these patterns.

In Procedure Part B, student-generated data will be used to create a class graph. Decide how you would like students to share their data (either on a single sheet of chart paper or on a visual aid). Set up the x-axis and the y-axis and post the empty template so each student can record their individual data for each week on the class graph.

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Elicit students' prior knowledge about the fishing industry.**

- Inform students that they are going to play a game to model the migration of a population of bluefin tuna. You may want to share some of the Teacher Background Information with students to emphasize the enormity of the global bluefin tuna fishing industry.
- Probe students to see how familiar they are with tuna as a food source in people's lives. Students may have varied ideas about the concept of tuna and fish as a food source based on family or cultural insights, practices, and personal histories. Acknowledge funds of knowledge as assets to building understanding. Encourage students to respond to this topic or to questions that arise from it by sharing their ideas during small-group or class discussions or by writing reflections in their science notebooks.
- In the mid–20th century, bluefin tuna populations faced severe declines due to intense overfishing. But international management efforts have led to a much more robust population. Let students know that the models in the activity do not reflect any specific time period of the bluefin tuna's history and are generalized to illustrate the function of different kinds of models.

2 **Students consider factors that impact bluefin tuna populations.**

- Use the Think-Pair-Share strategy with students. Ask, What are some factors that may affect how many of the bluefin tuna successfully migrate? Possible responses include food availability, water conditions, and predators such as sharks and fishers. Record student responses on the board so they can refer back to them at the end of the activity. Ask, How might these changes to these factors improve or worsen the size and health of tuna populations in the future? Students may predict that factors such as reducing fishing, increased management, and potential changes in predators or food availability could improve populations. Factors such as food availability or climate change, such as changing water temperatures, could hurt populations.

PROCEDURE SUPPORT (45 MIN)

3 **Support students as they explore a deterministic graph model in Procedure Part A.**

- You may want to review the brief scenario provided in Procedure Step 1 as a class and provide additional background. In the real-world system, bluefin tuna spend a few years feeding in the feeding ground areas before coming to maturity and migrating back to the spawning grounds to reproduce. The probabilistic game model that students will explore in Part B models the population of a school of bluefin tuna as they travel from the feeding grounds to the spawning grounds and then models the population shortly after they reproduce at the spawning grounds.
- Table 6.1 provides simple mathematical equations for students to calculate the bluefin tuna population as they travel from Week 0 to Week 5. Students use this information to construct a graph. Depending on your student population, you may want to do the calculations as a class or provide the population numbers shown in Table 6.1. Students who have difficulty interpreting graphs (such as students with dyscalculia) can be provided with a copy of the graphs and Visual Aid 1.2, "Interpreting Graphs" in advance.
- Sample data for the line graph is shown in Table 6.1, and a sample graph can be found on Visual Aid 6.1, "Bluefin Tuna: Deterministic Model."

Table 6.1: Bluefin Tuna Population Data

TIME (WEEK)	CALCULATING POPULATION CHANGE	TUNA POPULATION
0 FEEDING GROUNDS	Week 0 population	500
1	(Week 0 population) – (0.05 x Week 0 population)	*475*
2	(Week 1 population) – (0.05 x Week 1 population)	*451*
3	(Week 2 population) – (0.05 x Week 2 population)	*428*
4	(Week 3 population) – (0.05 x Week 3 population)	*406*
5 SPAWNING GROUNDS	(Week 4 population) + (0.2 x Week 4 population)	*487*

- In Procedure Step 3, students are asked to graph their data. A sample response is provided on Visual Aid 6.1, “Bluefin Tuna: Deterministic Model.” In Procedure Step 4, ask, What factors could explain the decline in the population? Student responses could include changes in environmental conditions (e.g., pollution, warming ocean temperature, changes in salinity), food availability, disease, and fishing.

TEACHER’S NOTE: The model incorporates an approximately 5% decline of the population over the time period, as indicated by the graph, which is realistic for a population that is overfished.

- Point out the increase in population from Week 4 to Week 5 and ask, What could explain the increase in population? Student responses may mention that an increase occurs at the spawning grounds and is likely due to reproduction.

- At this point in the activity, students have engaged with a deterministic model, but this concept has not yet been introduced. Wait to present this idea and the vocabulary until Part C when students will have an opportunity to compare the deterministic model to the probabilistic model that is explored in Part B.

4 Support students as they explore a probabilistic game model in Procedure Part B.

- 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 like 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.

- Consider how to best adapt the activity to the needs of your particular student population. Students who need more time processing language (such as students with dyslexia) can be provided with a copy of the cards in advance of the activity.

- Note that the terms *current population* and *ocean currents* appear on Week 5 of the Event cards. For emerging multilingual learners, you might need to distinguish between the use of these terms.

- In Procedure Step 5, review the game rules. You may find it helpful to model one round of the game and demonstrate how to complete Student Sheet 6.1, “Bluefin Tuna Game Tracker.”

- Hand out Student Sheet 6.1 and make sure students are recording their progress on it, not only to keep track of their school size but also to note the factors that are impacting the population. A sample student response to Student Sheet 6.1 is provided at the end of this activity.

5 **Students rate the factors in the game model according to orders of understanding.**

- In Procedure Step 11, students compare the final populations for their four schools of tuna and determine which school had the most successful migrations and the least successful migrations, based on population size (larger size indicates more successful migration). Ask, Which factors had the greatest impact on the population? Students should be able to observe from the data recorded on their student sheets that commercial fishing had a greater impact than natural predators. Climate change, in the form of water temperature increases, salinity, and currents, also had a large impact.

- You may want to remind students of the meaning of the term *orders of understanding* by providing an everyday example: a loss of electricity may have a greater impact on food spoilage of food stored in a refrigerator than how old the food is.

- Students should be able to rate the orders of understanding as follows: fishing had the greatest impact, followed by temperature, currents, and salinity. Predation and disease had much less of an impact.

Sample Student Response, Procedure Step 11

- Highest order of understanding: commercial fishing

- Lowest order of understanding: sharks, killer whales, disease

6 **Students graph the data collected in the bluefin tuna migration game.**

- Compile student data and collectively build the probabilistic model. This can be done on a blank visual aid or on chart paper. Each student should mark their data points (one point for each week of the game). Note that students will be graphing two data points from the first column of Student Sheet 6.1: the initial population of 500 (Week 0) and the population at the end of Week 1. A complete sample dataset is shown on Visual Aid 6.2, “Bluefin Tuna: Deterministic and Probabilistic Models.”

- Ask, What does each dot represent? Students should recognize that the dots are the population values for their school of bluefin tuna. Follow up with a more important question. Ask, How would you describe the population of the bluefin tuna for each week? Students may suggest that the best representation is an average, but a better answer would be that the probable population at any given time is better visualized as a range of values. In Procedure Step 12, create a graph on Visual Aid 6.2 of all the class data and connect the top and bottom of the population data to show the range. Students should record these lines (but they do not need all the specific data points) on their own graphs in their science notebooks (from Part A.)

- Ask, Is it possible for the population of bluefin tuna to drop to zero with this model? Students should respond that yes, the probabilistic model showed that sometimes the tuna had bad years, and the population dropped much more than predicted (5%). Because of this variation, there is a chance that a year with numerous adverse events could compound, resulting in a quick decline in population.

7 **Compare a deterministic model to a probabilistic model in Procedure Part C.**

- In Part C, students compare their graphs from Part B to those from Part A, as shown on Visual Aid 6.2.
- Review the terms *deterministic model* and *probabilistic model* as needed. If you have begun a word wall, add these terms and provide examples as needed. For more information on a Word Wall, see Appendix 1: Literacy Strategies.

  A **deterministic model** is a tool that produces a single predictable outcome for a given set of initial conditions.

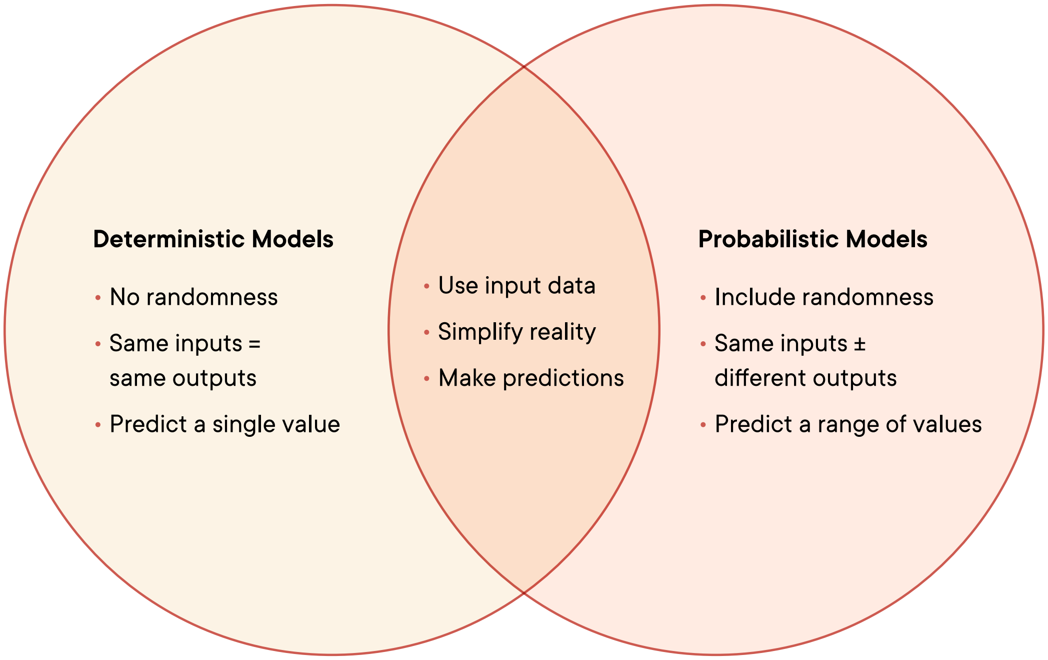
  The tuna model from Part A was a deterministic model.

  A **probabilistic model** is a tool that uses patterns in data to predict the likelihood of different outcomes. It produces a range of possible outcomes for a given set of conditions.

  The tuna model from Part B was a probabilistic model.

- Help students understand the similarities and differences between the two kinds of models by creating a Venn diagram. The Venn diagram will help students acquire vocabulary as they compare and contrast the concepts of deterministic and probabilistic models. With the class, designate topics or main ideas for each circle. Have each group brainstorm what to put in each circle of the Venn diagram and then work to come to a consensus on a complete and correct Venn diagram. For more information about Venn Diagrams, see Appendix 1: Literacy Strategies. A sample Venn diagram is shown here.

SCIENTIFIC MODELS



- In Procedure Step 16, students are asked to use the two models to predict what will happen to the population and range of the bluefin tuna during future migrations if nothing changes, fishing limits are introduced, and environmental change continues to warm ocean waters.

  Sample Student Response, Procedure Step 16

  Students will see the trend of decreasing population in both models, although the probabilistic model (from Part B) shows some chance that the population stays the same or increases. If fishing limits are introduced, the probabilistic model predicts that the populations will rise because the quantities of fish lost by commercial catches in the game were very large. The probabilistic model also showed that those in the cooler northern route were more likely to survive, indicating that warmer waters would decrease population.

SYNTHESIS OF IDEAS (10-15 MIN)

8 **Facilitate a discussion about modeling bluefin tuna populations during migration.**

- Ask, Which model is better suited to model the bluefin tuna population during migration? Students should understand that the game is a probabilistic model that incorporated the variability in events that the deterministic model missed and was the better model in this case. Probabilistic models are a good choice for modeling the randomness of nature.

- Point out that there are many cases in which a deterministic model is better for the task at hand, such as when projecting interest payments on an expensive purchase (e.g., a smartphone).

- To help students reflect on the role of the game as a model, first have them offer ways in which the game model could be altered to show a change in the ecological system. For example, if there were more fish caught by fishers in the real world, then more Event cards with fisher events could be added, or the fish quantities could be multiplied by a larger number when the number cube is rolled. To show changes in climate, more factors related to it could replace factors with lower orders of understanding, such as natural predators. Help students understand that the model can be adjusted to project the future by adjusting the factors and their relative importance in the model that best reflects the system that is being modeled.

- Explore with students the aspects of the real-world system that were or were not included in the game model and how they affected the population.

  Factors Representing the Real-World System That Were Included

  - Students may notice that the location where fishing occurred made a difference to their predictions. Many more fish were lost at spawning and feeding grounds vs. during the middle of the migration. This reflects the historical practices of commercial fishers who would wait for schools of tuna to arrive at the spawning grounds.

- Students may have also noticed that some of the Event cards resulted in a greater decrease to the tuna population along the southern route as compared to the northern route. This effect modeled the current real-world negative impact of warming ocean waters on the species. Increased temperatures at the spawning grounds also moved the range of the tuna northward and contributed to reduced reproduction.

Factors Representing the Real-World System That Were Not Included

- The variability of the length of the migration.
- The complexity of spawning from eggs to larvae to juveniles.
- Complex impacts of temperature increases on range and fish metabolism.
- Some aspects, such as the number of fish caught, were also simplified.

9 **Review how key content in the activity relates to orders of understanding.**

In Build Understanding item 2, students are asked to consider what factor is the most important to model. This supports the key concept and process skill about orders of understanding introduced in Activity 4. Support students as they distinguish those factors that had a greater impact on the tuna population in the game, such as commercial fishing and climate change, from those with a lesser impact, such as disease and natural predators.

10 **Revisit the concept of trade-offs and how it applies to fishing laws.**

- Build Understanding item 4 asks students to weigh the trade-offs of fishing limits. Trade-offs were introduced in Activities 1 and 4 and are further investigated in this activity. 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.

- For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 6.2, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use Student Sheet 6.2 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.

- Finish the activity by revisiting the Guiding Question, *How can models include uncertainty?* Use responses to this question to formatively assess students' understanding of the key concepts and process skills related to how different models can model the same phenomena and make predictions.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **Which type of model, deterministic or probabilistic, would be most useful for predicting the following phenomena? Explain your reasoning for each example.**

- a **The future population of bluefin tuna.**
  Probabilistic, because it provides a range of possible population data.
- b **The height of a bouncing ball as it loses energy.**
  Deterministic, because there are equations that can identify exactly where the ball will be located.
- c **The weather for next week.**
  Probabilistic, because there is uncertainty in what can happen in a weather system.
- d **The change in range of a species.**
  Probabilistic, because there is uncertainty due to all the factors in the ecology of an area.

② **In the game, what factors are a part of the highest and lowest order of understanding of the tuna population? Rate the factors included in the game model according to orders of understanding. Explain your reasoning.**

The factors that had the greatest impact were the commercial fishers because they often caught a large number of fish compared to other problems they may have faced, so that is the highest order of understanding. Factors related to climate change, such as increased temperature, poor salinity, and changing currents, had a significant impact, but not as much, so they were the next order of understanding. Things that did not kill as many fish, such as the factors of natural predators and recreational fishers, were lower orders of understanding.

③ **In this activity, the game was a model of bluefin tuna migration. Consider ways in which the model did or did not represent the real-world system. Describe one change you would make to improve the model, why you would make it, and how it would likely affect the population in this model.**

One change that I would make is the rate of fish being caught. Since global fishing management strategies have been implemented, I would reduce the fish caught by commercial fishers. The population would likely increase during migration instead of decreasing.

④ **Imagine that you live in a coastal town where the economy depends on the fishing industry. The local fish population has declined, and the remaining population has moved farther out to sea where fishing is more expensive and dangerous. A community group has proposed a law to protect the local fish population by severely limiting the number of fish that can be caught locally. Would you support the law? Support your answer with evidence from this activity and identify the trade-offs of your decision.**

Student responses may vary. One sample response is provided.

Yes, I would support the law because the decline in fish has been negatively impacting the fishing industry. Stopping local fishing will give the species a chance to survive and rebound its population. Without this change, fishers are going to run out of fish to catch to make a living. The trade-off is that many fishers in the area will not be able to make a living in the short term. People who disagree with my decision might say that the law will make people lose their jobs.

CONNECTIONS TO EVERYDAY LIFE

⑤ **Imagine you visit an ice-cream shop regularly, and you would like to know how many people will be in line when you arrive. Over 20 visits, you observed the following information, shown in Table 6.2.**

LINE LENGTH (NUMBER OF PEOPLE)	FREQUENCY OF THIS LINE LENGTH
0	1
1	4
2	8
3	5
4	2

TABLE 6.2
Lines at Local Ice-Cream Shop

a **What is the most likely line length in the shop? Explain your reasoning.**

The most likely length is 2 people in line. This is because 8/20 (or 40%) of the visits had 2 people, which is the highest probability in the data.

b **If you made a model from this data, would it show a deterministic system or a probabilistic system? Explain your reasoning.**

It would be probabilistic because the data does not show exactly how many people are in line, just the likelihood of each line length. Since the output is unknown for the same input, it would be a probabilistic system.

⑥ **Ride-sharing apps and websites that sell tickets to concerts or shows often use an on-demand pricing model. In this model, the price is determined by the number of people who want the service or the tickets. More demand results in a higher price. Do you think on-demand pricing is a deterministic model or a probabilistic model? Explain your reasoning.**

On-demand pricing is probabilistic because it forecasts uncertain future events to set the highest price for the seller. The model predicts the probability that the current demand will exceed the current supply in the immediate time window.

TEACHER’S NOTE: While the forecast is probabilistic, the final price often comes from a deterministic calculation within the model. For example, once the probabilistic forecast is complete (e.g., there is a 90% chance of a shortage in Zone 3), the model applies a deterministic rule: If the probability of a shortage is >85%, multiply the base price by 2.5.

REFERENCES

Marine Stewardship Council. (November 2024). Fisheries targeting tuna most at risk from climate change, new research suggests. https://www.msc.org/media-centre/press-releases/press-release/fisheries-targeting-tuna-most-at-risk-from-climate-change--new-research-suggests#:~:text=As%20ocean%20temperatures%20change%2C%20migratory,catch%2C%20potentially%20leading%20to%20overfishing

The PEW Charitable Trusts. (October 2017). The story of Atlantic bluefin. https://www.pew.org/en/research-and-analysis/issue-briefs/2017/10/the-story-of-atlantic-bluefin

STUDENT SHEET 6.1

BLUEFIN TUNA GAME TRACKER

NAME

Circle one: NORTHERN ROUTE SOUTHERN ROUTE

	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
	Event	**Event**	**Event**	**Event**	**Spawning Grounds**
Event description					
Initial population	500 (WEEK 0)				
Change in population					
Ending population					

STUDENT SHEET 6.1 | BLUEFIN TUNA GAME TRACKER | NAME SAMPLE STUDENT RESPONSE

Circle one: [✓ NORTHERN ROUTE] SOUTHERN ROUTE

	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
	Event	**Event**	**Event**	**Event**	**Spawning Grounds**
Event description	*commercial fishers*	*great speed*	*killer whales*	*high water temperatures*	*salinity*
Initial population	500 (WEEK 0)	*450*	*450*	*448*	*443*
Change in population	*–50*	*0*	*–2*	*–5*	*443 x 0.10 = +44*
Ending population	*450*	*450*	*448*	*443*	*487*

STUDENT SHEET 6.2

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

There is a lot of discussion about the issue of

declining fish populations.

My decision is that

there shouldn't be any fishing restrictions.

My decision is based on the following evidence:

First,

fish populations go up and down due to various factors, and we don't know what factors caused the decline.

Second,

we don't know if the decline is short term or long term. It's possible that the fish populations farther out may get larger and come back closer to shore.

Third,

if there are not enough fish to catch locally, the fishers will go farther out without any change in the laws.

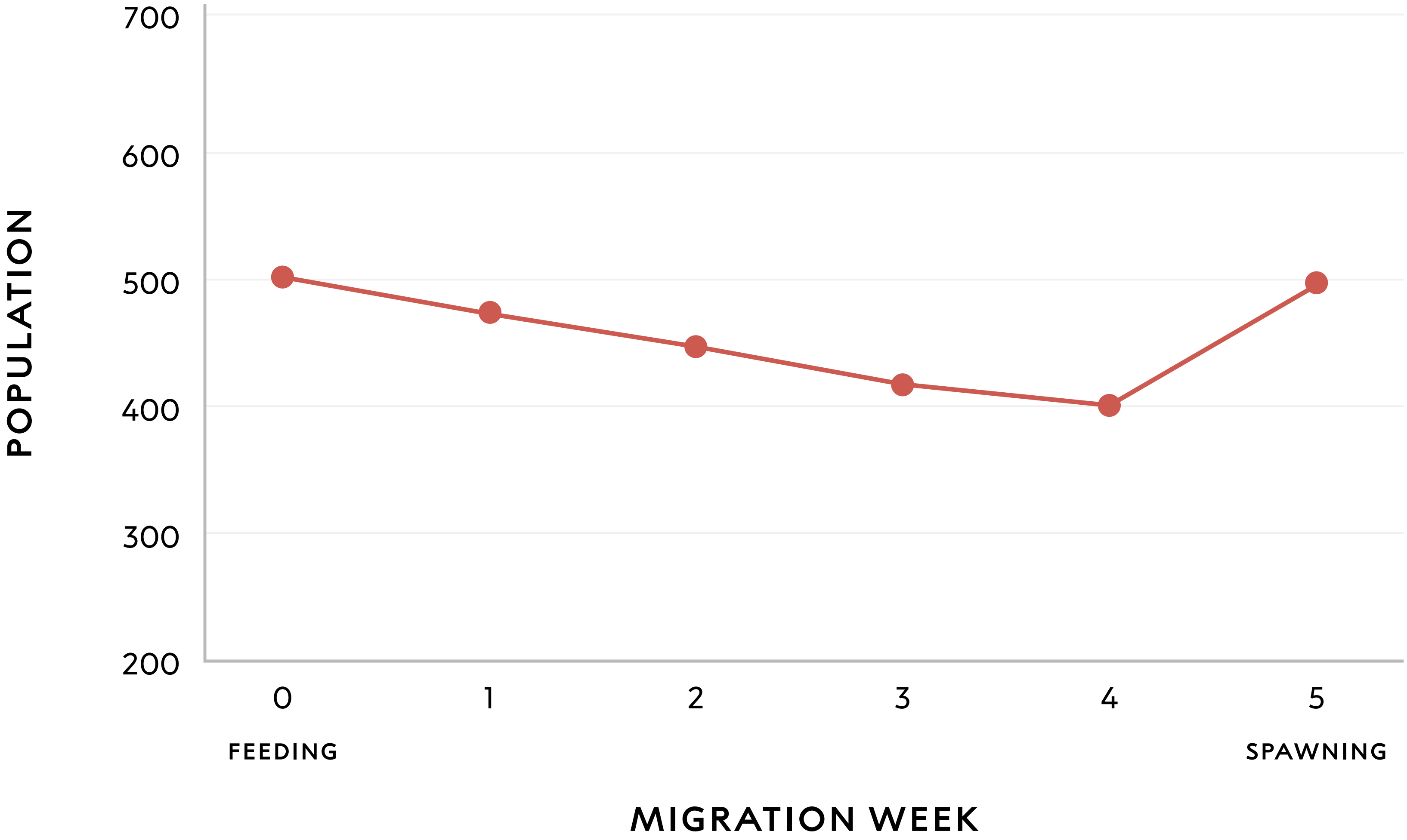
The trade-off(s)

is that the fish closest to shore may be overfished and never recover.

People who disagree with my decision might say that

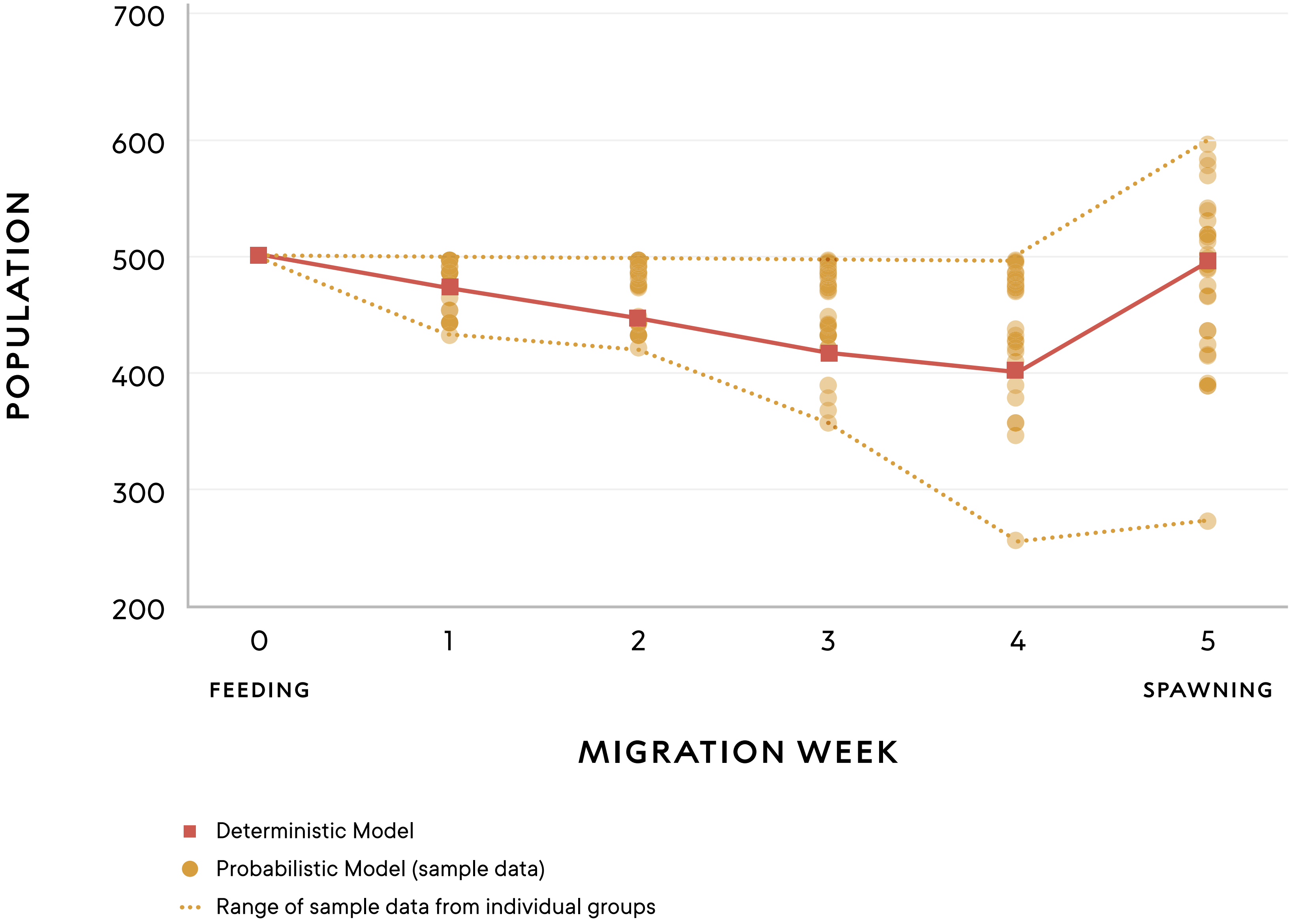
it's important to give fish the time and space to recover their populations.

BLUEFIN TUNA: DETERMINISTIC MODEL



The model shows a declining tuna population from week 0 to week 4 and then a significant increase in population from week 4 to week 5. If the trend continues, the model predicts that the population would continue to increase, possibly matching and exceeding the initial population.

BLUEFIN TUNA: DETERMINISTIC AND PROBABILISTIC MODELS



A group of commercial fishers wait near the hunting grounds, anticipating that the school will pass by as it starts migrating.

Determine how many tuna are fished by rolling the number cube and multiplying the number by 10.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school begins the migration strongly and sets a faster-than-usual pace.

Move up 3 spaces

OR

roll the number cube and move up the number of spaces indicated.

If you pass through an Event space, pick up the next Event card.
If you land on an Event space, pick up the next Event card.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school has a slow start due to nearby predators.

Roll the number cube to determine the number of tuna that are eaten by sharks:

⚀ OR ⚁ OR ⚂ → no tuna are lost
⚃ OR ⚄ → lose 5 tuna
⚅ → lose 10 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The area near the hunting grounds is filled with commercial fishers.

Roll the number cube to determine the number of tuna that are caught:

⚀ OR ⚁ OR ⚂ → 10 tuna
⚃ OR ⚄ → 20 tuna
⚅ → 50 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

ACTIVITY 6 | EVENT CARDS: WEEK 2 EVENT (FRONTS)

There are great conditions and plenty of prey, so the strong school of swimmers results in great speed.

There is no change in the school population

AND

move ahead 2 spaces.

If you pass through an Event space, pick up the next Event card.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Some of the fish in the school come down with an infection that can be fatal.

If the school is on the Northern route, roll the number cube to determine how many tuna are lost to disease.

If the school is on the Southern route, the warmer water negatively impacts tuna health and tuna are more likely to catch and die from the disease. Roll the number cube and multiply it by 10 to determine how many tuna are lost.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The tuna comes upon a large school of tasty herring. The tuna circle around and feed, but some tuna are caught by local fishers.

Roll the number cube to determine the number of tuna that are caught by fishers:

⚀ OR ⚁ OR ⚂ → lose 1 tuna
⚃ OR ⚄ → lose 5 tuna
⚅ → lose 10 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school travels and hunts for a while with another school made up of a different species of fish.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

ACTIVITY 6 | EVENT CARDS: WEEK 3 EVENT (FRONTS)

Because of human activities, the temperature of the water is warmer than the tuna is used to, endangering its metabolism. The school seeks cooler water to the north, but that area has fewer prey.

If the school is on the Northern route, roll the number cube to determine how many tuna are lost to starvation.

If the school is on the Southern route, roll the number cube to determine the number of tuna that are lost in the warmer temperatures:

⚀ OR ⚁ OR ⚂ → lose 10 tuna

⚃ OR ⚄ → lose 20 tuna

⚅ → lose 50 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school swims near a group of killer whales. The school speeds away but loses some tuna to the predators.

Lose 2 tuna

AND

move ahead 1 space.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school makes steady progress.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school accidentally swims near a small group of commercial fishing boats. The school speeds away but loses some tuna to the predator.

Move ahead 2 spaces and lose 50 tuna

OR

roll the number cube and multiply it by 10 to determine how many tuna are lost.

If you pass through an Event space, pick up the next Event card.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school makes steady progress.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

As the school approaches the end of its journey, a group of commercial fishing boats awaits its arrival.

Determine how many tuna are lost by rolling the number cube and multiplying the number by 10.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Outside the spawning grounds is an area full of prey, so the school circles and eats. One tuna is caught and released with a tracking device put on it by a group of ecologists.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

As the school approaches the end of its journey, a group of commercial fishing boats awaits its arrival.

Roll the number cube to determine the number of tuna that are caught by fishers:

⚀ OR ⚁ → lose 10 tuna

⚂ OR ⚃ OR ⚄ → lose 20 tuna

⚅ → lose 100 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4

EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Because of human activities, the temperature in the spawning grounds is too high for successful egg laying. Some tuna's eggs are not viable. Those who move farther north to spawn found less food availability and more predators.

Add 5% of the current population to represent new juvenile tuna added to the school combined with the adult tuna that do not survive in the new location.

The ocean currents in the spawning grounds have shifted from changes in weather patterns due to human activities. The shifts result in fewer eggs surviving and less food for those that do.

Add 10% of the current population to represent new juvenile tuna added to the school combined with the adult tuna that do not survive in the new conditions.

The spawning grounds have been protected by a fishing limit law, so the tuna are able to reproduce at typical rates.

Add 20% of the current population to represent new juvenile tuna added to the school.

The salinity of the ocean at the spawning grounds has increased due to human activities. Larvae survival rates decrease as a result.

Add 10% of the current population to represent new juvenile tuna added to the school.

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

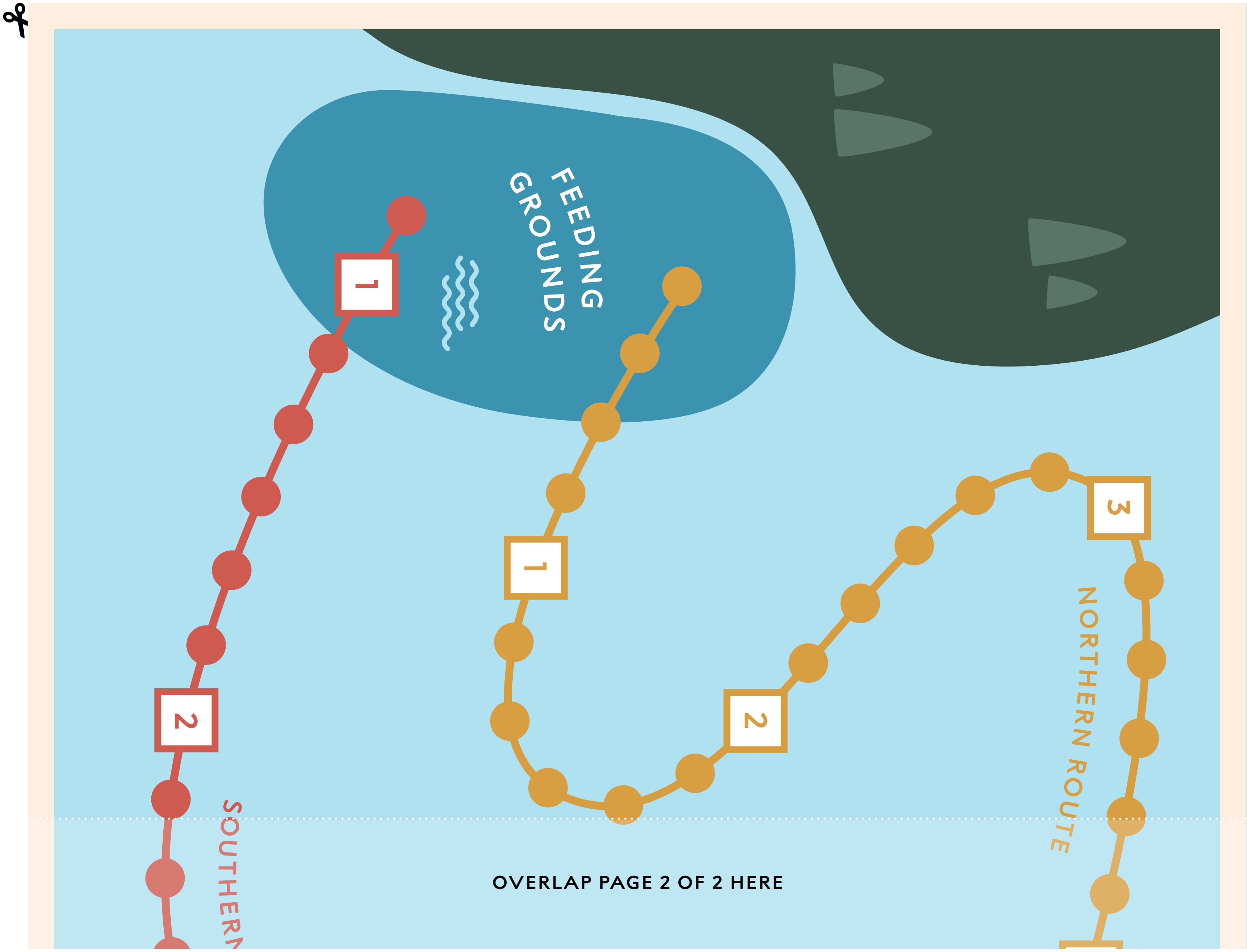
SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS



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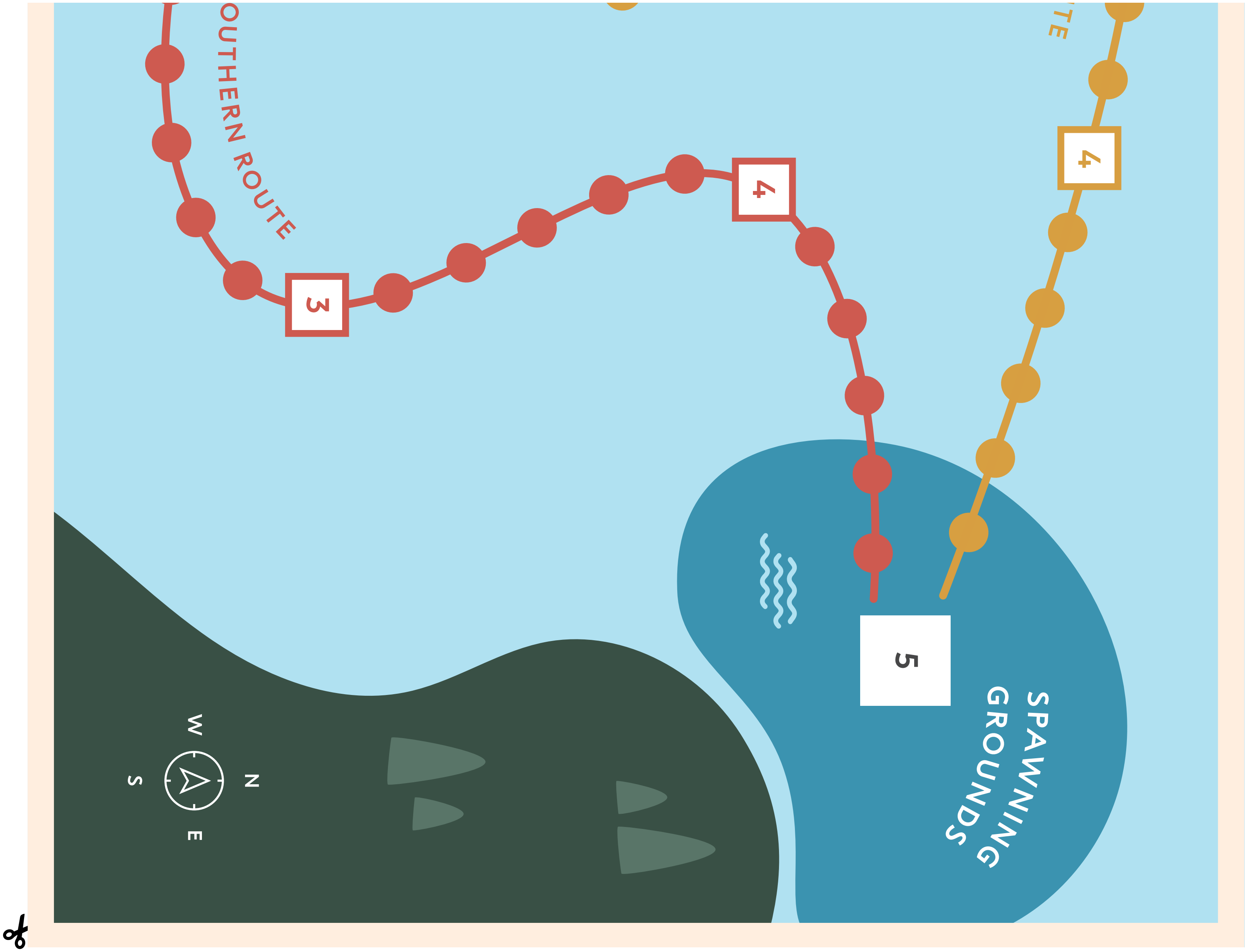
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SPAWNING GROUNDS
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ACTIVITY 7

Fermi Estimations

DATA ANALYSIS

ACTIVITY 7

Fermi Estimations

ACTIVITY SUMMARY

Students are introduced to Fermi estimates and powers of 10 as approaches to mathematical modeling. They begin as a class to estimate the number of trees lost in Arizona's 2020 Bighorn Fire. They discuss the available information and the assumptions that can be made and use this information to make an informed estimate. Students discuss the likely accuracy of their estimate based on the powers of 10 and discuss how refining their assumptions could affect their estimate. They then make their own Fermi estimates on the population size of house sparrows in their local community and compare and evaluate the powers of 10 of their estimates as a class. Students use the Bighorn Fire estimate to inform a decision about the replanting of trees for ecosystem restoration.

ACTIVITY TYPE
DATA ANALYSIS

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a *Fermi estimate*—can be used to approximate unknown quantities that are difficult to measure.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. (*Science and Engineering Practice: Developing and Using Models*)

CONCEPTUAL
TOOLS

SCIENTIFIC MODELING

FERMI ESTIMATIONS

VOCABULARY DEVELOPMENT

Fermi estimate

a method of calculating an approximate value of a difficult-to-know quantity

powers of 10

10 multiplied by itself a number of times, which is often indicated in scientific notation as 10 = 10^1, 100 = 10^2, 1,000 = 10^3, and so on, to refer to approximations of size, value, or quantity

TEACHER BACKGROUND INFORMATION

Fermi Estimation

In many cases, it is not possible to determine a quantity precisely, but it is useful to have a very rough estimate. One mathematical modeling approach is known as a Fermi estimate, a method of calculating an approximate value of a difficult-to-know quantity. Fermi estimates are sometimes referred to as "back-of-the-envelope" estimates because they literally have been calculated on the back of an envelope. They are useful when a more precise answer is not yet known, is too time-consuming, or is too expensive to work out.

The technique is named after the Italian and naturalized American physicist Enrico Fermi (1901–1954) who was known for his ability to make accurate estimates with limited data. He estimated the strength of the Trinity Test atomic bomb by seeing how far pieces of paper were blown by the bomb. His resulting estimate of 10 kilotons of TNT was the same powers of 10 as the now-accepted value, 21 kilotons.

Typically, a quantity to be estimated is broken down into easier-to-estimate or known quantities based on available information and/or reasonable simplifying assumptions so a calculation can be made. The goal is to make an estimate within the correct powers of 10 (e.g., if the true number is 500, a Fermi estimate anywhere from 100 to 1,000 would be acceptable). Fermi estimates require enough background knowledge to make some reasonable guesses and/or basic assumptions (as well as an understanding of scale). When a precise estimate is not possible, a Fermi estimate of the possible range can be used instead of a specific number by estimating the lowest and highest plausible numbers. Such rough estimates or ranges can be useful for decision-making and for judging the plausibility of numbers. For example, when determining how much a tiger weighs, you may be able to guess that it is more than 100 pounds and less than 1,000 pounds. Estimating upper and lower bounds in this way can build confidence in a Fermi estimate.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 7.1 “Another Fermi Estimate Example: Shoes”

FOR EACH STUDENT

- CALCULATOR
- 2 COPIES OF STUDENT SHEET 7.1 “Making a Fermi Estimate”
- STUDENT SHEET 7.2 “Writing Frame: Evidence and Trade-Offs” (OPTIONAL)
- STUDENT SHEET 1.3 “Unit Concepts and Skills” (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Introduce Fermi estimates and the role of the powers of 10.**

- So far in this unit, students have explored changing species distribution. Some of the models have predicted changes in population size or range. Ask, What are ways in which you could find answers to scientific questions about future populations? Students may suggest online research, field research, observations, talking with experts, etc. In this activity, students will utilize another approach by creating a Fermi estimate, a method of calculating an approximate value of a difficult-to-know quantity.
- Explain that Fermi estimates are most useful when a more precise numerical answer is unavailable, not yet determined, or too time-consuming to work out. Highlight that the power of this technique is that you can get a useful approximate value based solely on what you know, including data from observations or prior research. Note that the skill of Fermi estimation enables people to calculate and check the plausibility of numeric claims, using their own knowledge and calculations. It can be a good way to build students' intuition about large numbers as they practice seeing how numbers relate to one another in real-world contexts.
- Share the following example (you may wish to modify the numbers to better reflect your local setting):

Imagine you are organizing a school dance. How many snacks should you provide?

Information and assumptions:
- approximate number of students at the school: 2,000
- percentage of students likely to go to the dance: 20%
- average number of snacks each student is likely to eat: 2

Calculations:
- 2,000 students x 0.2 = 400 students
- 400 students x 2 snacks each = 800 snacks for the dance

Review the estimate to see if the powers of 10 make sense:
- Compare 800 snacks (vs. 80 snacks vs. 8,000 snacks) for 400 students = seems okay

- It is important to make clear to students that Fermi estimates are general estimates, not precise numbers, and are usually rounded to the nearest powers of 10: 10 multiplied by itself a number of times, which is often indicated in scientific notation as $10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$, and so on, to refer to approximations of size, value, or quantity. For example, the number of students at the school may be 1,819 or 2,167. The exact numbers are not as important in making the estimate and, therefore, numbers are rounded to the nearest powers of 10 ($10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$...). Use the Introduction in the Student Book as an example to further review this concept.

- Depending on your student population, you may want to further review the scale of powers of 10. If so, you can easily find short videos on the powers of 10 online. You also may want to introduce the term *orders of magnitude*, which is a way to approximate the scale of a number and is represented by powers of 10. Two numbers are within an order of magnitude of each other if the ratio of the greater to the lesser is between 1 and 10. In other words, the two numbers are within about a factor of 10 of each other. Orders of magnitude is not introduced in this unit to avoid confusion with the term *orders of understanding*, which is first introduced in Activity 4.

- Explain that one of the reasons Fermi estimates work is that the overestimates and underestimates for the different pieces of a problem often cancel out, especially when there are multiple steps to the estimate.

- Ask, How can Fermi estimates influence decision-making? Based on the example questions, students may recognize that one use of Fermi estimates is to determine how many resources are likely needed for a given purpose, such as snacks for the school dance, how big of a room is needed for an event, which of several fundraising initiatives is likely to raise the most money, etc.

2 **Review the use of scientific notation (optional).**

- While scientific notation is not required to complete this activity, it can make quantities simpler to record. If appropriate, review the use of scientific notation as shown in the following table. Encourage students to use this notation during their estimates. For students who need support with scientific notation, you may wish to review the purpose of scientific notation, which is to present very large numbers or very small numbers in a simpler form. A good review and examples can be found at Khan Academy.

SCIENTIFIC NOTATION		
one	1	$1 \text{ X } 10^{0}$
ten	10	$1 \text{ X } 10^{1}$
one hundred	100	$1 \text{ X } 10^{2}$
one thousand	1,000	$1 \text{ X } 10^{3}$
one million	1,000,000	$1 \text{ X } 10^{6}$
one billion	1,000,000,000	$1 \text{ X } 10^{9}$
one trillion	1,000,000,000,000	$1 \text{ X } 10^{12}$
one quadrillion	1,000,000,000,000,000	$1 \text{ X } 10^{15}$

PROCEDURE SUPPORT (20 MIN)

3 Students examine the flowchart (Figure 7.1) in Procedure Step 1.

- Review the flowchart in the Student Book, which shows a simplified set of steps for making a Fermi estimate. Students will use a mostly blank version of this flowchart to make their Fermi estimates.

4 Use Visual Aid 7.1, "Another Fermi Estimate Example: Shoes," to demonstrate how to use the flowchart to make a Fermi estimate.

- Visual Aid 7.1, "Another Fermi Estimate Example: Shoes," considers how many pairs of shoes are thrown away in the world each year. First, ask students to guess their responses without any other information or calculations.

- The assumptions that are being made as part of the Fermi estimate are often themselves estimates. For example, assuming that ¼ of shoes wear out in a given year is a numeric estimate. Someone else might estimate that only ⅒ of shoes wear out in a given year. Depending on your student population, you may want to use the term *estimate* instead of assumption for some of these statements since they are, in fact, estimates used to determine the Fermi estimate.

- Use Visual Aid 7.1 to complete the Fermi estimate.

- Point out that a Fermi estimate is most useful when the specific value is not available, meaning it is not possible or easy to find the "correct" answer. It is sometimes possible to refine the estimate or evaluate its accuracy with additional information. For example:

  Additional Information:

  - In 2020, 20.5 billion pairs of footwear were produced around the world.
  - In the United States, about 2.5 billion pairs of shoes are bought each year, and about 300 million pairs of shoes are thrown away.
  - The number of shoes thrown away is 12% of the shoes purchased in an average year.

  Refining Estimate/Evaluating Accuracy:

  - 12% of 20.5 billion pairs is about 2.5 billion pairs thrown away per year, which is reasonably close to the Fermi estimate of 2 billion pairs. The Fermi estimate is in the same powers of 10 as the 2.5 billion estimate, so it is a fairly accurate estimate.

- Ask, How might this Fermi estimate influence student decision-making? A person might consider how long they would like to wear a pair of shoes before discarding them, or they might consider purchasing longer-lasting shoes.

- You may wish to share or have the class to brainstorm questions that could be informed by a Fermi estimate, such as:

  - How many ants are there on school property?

  - How many wildflowers bloom in local parks during the month of June?

- How many deciduous leaves are raked every weekend in October?
- How many people will come to the school book fair?
- How much money could be raised in a garage sale school fundraiser?
- How many cars in our community get dirtied by bird droppings on an average day?
- How many pieces of gum can be found on our city's sidewalks?

5 **As a class, complete Procedure Part A.**

- Read the information presented in Procedure Step 2 as a class, which sets up the Fermi estimate question: *How many trees were likely lost as a result of the 2020 Bighorn Fire in Arizona?* Students may wish to share their own experiences related to this type of situation, such as experience with wildfire, tree loss, observations of fire-scarred areas, etc.

- Students may have personal experiences with and prior knowledge of issues related to wildfires, tree loss, observations of fire-scarred areas, etc. 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 may require particular care and sensitivity, depending on students' individual experiences. For example, some students may have prior experience with wildfires and may have experienced loss related to wildfires or other natural hazards.

- Hand out Student Sheet 7.1, "Making a Fermi Estimate" and let students know they will complete the Fermi estimate as a class. Students should record the question being investigated in the first box of the flowchart: *How many trees were likely lost in the Bighorn Fire?*

- Have each student make an initial guess of the number of trees lost in the Bighorn FIre based on the powers of 10. Point out that the goal is not to have the correct answer but to develop a sense of large-scale numbers in terms of the powers of 10. This skill is best developed individually and through practice.

- As a class, complete the Fermi estimate of the number of trees likely lost in the Bighorn Fire. A sample student response for Student Sheet 7.1 is provided at the end of this activity. You may wish to use the sample assumptions provided (found in the third box of the flowchart) or have students generate their own assumptions as a class.

6 **Evaluate the likelihood of the final estimate in terms of the powers of 10.**

- Discuss the relative accuracy of the Fermi estimate by first acknowledging that there is **no known correct answer to this question, only more accurate or less accurate estimates.**

- Discuss the likelihood that 10 million trees could exist in 200 square miles. One way to assess the likelihood of this result is to use other information to make calculations to determine the number of trees in an area. For example, you can estimate the number of trees in an acre and roughly calculate the number of trees in 200 square miles.

  One acre = 43,560 square feet, rounded to 40,000 sq ft

  1 square mile = 640 acres

  Assume 1 tree per 20 sq feet
  - 1 tree x (40,000 sq ft/20 sq ft) = 2,000 trees per acre
  - 640 acres/sq mile x 2,000 trees per acre = 1.3 million trees/sq mile, rounded to 1 million
  - 200 sq miles x 1 million trees/sq mile = 200 million trees

  This is powers of 10 higher than 10 million trees, suggesting that 10 million trees could easily have been destroyed in a 200 acre fire, even if many trees survived and not all the burnt ground was forested.

7 **Discuss the role of assumptions in the accuracy of estimates.**

- Begin discussing the limitations of the assumptions made in this estimate by asking, Do you agree with the assumptions we made to make this estimate? Why or why not? How might changing these assumptions affect the Fermi estimate? Students will have different ideas depending on the class assumptions. If one assumes that not all the burned area was forested (instead, some was covered by roads, homes, etc.), the amount of land burned could be reduced by an estimated percentage, such as 10%. This would reduce the burned area to 180 square miles and the total estimated number of trees lost to 9 million (instead of 10). Ask, Is this significant in terms of the powers of 10? Both of these values are in millions (10^6) and have the same powers of 10. From this perspective, there is no significant difference in these estimates. A similar calculation can be made if one assumes that some of the trees in the burned area survived. In the case of the Bighorn Fire, some of the burned area was not forested, and some trees did survive, but these assumptions simplified the calculation for the Fermi estimate.

- Highlight the idea that identifying and refining assumptions can help improve calculations and result in more accurate estimates.

- Depending on your student population, you may wish to use the limitations of the assumptions as an opportunity for students to make a revised Fermi estimate after developing a set of revised assumptions.

- Ask, What decisions might be influenced by this Fermi estimate? Students may propose different human interventions such as reforestation, species reintroduction, rebuilding, evacuation plans, etc.

8 Students complete Part B in pairs.

- Part B provides students an opportunity to complete a Fermi estimate independently and to build on ideas raised in the previous activities about populations of organisms in the local community. To provide structure to the activity, the focus is on the wide-ranging house sparrow.

- Hand out a second copy of Student Sheet 7.1. Emphasize that students should focus on practicing the skill of making a reasonable Fermi estimate and be less concerned about whether they are correct.

- Depending on your student population, you may wish to have Part B be more open-ended than is described in the Student Book and have students select an organism that they observed on the field trip. If so, be prepared to provide some basic information for students to begin their Fermi estimates.

- Review what is meant by "your community." Depending on where you live, your community may be a city, town, township, county, or some other geographic area. Decide as a class the boundaries of the community for which you are making a Fermi estimate.

- In Procedure Step 13, students are asked to compare their final estimates to the powers of 10 of their initial guesses and identify additional information needed to determine a more precise number for the number of house sparrows in your community. Possible responses may include: the number of birds in a flock of sparrows, the number of flocks of sparrows in a given area (i.e., population density), the frequency of egg-laying, the number of eggs in a clutch, the survival rates of chicks, the size and location of predator populations (or other factors that might reduce populations such as disease or human structures such as airports), the diet of house sparrows, and so on.

- A sample student response is provided at the end of this activity. Note that the response has the boxes "No" and "The estimate doesn't make sense—need to refine the estimate" circled. You may want to share this example after students have completed their work and discuss why this estimate might need to be refined. Ask, Given your own observations, does the scale of the estimate (750 birds in 25 square miles) seem reasonable? The estimate seems low when considering the overall population density of birds. If students are unsure about evaluating the 750 estimate, point out that this example described an observation of 10 birds in a flock in trees and grassy areas. One way to revise this estimate would be to assume how many such areas could be found in the town and multiply by 10. A town of this size might have 1,000 or more trees and grassy areas, resulting in a Fermi estimate of 10,000 birds, or 10^4. This is a significantly larger population estimate in terms of the powers of 10 than the original 750.

- Highlight the role of the numerical assumptions in the final estimate and the idea that there is not one correct way to make a Fermi estimate. Improving the quality of the numerical values improves the quality of the estimate.

SYNTHESIS OF IDEAS (20 MIN)

9 **Facilitate a class discussion about the results of the Fermi estimates for the house sparrow.**

- Have students compare Fermi estimates with others in the class by putting their estimates on a whiteboard. Have students share how they made their calculations and what assumptions they made.

- Discuss the range of results and whether or not they are significantly different in terms of the powers of 10. A Fermi estimate is not about estimating to produce an exact number; rather, it is to make an estimate in an accurate range of possibilities. Use the class range of data to evaluate the accuracy of the final estimate in terms of the powers of 10. For instance, did most students have an estimate to the same powers of 10? If so, students may be more confident in their Fermi estimates. If not, they may want to consider how their estimates could be improved.

- Identify how varying assumptions may contribute to differences in the scale of the powers of 10 and have students refine their estimates as needed. You may want to consider listing the various assumptions students made and discuss them with a goal of deciding which ones are likely to be the most correct (based on personal evidence, repeated experiences from different individuals, etc.). Students can use these revised assumptions to refine their Fermi estimates.

- Point out that averaging all the original estimates could help overestimates and underestimates cancel out. This process only works if all estimates are truly independent and do not share the same biases (which can result from sharing the same assumptions). Students may want to get rid of numerical outliers or use only estimates with the same assumptions, which can result in higher overestimates or underestimates because they can exaggerate shared biases.

10 **Students apply the Fermi estimate for the Bighorn Fire to make a decision in Build Understanding item 3.**

- Build Understanding item 3 applies the concepts of evidence and trade-offs to decision-making. 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 optional 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.

11 **Discuss Fermi estimates as an example of probabilistic mathematical modeling.**

- A key aspect of a Fermi estimate is that the overall errors from the individual factors can cancel each other out—some factors are overestimated, while others are underestimated. The inherent lack of certainty in the individual factors means that a Fermi estimate is best expressed as a range to account for this uncertainty.

- In Activity 6, students explored deterministic models and probabilistic models. Ask, Are Fermi estimates deterministic or probabilistic? Student responses should understand that Fermi estimates are an example of probabilistic mathematical modeling because they rely on reasoning and the mathematical properties of uncertainty to arrive at a reasonable estimate, rather than on precise data. The final answer is implicitly understood to be the mean or median of a wide, mathematically defined range of possible answers.

- In Connections to Everyday Life item 4, students estimate their phone usage. Most phones measure usage and contain this data. After students have responded to the item, you may want them to compare their estimate to the measure value.

- Revisit the Guiding Question, *How can you use mathematical modeling to make an estimate?* Many important calculations in science can be done by estimation, and they provide a quick way to gain insight by using approximate numbers.

12 **Use optional Student Sheet 1.3, "Unit Concepts and Skills," to help track important concepts of the unit.**

- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about Fermi estimates and the powers of 10.

- Encourage students to think metacognitively by identifying what they understand about the process of Fermi estimates and the powers of 10, as well as what questions they may have and/or what aspects of the Fermi estimates they find difficult. Support student understanding by answering any questions that arise.

EXTENSION (10 MIN)

13 Use the Extension as an opportunity for advanced learning.

Students can look online to further investigate how other people estimate the number of trees in a particular area of land. For example, there is a YouTube video by Rhett Allain, *How Much Land for 20 Million Trees?*, and a Tree Spacing Calculator offered by the tree planting advocacy organization Tree Plantation. Such resources can help students identify assumptions being made (e.g., all trees need the same amount of space, trees grow at the same rate, different tree species do not compete, native trees outcompete invasive species) and discuss how refining the assumptions could improve the accuracy of the estimate.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **Explain whether or not it is reasonable to make a Fermi estimate in each of the following situations.**

a **the total number of squirrels in the United States**

It makes sense to make a Fermi estimate since squirrels are widely distributed and common across the country, and it would be impossible to count them all.

b **the possible side effects of a new medication**

A Fermi estimate is not possible because this is not a numerical estimate.

c **how much money it would take to empty all the trash cans in national parks**

It makes sense to make a Fermi estimate because it is possible to gather basic information, make some general assumptions, and calculate an approximate value.

d **the geographic range of a species**

A Fermi estimate is not possible because this is not a numerical estimate.

② **The National Audubon Society, a nonprofit birding organization, estimates that the population of house sparrows is approximately 740 million.**

a **Compare this population estimate with your Fermi estimate. How might this information affect your Fermi estimate? Include the powers of 10 in your response.**

My Fermi estimate was based on 82 million sparrows in the United States. At 740 million, this estimate is about 9 times larger—it is different by a power of 10 (8.2 x 107 vs. 7.4 x 108) but it is still in millions. My final estimate of the number of sparrows in my community was 750 million. An estimate that was almost 10x larger would be closer to 7,500, which would change the powers of 10 of my Fermi estimate from hundreds to thousands.

b **Upon closer reading, you notice that the National Audubon Society estimate is based on the global population of house sparrows. How would this affect your understanding of your estimate?**

It means that the assumptions I used for my original estimate were probably correct. I could use the Audubon data if I were making a Fermi estimate of global house sparrow populations.

③ **After the Bighorn Fire, the U.S. Forest Service planted 43,000 ponderosa pine trees to help restore the ecosystem. Based on your Fermi estimate from Part A, should they plant more trees? Support your answer with evidence (including the powers of 10) and identify the trade-offs of your decision.**

Two sample responses are shown:

There is a lot of discussion about the issue of how many trees to replant after the Bighorn Fire. My decision is that they should plant more trees. My decision is based on the following evidence: First, I estimated that 10 million trees burned down, which is a powers of 10 larger than the 43,000 trees replanted. Second, not all the trees that are planted will survive, so it's better to plant more trees. Third, trees provide a habitat for other organisms, which will help rebuild the ecosystem. The trade-off is that it takes a lot of effort and money to plant trees. People who disagree with my decision might say that ecosystems change naturally, and trees will eventually grow back.

I don't think they should plant more trees because even though I estimated that 1 million trees burned down, I assumed that all the trees in the area died. While my estimate is a powers of 10 larger than the thousands of trees planted, it is likely that not all the trees in the burned area died. It takes a lot of money to plant trees, and that money could be used for other things. Trees will grow back no matter what, it just takes time. The trade-off is that things will happen more slowly. Some people might not want to wait.

CONNECTIONS TO EVERYDAY LIFE

④ **Guess the number of hours you spend on your phone in a year. Then take a few minutes to make a calculated Fermi estimate and show your work.**

a **How close was your initial guess to your Fermi estimate?**

I guess I spend 500 hours a year on my phone. If I assume that I am on my phone on average 3 hours a day, and I know there are 365 days in a year, I would be on my phone closer to 1,000 hours a year. That is about double what I first guessed.

b **What assumptions did you make?**

I assumed that I use my phone less on average than I probably do.

⑤ **Think about a situation in your everyday life when you use estimation. What happens when your estimate is incorrect by the powers of 10?**

I often estimate how long it will take me to do something, like finish my homework or get ready for school. When my estimate is off by a powers of 10 (closer to 100 minutes than 10 minutes), I am very late!

REFERENCES

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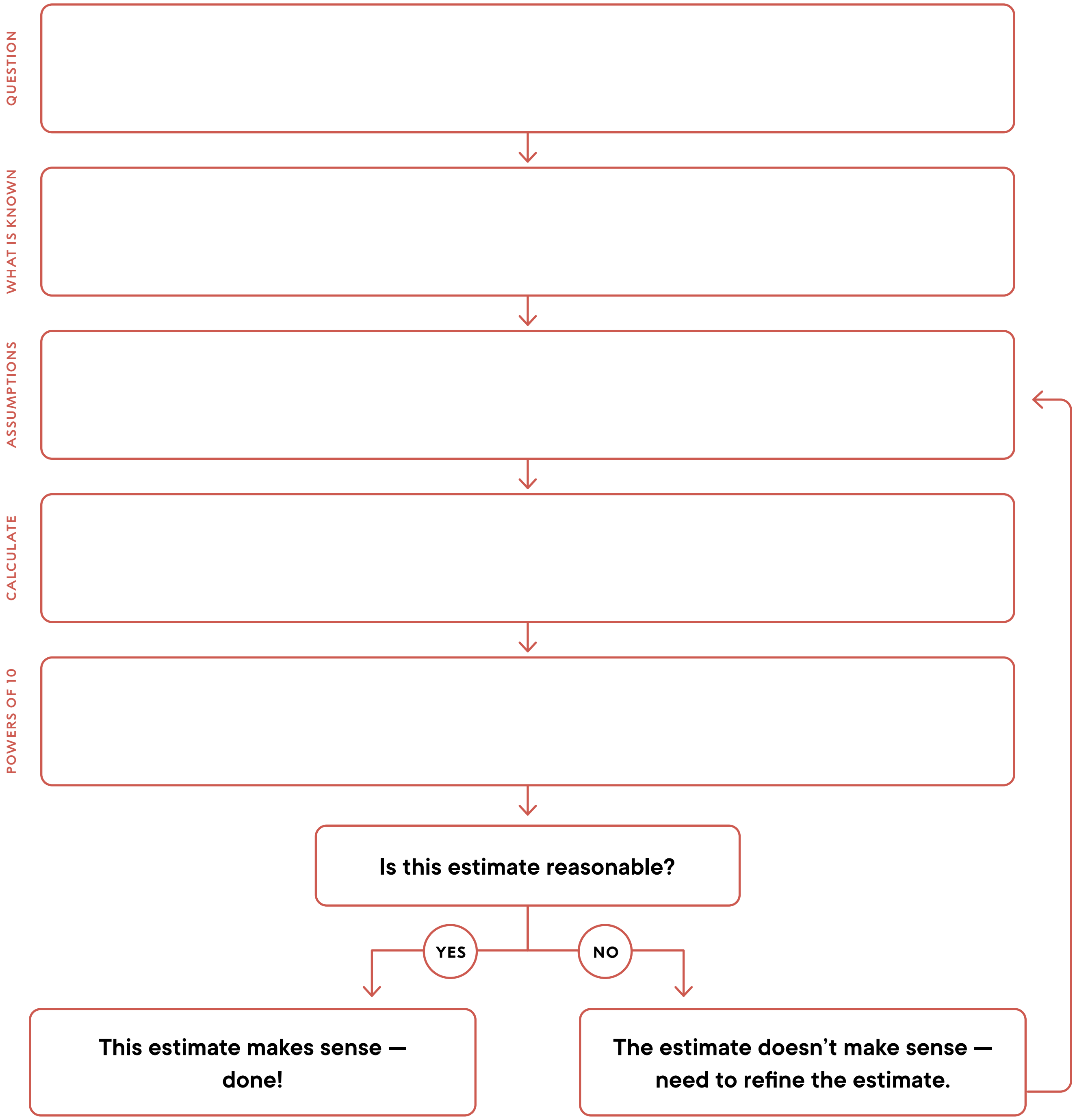
McFarland, Daniel. (April 25, 2024). *Climate matters: Replanting trees after fires in Arizona*. News 4 Tucson KVOA.com. www.kvoa.com/weather/climate-matters/climate-matters-replanting-trees-after-fires-in-arizona/article_60aca4b6-0330-11ef-b742-b39e18dc823b.html

STUDENT SHEET 7.1 | **MAKING A FERMI ESTIMATE** | NAME ____________________

I am making a Fermi estimate for: ____________________

My initial guess is (circle one):

TENS HUNDREDS THOUSANDS MILLIONS BILLIONS



STUDENT SHEET 7.1 | **MAKING A FERMI ESTIMATE** | **NAME** SAMPLE STUDENT RESPONSE 1

I am making a Fermi estimate for: *number of trees lost in the Bighorn Fire*

My initial guess is (circle one):

TENS HUNDREDS [✓ THOUSANDS] MILLIONS BILLIONS

QUESTION

How many trees were likely lost in the Bighorn Fire?

WHAT IS KNOWN

Bighorn Fire covered 200 mi^2 (500 km^2)
A square mile is equivalent to approximately 500 football fields.

ASSUMPTIONS

Entire area was forested.
All trees in the fire died.
If a football field was a forest, it would probably have 100 mature trees.

CALCULATE

100 trees per field x 500 fields per mi^2 = 50,000 trees per mi^2
50,000 trees per mi^2 x 200 mi^2 = 10 million trees

POWERS OF 10

10 million trees, or 10^7 in 200 square miles.

Is this estimate reasonable?

YES → **This estimate makes sense — done!**

NO → **The estimate doesn't make sense — need to refine the estimate.**

STUDENT SHEET 7.1 | MAKING A FERMI ESTIMATE | NAME SAMPLE STUDENT RESPONSE 2

I am making a Fermi estimate for: *house sparrows in my community*

My initial guess is (circle one):

TENS HUNDREDS [✓ THOUSANDS] MILLIONS BILLIONS

QUESTION

What is the population of house sparrows in my community?

WHAT IS KNOWN

Often see or hear house sparrows in groups of 10 in trees and grassy areas.
Nonmigratory species — stays within a range of 5 miles.
Population of house sparrows in the United States is 82 million.
The area of the continental United States is approximately 3 million square miles.
My town is about 25 square miles.

ASSUMPTIONS

The population of sparrows is stable from year to year.
The population of house sparrows is spread across the United States.

CALCULATE

82 million birds ÷ 3 million mi^2 = 30 birds per mi^2
30 birds per mi^2 x 25 mi^2 town = 750 birds in my town

POWERS OF 10

750 birds, or 10^2 in 25 square miles.

Is this estimate reasonable?

YES [✓ NO]

YES: **This estimate makes sense — done!**

NO: **The estimate doesn't make sense — need to refine the estimate.**

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

how many trees to replant after the Bighorn Fire.

My decision is that

they should have planted more trees.

My decision is based on the following evidence:

First,

I estimated that 10 million trees burned down, which is powers of 10 larger than the 43,000 trees replanted.

Second,

not all the trees that are planted will survive, so it’s better to plant more trees.

Third,

trees provide a habitat for other organisms, which will help rebuild the ecosystem.

The trade-off(s)

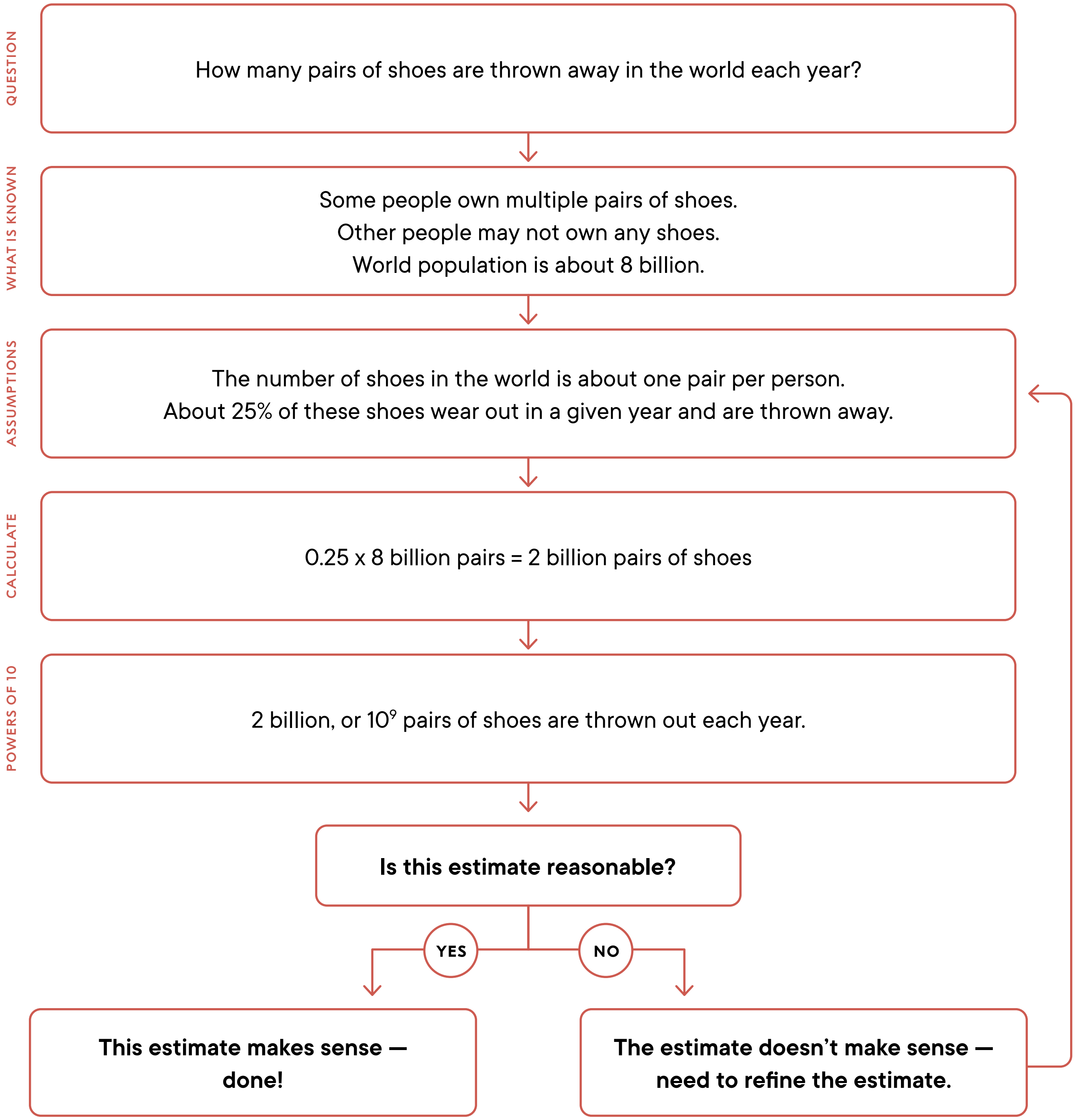
is that it takes a lot of effort and money to plant trees.

People who disagree with my decision might say that

ecosystems change naturally, and trees will eventually grow back.

VISUAL AID 7.1 | **ANOTHER FERMI ESTIMATE EXAMPLE: SHOES**

Another Fermi Estimate Example: Shoes



How many pairs of shoes are thrown away in the world each year?

Some people own multiple pairs of shoes.
Other people may not own any shoes.
World population is about 8 billion.

The number of shoes in the world is about one pair per person.
About 25% of these shoes wear out in a given year and are thrown away.

0.25 x 8 billion pairs = 2 billion pairs of shoes

2 billion, or 10^9 pairs of shoes are thrown out each year.

Is this estimate reasonable?

This estimate makes sense — done!

The estimate doesn't make sense — need to refine the estimate.

v 1.0

ACTIVITY 8

Modeling a Method

INVESTIGATION

ACTIVITY 8

Modeling a Method

ACTIVITY SUMMARY

Students explore a model of the method of mark and recapture for estimating population size. They identify the assumptions and limitations of the model and suggest changes to the model based on their analysis. They then conduct their revised models and compare the resulting estimates. Students identify ways in which the model represents or excludes elements of real-world systems.

ACTIVITY TYPE
INVESTIGATION

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. *(Science and Engineering Practice: Developing and Using Models)*

CONCEPTUAL
TOOLS

SCIENTIFIC MODELING

FERMI
ESTIMATIONS

VOCABULARY DEVELOPMENT

mark and recapture

`a method of estimating population size by catching as many organisms as possible during a certain period, marking and releasing them, then returning at another time to repeat the process, and this time recording how many newly captured organisms were marked as having been captured before`

TEACHER BACKGROUND INFORMATION

Estimating Population Size

The most accurate method to measure the size of a population is to count all the individuals in that population. This is possible when determining the population sizes of small numbers of slow-moving or stationary organisms, such as snails or trees. If the organism is mobile (such as a bird) or is present in large quantities (such as a colony of ants), counting every individual is difficult. In the case of some ocean species, such as minke whales, estimates have differed by as much as the powers of 10.

The Method of Mark and Recapture

One method often used to estimate population size is mark and recapture in which scientists capture some animals from the population, mark them, and release them. At a later time, the scientists again capture animals from the same population and observe how many of them are marked. The method assumes that the ratio of the actual population to the sample size is the same as the ratio of the number of marked animals to the number marked in the recapture sample. Knowing three of the four values—number originally marked (N_1), recapture sample size (N_2), and number marked in the recapture sample (R)—scientists can calculate an estimate of the actual population size (P).

$$P = (N_1 \times N_2)/R$$

where **P** = total size of population
N_1 = size of first sample (all marked)
N_2 = size of second sample (recapture: some will be marked, some won't)
R = number of marked individuals recaptured in second sample

This estimate makes the following assumptions:

- The population of organisms must be closed, with no immigration or emigration.
- The time between samples must be very small compared to the lifespan of the organism being sampled.
- The marked organisms must mix completely with the rest of the population during the time between the two samples.

Other Methods of Estimating Populations

Another method for estimating population size, the line-transect survey, involves observing every animal seen while they are traveling in a straight line. Although traditionally used for counting land animals, the line-transect survey method has recently been applied to whales, providing more reliable data.

The quadrat method of population estimation involves placing a series of squares, or quadrats, of a set size in the habitat and recording the species found within each quadrat. The quadrats can be used to estimate population abundance, density, frequency, and distribution of less mobile species.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- JAR FILLED WITH ONE TYPE OF OBJECT (e.g., marbles, pennies, beads)

FOR EACH PAIR OF STUDENTS

- BAG OF 150 PLASTIC DISKS (or other markable objects)
- TIMER
- MASKING TAPE
- CALCULATOR

FOR EACH STUDENT

- STUDENT SHEET 8.1 “Mark and Recapture”

Fill a jar with one type of small object such as marbles, pennies, or beads. The jar should hold enough of the object that it is impossible to count all of them directly. You will use this jar in Teaching Step 2.

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Connect the idea of Fermi estimates to estimating a population size.**

- In Activity 7, students generated Fermi estimates, a mathematical modeling approach to estimating difficult-to-know quantities. Ask, In what situations are Fermi estimates most useful? Review the idea that this type of estimation is helpful when there is limited data and when a rough estimate can provide useful information.

- Hold up the jar of objects you prepared and ask students to estimate how many objects are in the jar. Give students a minute to come up with their estimates. Call on a few students and ask, What is your estimate and what method did you use to come up with that estimate? Some students may say that they simply guessed, while others may already be using a Fermi estimate. Point out that some students may have used proportional reasoning to come up with their guesses. For example, a student might say that they counted the number of marbles they could see along the surface of the jar and then estimated that there were 10 times as many on the inside. So, if they counted 100 marbles on the surface, there would be 1,000 more on the inside, for a total of 1,100 marbles.

- Ask, If the objects were not stationary and they could freely come and go from the jar, would you use the same method to count them? Help students realize that they would probably need to use a different method because they wouldn't know if they were counting the same object more than once. Students would need some way to keep track of the objects.

2 **Share the story of the Azores bullfinch to introduce population estimation methods.**

- The Introduction in the Student Book contains a brief real-life example that can be shared with the class in multiple ways. Read it aloud to the class (using a storytelling approach), have individual students read a paragraph aloud to the class while others follow along with the text, or have students read it individually or cooperatively in their groups of four.

- Reading the Introduction 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 Introduction independently.

- Help students distinguish between the population estimation method (mark and recapture) and the modeling of that method. Students will model this method for estimating population size. Briefly describe mark and recapture (referred to in the Azores bullfinch story). It estimates populations by capturing individuals, marking them (e.g., banding, tagging), releasing them back to the environment, and then capturing a second sample to determine the proportion of marked to unmarked individuals. Just like the jar example, this method relies on mathematical thinking to determine an estimate. This method is what you might use if the objects could come and go from the jar. In this activity, students will not actually be marking and recapturing real organisms; instead, they will explore a model of this method of population estimation.

PROCEDURE SUPPORT (25 MIN)

3 **Students model the method of mark and recapture for estimating population size.**

- Hand out Student Sheet 8.1, "Mark and Recapture," and direct pairs to begin conducting the model of mark and recapture.
- If your students are finding the math challenging, you may want to review an example, as provided here.

Method of Mark and Recapture

On Day 2, we recaught 4 birds. These 4 birds were 4/20, or 20%, of the total number of birds we caught on Day 2. This means that the 18 birds we caught on Day 1 should be approximately 20% of the total number of birds in the population, N. We can set up the equation this way:

$$\frac{18}{N} = \frac{4}{20}$$

Then solve for N = (18 x 20)/4 = 90
The size of the population is approximately 90 birds.

- A sample student response for Student Sheet 8.1 is provided at the end of this activity.
- Have students evaluate the likelihood of their estimate in terms of powers of 10. Stopping to consider whether their estimate is reasonable can be helpful for sensemaking.
- In Procedure Step 8, students are asked to respond (in their groups) to the following questions about the model. Remind students to focus on the model of mark and recapture and not on the estimation method itself (which also contains assumptions and has limitations).

Sample Student Response, Procedure Step 8

What assumptions were made about how well this physical model represented the real-world method of mark and recapture? (How might the model not represent the method of mark and recapture correctly?)

- *Assumption that the act of shaking the bag perfectly mixes the marked disks back into the unmarked population.*
- *Assumption that the procedure of removing disks from the bag provides a random and unbiased sample.*
- *Assumption that there are no human errors in counting the number of disks marked, the number captured, and the number recaptured.*

What were the limitations of the model? (What could it not explain or predict?)

- *The model of mark and recapture cannot explain or predict real bird behavior or habitat. For example, the bag represents the variety of a bird's habitat, with every bird equally accessible for counting (being taken out of the bag).*

- In Procedure Step 9, students are asked to revise their models by modifying the procedure. Possible changes to the model include:

Sample Student Response, Procedure Step 9

- *Increase sampling time: Taking larger initial and recapture samples by increasing sampling time reduces sampling error and improves the reliability of the population estimate.*
- *Random sampling: Ensures both the initial capture and recapture are random and covers the entire habitat to avoid bias. (For example, close eyes while sampling.)*
- *Repeat the process: Instead of just two samples, I can conduct multiple rounds of mark and recapture to get an average estimate.*

- Students then test their revised models by repeating the procedure with their changes. Assuming that students increased sampling time, improved their sampling of the disks, or averaged multiple samples, their estimates are likely to become more accurate. Students can compare the changes they made to their models to identify which changes most helped improve the accuracy of their population estimates.

SYNTHESIS OF IDEAS (20 MIN)

4 **Students compare estimates of population size obtained by different pairs to discuss why there is variation.**

- Facilitate a brief discussion about why there is variability and what scientists might do about this variability in the data. Scientists might take repeated measures and then take an average; this larger sample size gives them more confidence in the estimate. Point out that the class modeled this process by having multiple pairs take measures. Scientists might also express the population size as a range instead of a single number.

- Ask, What type of model—deterministic or probabilistic—does mark and recapture rely on? Students should understand that it is a probabilistic model because its output, the estimated population size, is not a certain, fixed value. Instead, it is an estimate based on chance and ratios and contains uncertainty. The assumption is that the second sample is taken randomly from the total population, and the probability of capturing a marked individual is assumed to be the same as the probability of capturing an unmarked individual.

- Ask students how they think mark and recapture compares with other methods of population estimation, such as a line-transect survey or the quadrat method (see Teacher Background Information for brief explanations of both methods). Ask, Which type of method would be best for estimating snails? Whales? Sea jellies? The quadrat method is useful for snail populations, mark and recapture (and aerial surveys) for whale populations, and direct sampling from fishing nets for sea jellies. Let students know that scientists have found, through extensive studies, that different methods of estimation can be reliable methods and useful for different types of organisms.

- Have students briefly share their ideas about how population estimation data might be used in the real world. Accept all reasonable responses.

5 **Identify ways in which the model of mark and recapture did or did not represent real-world systems.**

- In this activity, students modeled a real-world method for estimating population. Ask, What aspects of real-world systems were included in the model and what elements were excluded? Student responses should indicate that the model used disks to represent the entire population of a species as individual organisms in a habitat (the disks in the bag). It did not address bird behavior (e.g., hiding), births, deaths, migration, disease, predation, or weather—all of which are factors that could affect the size of a population in a real-world system.

- Finish the activity by revisiting the Guiding Question, *How can you revise a model for estimating population size?* Use responses to this question to formatively assess students' understanding of the key concepts and process skills related to how models can be made more accurate through the process of iteration.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **In this activity, you modeled the method of mark and recapture for estimating populations.**

a **What are two assumptions of the model of mark and recapture?**

Possible responses include:

- The marked species (the disks) will completely reintegrate into the population.

- In subsequent captures, the probability of capturing a marked organism is the same as that of capturing any (unmarked) member of the population.

- The marks (tags) will not be lost.

b **Select one assumption and explain how it would affect the population estimate if the assumption was false.**

Possible responses include:

If the species (the disks) does not reintegrate, the model will underpredict the total population size because it mistakenly assumes that because a high percentage of the sample was marked, the total population must be small.

If the probability of capturing a marked organism is not the same as that of capturing any (unmarked) member of the population (because the person sampling is choosing the marked disks, for example), the model will underpredict the total population size. This is because it mistakenly concludes that since a high percentage of the sample was marked, the total population must be small.

If marks (tags) are lost, the model will overpredict the total population size because the number of recaptures suggests that the small number of marked organisms must have been spread throughout a very large total population. In reality, the marked organisms were simply hidden by missing tags.

② **Imagine a city uses a model to predict the number of seagulls on the main public beach to better plan for trash management. The model included 2 factors: the number of tourists and the time of year. The model predicted an average of 200 seagulls per day in July. Local researchers then used data from the method of mark and recapture from 3 days in July to estimate that the average number of seagulls per day in July was 350 seagulls.**

a **Why are the two estimates different, and which is likely to be more accurate? Explain your reasoning.**

The first model only included two factors to estimate population. These factors may not have been the ones that have the greatest effect on the population. The mark and recapture estimate was based on a sample of the seagulls present at the site on three days and then averaged. If those three days were representative of the number of seagulls on most days, this estimate is likely more accurate.

b **Describe two specific ways the city could revise their model to improve its accuracy by adding specific real-world factors that were initially left out.**

The model could include food availability and birth rates. It assumes that the presence of tourists is the primary source of food, but there may be other sources. It also does not take into account how the population may be growing from year to year, for example, by having lots of offspring.

③ **Imagine you are studying a forest ecosystem in which a nonnative bird species has recently been seen. Which estimation method would be most useful in addressing each of the following scientific questions? Explain your reasoning.**

Question A: **What is the population size of this newly introduced bird species?**
Mark and recapture would be the most useful because it uses probability to estimate the population. It doesn't require counting every bird; it just requires estimating the ratio of marked to unmarked birds in a sample.

Question B: **You observe that the nonnative bird species nests only in mature oak trees. How many mature oak trees are there in this area?**
You could use a Fermi estimate because the trees are not moving. You can estimate the size of the area, the density of trees, and the percentage of mature oak trees, and then calculate a rough estimate.

CONNECTIONS TO EVERYDAY LIFE

④ **Imagine you built a simple model on your phone to help you get to school on time. Your model predicts the exact time you need to leave your home to arrive at school on time. In your model, you include the time you woke up and the total time it took you to get to school yesterday. After the first week, you realize that you are still arriving at school after the bell rings. Suggest two specific ways you could revise your model to make it more accurate.**

I could include local traffic conditions and weather, because it seems to take longer than it should to get from my home to school.

REFERENCES

International Fund for Animal Welfare. (2025). 15 animals that recovered from being endangered. Retrieved from: https://www.ifaw.org/journal/animals-recovered-being-endangered

STUDENT SHEET 8.1 | MARK AND RECAPTURE | NAME

Data From Original Model

NUMBER OF BIRDS CAUGHT ON DAY 1	
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	
NUMBER OF BIRDS CAUGHT ON DAY 2	

$$\text{Estimated population size} = \frac{\left(\text{Number of birds caught on Day 1}\right) \times \left(\text{Number of birds caught on Day 2}\right)}{\text{Number of marked birds caught on Day 2}}$$

Calculations for population estimate:

Planned changes to the model and my explanation for the changes:

Data From Revised Model

NUMBER OF BIRDS CAUGHT ON DAY 1	
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	
NUMBER OF BIRDS CAUGHT ON DAY 2	

Calculations for population estimate:

STUDENT SHEET 8.1 | **MARK AND RECAPTURE** | **NAME** SAMPLE STUDENT RESPONSE

Data From Original Model

NUMBER OF BIRDS CAUGHT ON DAY 1	18
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	4
NUMBER OF BIRDS CAUGHT ON DAY 2	20

$$\text{Estimated population size} = \frac{\left(\text{Number of birds caught on Day 1}\right) \times \left(\text{Number of birds caught on Day 2}\right)}{\text{Number of marked birds caught on Day 2}}$$

Calculations for population estimate:

$$\frac{18}{N} = \frac{4}{20} \qquad N = \frac{(18 \times 20)}{4} = 90$$

Estimated population = 90 birds

Planned changes to the model and my explanation for the changes:

We plan to increase the sampling time from 15 to 20 seconds so we can have larger initial and recapture samples. This should result in a more accurate estimate.

Data From Revised Model

NUMBER OF BIRDS CAUGHT ON DAY 1	25
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	6
NUMBER OF BIRDS CAUGHT ON DAY 2	24

Calculations for population estimate:

$$\frac{25}{N} = \frac{6}{24} \qquad N = \frac{(25 \times 24)}{6} = 100$$

Estimated population = 100 birds

ACTIVITY 9

Constructing Predictive Models

PRESENTATION

v 1.0

ACTIVITY 9

Constructing Predictive Models

ACTIVITY SUMMARY

Students brainstorm factors that affect the size of a population. They then develop a scientific question about a local species and its future interactions, population size, or population range within their community. By identifying and selecting factors relevant to their question, they construct models. Students use their models to make Fermi estimates for the present and to predict the future. They then discuss the strengths and limitations of their models.

ACTIVITY TYPE
PRESENTATION

NUMBER OF
40–50 MINUTE
CLASS PERIODS
1-2

KEY CONCEPTS & PROCESS SKILLS

1 Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

2 Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

3 Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.

CONCEPTUAL TOOLS

SCIENTIFIC MODELING

FERMI ESTIMATIONS

ORDERS OF UNDERSTANDING

4 Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.

5 When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*

6 One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a Fermi estimate—can be used to approximate unknown quantities that are difficult to measure.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (*Science and Engineering Practice: Developing and Using Models*)

TEACHER BACKGROUND INFORMATION

Scientific Optimism

Professional and amateur scientists continue to research the world scientifically, even when they are met with obstacles and errors. This approach of adopting a can-do attitude in light of challenges and believing that scientific problems are solvable are aspects of scientific optimism. Scientific optimism enables scientists to continue to focus on solving difficult problems over long periods of time. While this unit addresses some negative impacts of global changes, it has been developed to incorporate an approach of scientific optimism.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- FOOD WEB MODEL CONSTRUCTED IN ACTIVITY 3 (one student's model)
- VISUAL AID 1.1 "Interpreting Graphs" (OPTIONAL)
- VISUAL AID 2.1 "Developing Communication Skills" (OPTIONAL)

FOR EACH STUDENT

- STUDENT SHEET 9.1 "Developing Model Components"
- STUDENT SHEET 9.2 "Developing Fermi Estimates"
- STUDENT SHEET 9.3 "Developing Scientific Questions" (OPTIONAL)
- FOOD WEB MODELS CONSTRUCTED IN ACTIVITY 3 (OPTIONAL)

The Extension (Teaching Step 8) suggests using an online student-friendly computer modeling program to further explore cause-and-effect relationships and test ideas. The following are links to free online modeling programs:

- Concord Consortium's and the CREATE for STEM Institute at Michigan State University's SageModeler https://sagemodeler.concord.org/
- Howard Hughes Medical Institute's (HHMI) *Model Builder* https://www.biointeractive.org/classroom-resources/model-builder
- LOOPY https://ncase.me/loopy/
- Insight Maker https://insightmaker.com/

TEACHING NOTES

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

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

GETTING STARTED (5 MIN)

1 **Introduce the activity by using an example of a food web model from Activity 3.**

- In Activity 3, students constructed their own food web models. Remind students of these models by briefly displaying and reviewing one example from that activity. Ask the class, What determined what was included in your model? In this case, the model was based on prior knowledge, observations from the field trip, and research; both the prior knowledge and research also drew on observations, though from different times and from people. Ask, Did your model help you explain a phenomenon or make a prediction? Students may recognize that their food web models from Activity 3 were primarily an approach to explaining the feeding relationships in a location ecosystem, though the class discussed how to use the model to make predictions about changes to one population if another population increased or decreased.
- Point out that the model was students' first experience in this unit to construct a model. In this activity, students will construct a model to accomplish both the explanatory and predictive natures of scientific modeling, and they will use their models to inform a Fermi estimate. You may want to use the Introduction in the Student Book to explain the field of ecological forecasting; some students may wish to consider it as a future area of study.

PROCEDURE SUPPORT (45-60 MIN)

2 **Brainstorm factors that affect population size.**

- Hand out Student Sheet 9.1, "Developing Model Components." Pairs select and record a local species and develop a scientific question related to its future distribution within their community. Facilitate the engagement of students with learning disabilities and neurodiverse learners by providing targeted support. Consider how to best adapt the activity to the needs of your particular student population. For example, you may want to provide optional Student Sheet 9.3, "Developing Scientific Questions," for additional support.

- In Procedure Step 3, partners brainstorm and list five factors that affect population size. This may feel familiar to students since they have been considering factors that affect population size throughout the unit. Guide students as needed. Students can add any additional factor(s) specifically relevant to their species. Possible responses include:
  - food availability
  - water availability
  - disease
  - competition
  - predation
  - temperature (and/or other environmental factors)
  - migration
  - urbanization (and/or other human effects)
  - natural hazards
- Pairs then further analyze their list of factors.
  - For each factor, they predict the present and likely future effects on their species' distribution.
  - For each factor, they rate it according to orders of understanding.
  - They decide which three factors to incorporate into their model.
- Remind students that they rate the orders of understanding by determining which factors are likely to have the greatest impact on the scientific question they are investigating, with 1 being the most important factor(s) related to their scientific question.
- If your student population needs additional support, use the list of word cues associated with each rating you may have developed in Activity 4. For example, factors that have "serious impact/significantly reduce/primary impact" could be rated 1 (greatest impact), factors that are "constant/steady" rated 2 (medium impact), and factors that are "little/no impact" rated 3 (least impact).
- A sample response to Student Sheet 9.1 is provided at the end of the activity.

3 **Students develop their models, using their selected factors.**

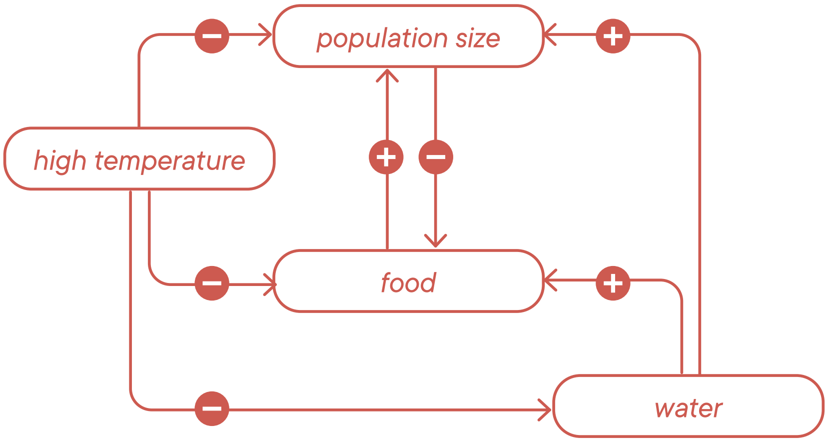
- To provide structure and guidance to the process of model construction, the Student Book provides a sample model that was first presented in Activity 2, Build Understanding item 2. Review the sample model as needed. Students can draw their individual models on the reverse side of Student Sheet 9.1.
- Depending on your student population, you may want to make the activity more open-ended by encouraging students to decide on their own approaches to constructing their models. For example, students could use optional Student Sheet 3.2, "An Ecological Relationship Model," as the framework for their model, or they can create their own approach and provide a key. Alternatively, provide additional support to those students who need more structure. For example, discuss the likely relationship between factors and population and then provide students with an empty framework to fill in. (A blank model is not provided because the framework depends on the relationship between the factors chosen to be included in the model. A factor may be connected to another factor or independently affect the population.)

- Students use the sample model first introduced in Activity 2 of the Student Book and their three identified factors to construct a model that would help address the scientific question they developed. A sample student response is provided.

Sample Student Response, Procedure Step 6

My Species: *Deer*

Scientific Question: *Will an increase in average local temperature reduce the number of deer in urban areas?*



An increase in food availability increases the population size, while a decrease in food availability decreases population size. Lots of water can result in more food and an increase in population, while a lack of water could reduce the size of the population. High temperatures could reduce the availability of food and water, resulting in a decrease in the population size. High average temperatures could also directly reduce the population due to migration or an increase in disease.

4 **Pairs share their models with the other half of their groups.**

- Support students in explaining their models to the other half of their groups. Students can address comments or suggestions by modifying their models. If needed, use Visual Aid 2.2, “Developing Communication Skills,” to support student conversation.

5 **Pairs make Fermi estimates of their species’ population size now and in the future.**

- Provide students with both pages of Student Sheet 9.2, “Developing Fermi Estimates.” Remind students to use their models to consider which factors would likely be affected under future conditions and how it might affect their future estimate.
- You may want to list some local relevant information, such as the relative size of your town or neighborhood.

- A sample response to Student Sheet 9.2 is provided. Procedure Step 9 lists three discussion questions. Sample responses are provided.

  Sample Student Response, Procedure Step 9

  What data would you want to collect to test your model?

  We may want to test our model by using other methods of measuring/estimating population size now and in the future, as well as collecting data about other measurable factors in our model. For example, we may want more accurate data about the population of our selected species. We could gather this through population estimation methods such as mark and recapture or thorough research of scientific studies that have done this work. We might also want more complete information about the conditions that we are investigating, such as temperature or traffic.

  If the data did not support your model, how would you revise it?

  Models can be made more accurate by adding or deleting relevant factors or modifying the relationship between factors. For example, our model may be revised by changing the ways in which the interactions are presented, like adding or removing arrows, changing +/- projections.

  How could this type of data help make your Fermi estimates more accurate?

  It would reduce uncertainty in the assumptions and likely result in more accurate estimates.

SYNTHESIS OF IDEAS (30-45 MIN)

6 Students present their models and estimates to the class.

- In Procedure Step 10, have students present their models to the class. Their presentations should include the local species being investigated, their scientific questions, their models, an explanation of their models, and their Fermi estimates (including an explanation of how their model informed their estimates).
- For students who have chosen the same species, you may want to have them compare Fermi estimates with others in the class by putting their estimates on a whiteboard. Discuss the powers of 10 of the Fermi estimates for similar species in the present vs. the future. Ask, Does the predicted population size increase or decrease over time? In the sample student response for Procedure Step 6, the deer population declined by the powers of 10 from thousands to hundreds. Ask, Why (what factors are being addressed in the various models/what assumptions are being made)? In the sample student response, assumptions included the percentage of deer observed, the projected effect of changing environmental conditions on food availability, and the projected effect of changing environmental conditions on the deer population. Have students share how they made their calculations and what assumptions they made.

- Have students discuss the strengths and limitations of their models. Students may note that their models helped focus on key elements related to their scientific questions and identified interactions among those elements and population size. The models were limited in their focus to three factors, and students may have had uncertainty about the exact nature of relationships among the selected factors.

7 **Introduce or review the concept of scientific optimism.**

- Professional and amateur scientists continue to research the world scientifically, even when they are met with obstacles and errors. This approach of adopting a can-do attitude in light of challenges and believing that scientific problems are solvable are aspects of scientific optimism. Scientific optimism enables scientists to continue to focus on solving difficult problems over long periods of time.
- Ask, What examples of scientific optimism have you observed in this unit so far? Create a list of student responses on the whiteboard. Ask, In what ways can your model contribute to scientific optimism? Accept all responses. Encourage students to consider ways in which their models could contribute to scientific knowledge and/or inform decision-making about issues informed by science.
- Finish the activity by revisiting the Guiding Question, *How can a model be used to predict changes to the distribution of a population?* Using a model to describe how the most relevant parts of a system interact can provide the basis for explaining systems and making predictions.

EXTENSION (10 MIN)

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

On the Internet, students can find student-friendly computer programs to model complex systems that explore cause-and-effect relationships and test ideas. Students can find one of these tools to construct their population models and explore how the factors in their models interact.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **A local group wants to use your model to help determine land use, such as the location of housing vs. open space.**

a **What would you tell them about sources of uncertainty in your model?**

Student responses will vary based on their models and sources of uncertainty. A sample response is provided.

My model contains uncertainty about the relationship between high temperature and deer populations. I don't know for sure the direct effect of high temperatures on deer.

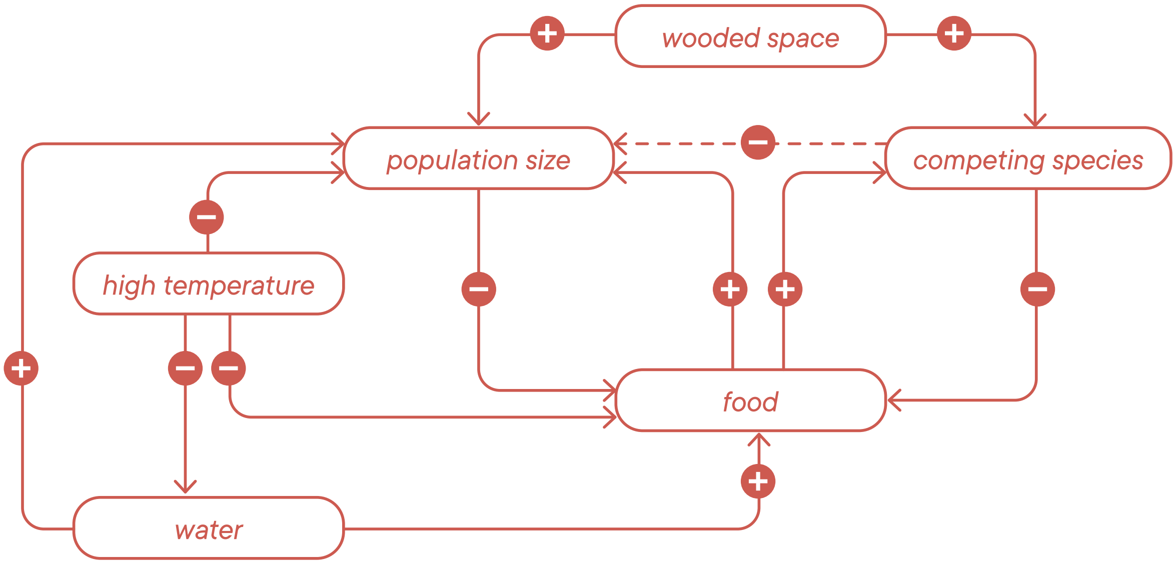
b **How could you test your model to evaluate its accuracy?**

Student responses will vary based on their models. A sample response is provided.

I could gather historical data on the annual deer population and average temperatures to determine if there was a relationship. If high temperatures corresponded to years where there were fewer deer, I would know my model is accurate.

② **Imagine that a new species is accidentally introduced into your community. It can successfully outcompete your local species in wooded areas but not in other spaces. Explain how you would modify your model (in words or in a drawing) to account for this new species.**

I investigated an urban deer population. The competing species would affect the population size of the deer in wooded areas where more of the deer live. The new species would be competing for space and food. I'm not sure how it would be affected by higher temperatures nor if there would be competition for water since there is a large lake nearby. My modified model is:



CONNECTIONS TO EVERYDAY LIFE

③ **A high school soccer coach wants to create a simple predictive model to guess the probability of winning the next game.**

Model 1: This model uses the team's number of game wins over the last five seasons.

Model 2: This model uses the number of goals scored per game, plus three other factors: the number of rained-out games, the number of games played on the weekend, and the number of injuries in the previous season.

Which model would you use and why?

I would use Model 1 because it is common to use historical data to predict the future. Model 2 also uses historical data, but the number of goals scored only matters in comparison to the other team's goals, so it is not likely to be predictive of wins, only the number of goals. The other factors in Model 2 do not have a big impact on the game outcomes (low orders of understanding), so they do not add much accuracy to the model. So while Model 2 is more sophisticated, it is not likely to give a more accurate prediction.

STUDENT SHEET 9.1 | DEVELOPING MODEL COMPONENTS | NAME

Local Species: ____________________

Scientific Question:

FACTORS	PRESENT AND LIKELY FUTURE EFFECTS ON POPULATION DISTRIBUTION	RELATIVE IMPACT ON POPULATION 1 = GREATEST IMPACT 3 = LEAST IMPACT	3 FACTORS TO INCLUDE IN YOUR MODEL

STUDENT SHEET 9.1

DEVELOPING MODEL COMPONENTS

NAME SAMPLE STUDENT RESPONSE

Local Species: Deer

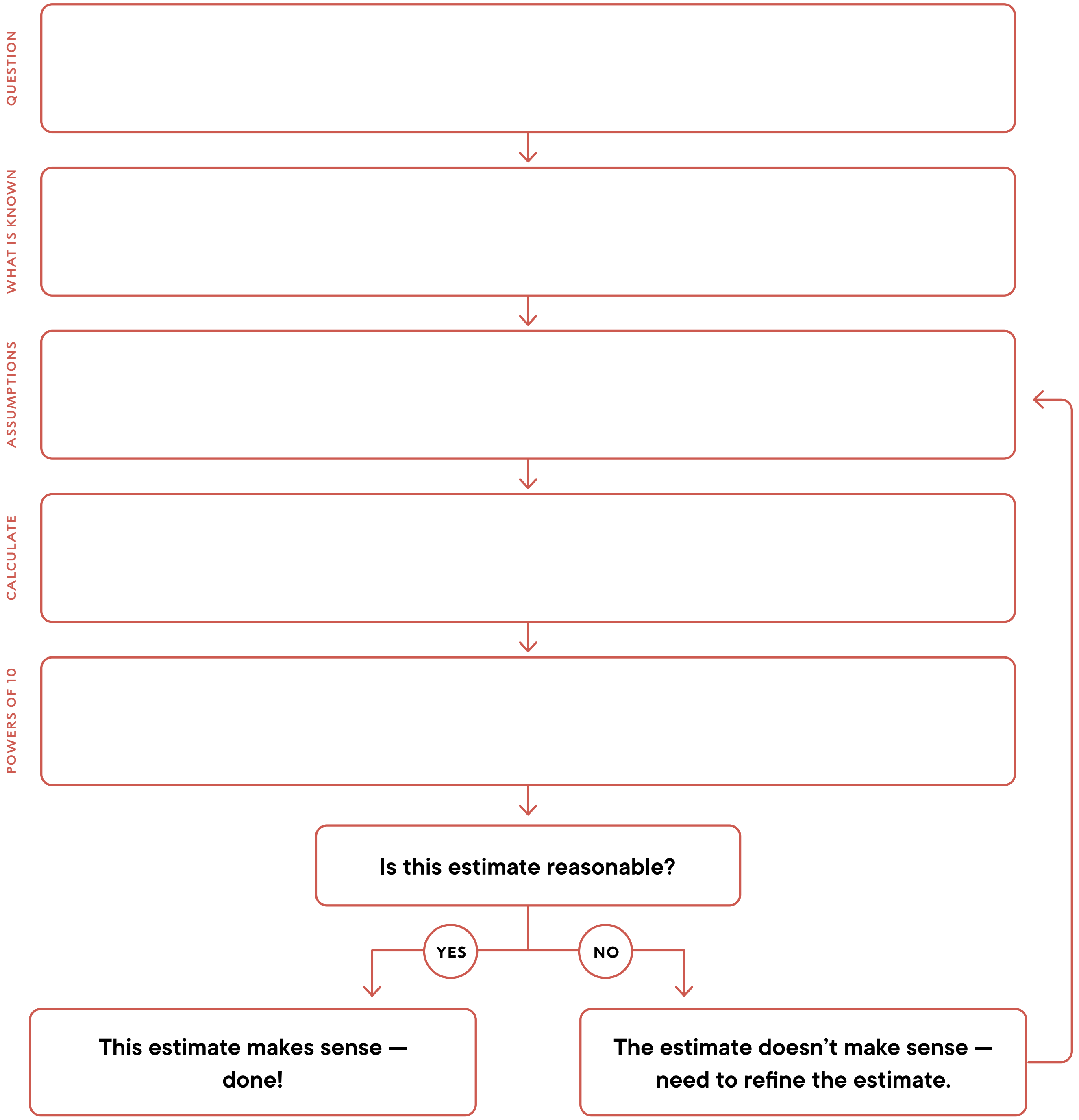
Scientific Question:

Will an increase in average local temperature reduce the number of deer in urban areas?

FACTORS	PRESENT AND LIKELY FUTURE EFFECTS ON POPULATION DISTRIBUTION	RELATIVE IMPACT ON POPULATION 1 = GREATEST IMPACT 3 = LEAST IMPACT	3 FACTORS TO INCLUDE IN YOUR MODEL
Food availability	*More food, more deer.* *Deer can move to where food is, food availability could be reduced by high temperatures.*	*1*	*X*
High temperatures	*No known effect.* *Change in average temperature could affect food availability.*	*1*	*X*
Traffic	*Reduces population size.* *Increase in traffic will likely reduce population.*	*3*	
Predation	*Reduces population size.* *Increase in urban coyotes may decrease population or cause them to move to different range.*	*2*	
Water availability	*No water, fewer deer.* *Deer can move to where water is, water availability could be reduced by high temperatures.*	*1*	*X*

STUDENT SHEET 9.2 | DEVELOPING FERMI ESTIMATES | NAME

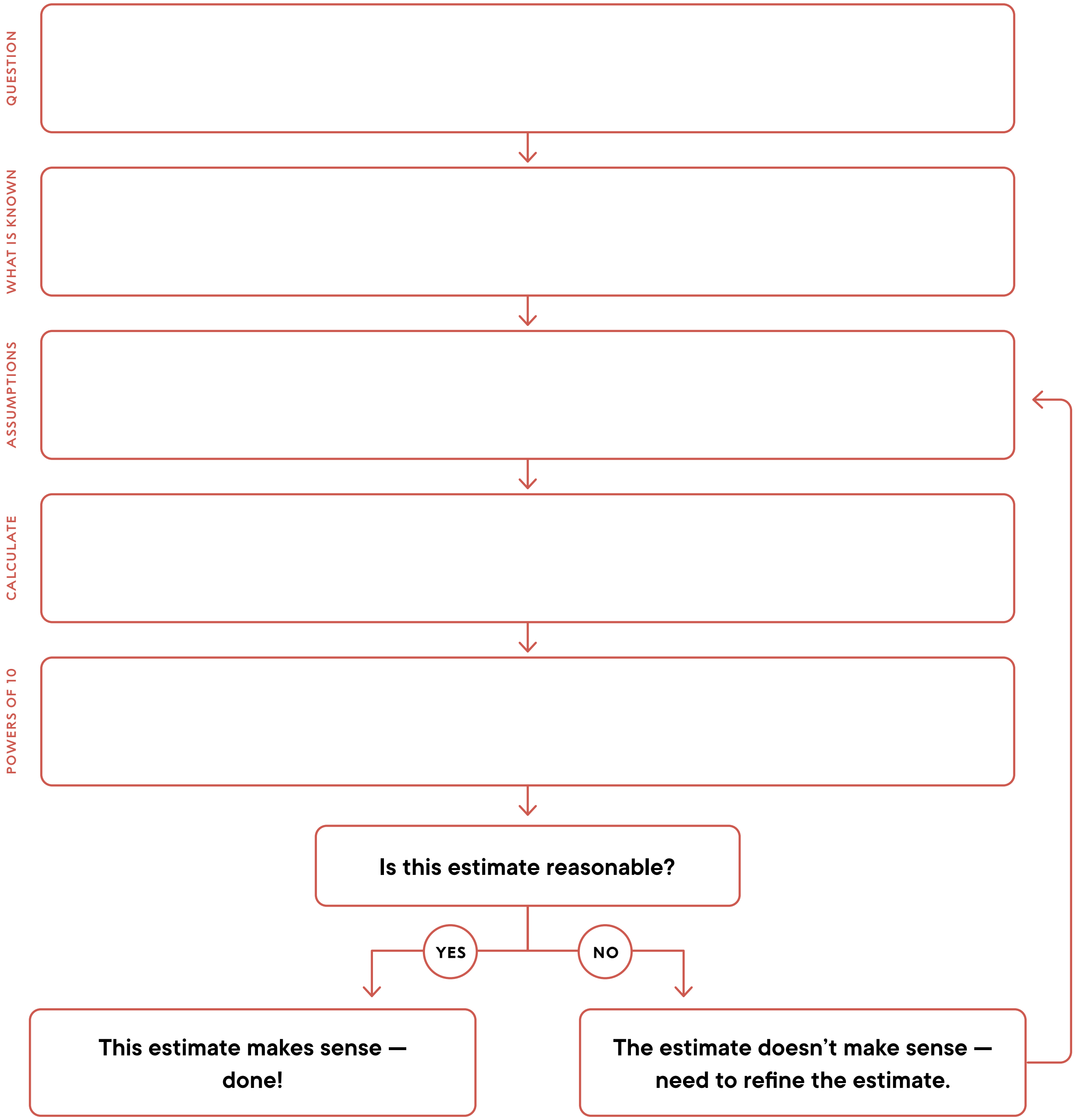
Fermi Estimate: Present Population



STUDENT SHEET 9.2 | **DEVELOPING FERMI ESTIMATES** | **NAME**

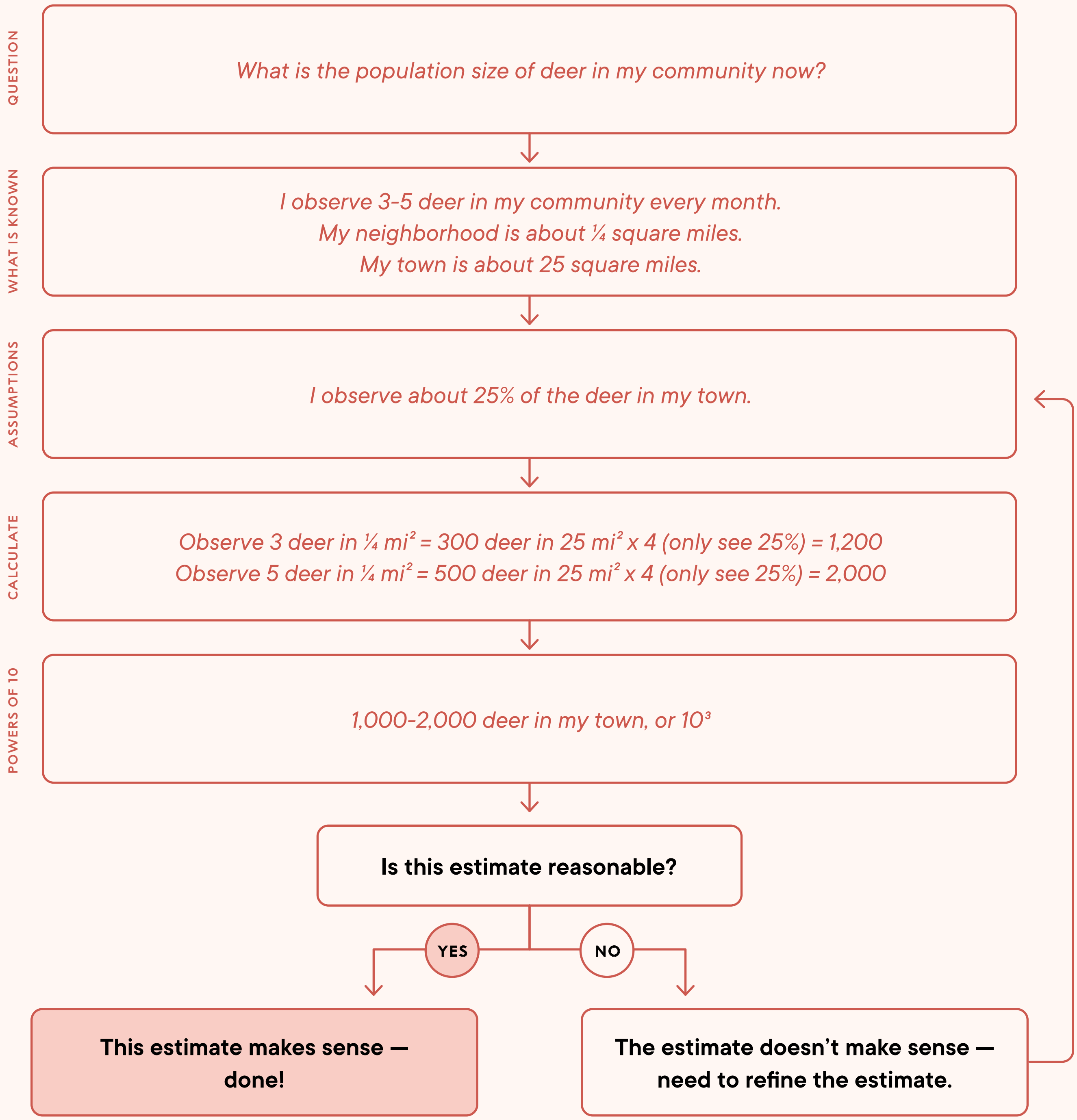
CONTINUED

Fermi Estimate: Population 50 Years in the Future



NAME SAMPLE STUDENT RESPONSE

Fermi Estimate: Present Population



QUESTION

What is the population size of deer in my community now?

WHAT IS KNOWN

I observe 3-5 deer in my community every month.
My neighborhood is about ¼ square miles.
My town is about 25 square miles.

ASSUMPTIONS

I observe about 25% of the deer in my town.

CALCULATE

Observe 3 deer in ¼ mi^2 = 300 deer in 25 mi^2 x 4 (only see 25%) = 1,200
Observe 5 deer in ¼ mi^2 = 500 deer in 25 mi^2 x 4 (only see 25%) = 2,000

POWERS OF 10

1,000-2,000 deer in my town, or 10^3

Is this estimate reasonable?

YES

This estimate makes sense — done!

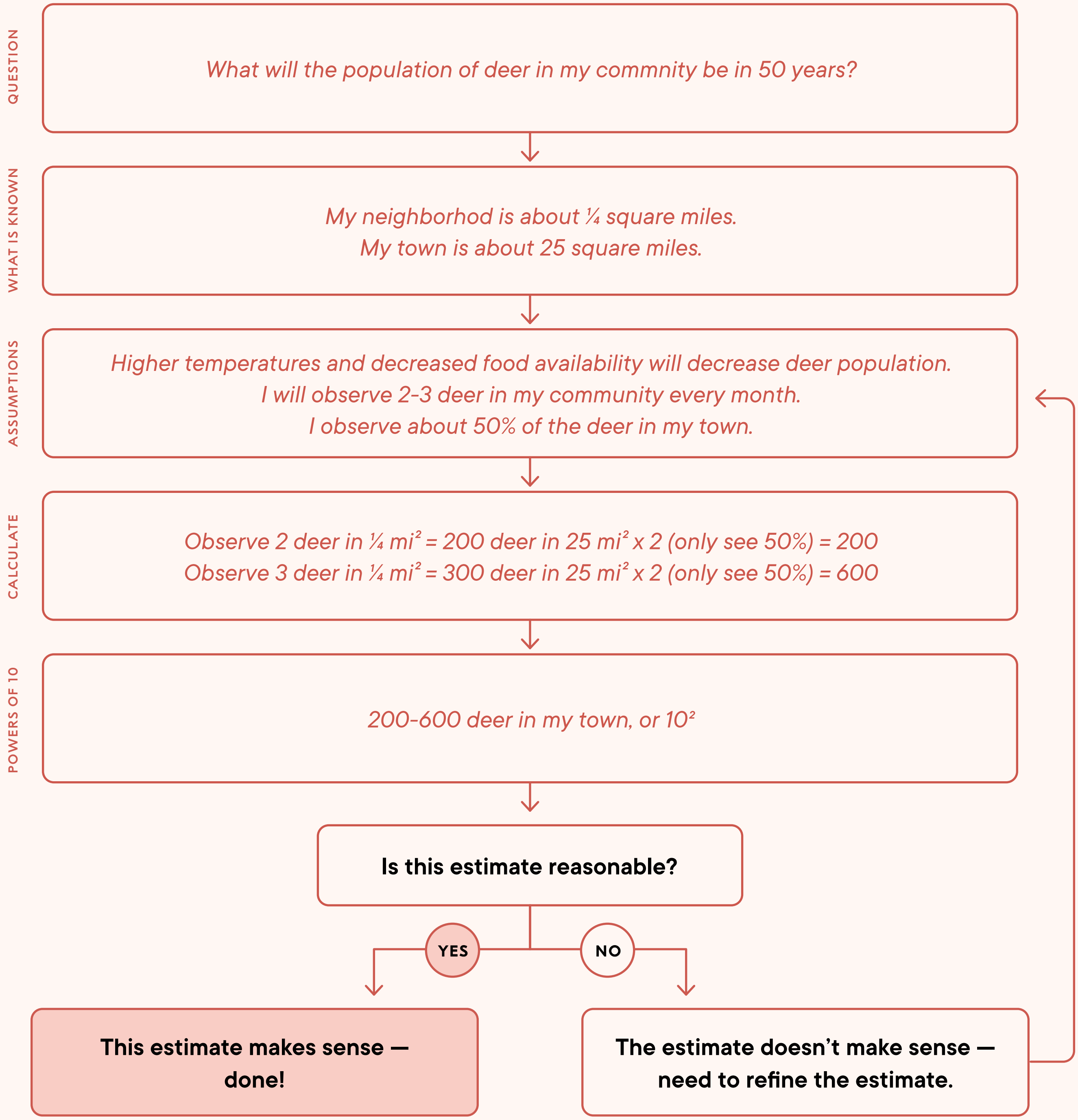
NO

The estimate doesn't make sense — need to refine the estimate.

STUDENT SHEET 9.2 | DEVELOPING FERMI ESTIMATES | NAME SAMPLE STUDENT RESPONSE

CONTINUED

Fermi Estimate: Population 50 Years in the Future



QUESTION

What will the population of deer in my commnity be in 50 years?

WHAT IS KNOWN

My neighborhod is about ¼ square miles.
My town is about 25 square miles.

ASSUMPTIONS

Higher temperatures and decreased food availability will decrease deer population.
I will observe 2-3 deer in my community every month.
I observe about 50% of the deer in my town.

CALCULATE

Observe 2 deer in ¼ mi^2 = 200 deer in 25 mi^2 x 2 (only see 50%) = 200
Observe 3 deer in ¼ mi^2 = 300 deer in 25 mi^2 x 2 (only see 50%) = 600

POWERS OF 10

200-600 deer in my town, or 10^2

Is this estimate reasonable?

YES → **This estimate makes sense — done!**

NO → **The estimate doesn't make sense — need to refine the estimate.**

DEVELOPING SCIENTIFIC QUESTIONS

NAME

Local Species: ______

Scientific Questions

① **Read the following list of scientific questions. Use the list to either brainstorm a new question, choose one of the questions, or modify an existing question.**

- How will the predicted changes in local temperature affect the population distribution of this local species?
- Will the population of a new competing species grow large enough to affect the distribution of this local species?
- If the regional park is made larger, will the distribution of this local species change?
- Will an increase in stormwater runoff during heavy rains affect the distribution of this local species?
- How will the future availability of its primary food source change the distribution of this local species?
- If a species that this local species relies on for food disappears, will the local population be able to adapt to another food source?
- Will the building of a new major road affect the distribution of this local species?

② **Record the scientific question you have about your local species.**

STUDENT SHEET 9.3 | DEVELOPING SCIENTIFIC QUESTIONS | NAME SAMPLE STUDENT RESPONSE

Local Species: *Deer*

Scientific Questions

① **Read the following list of scientific questions. Use the list to either brainstorm a new question, choose one of the questions, or modify an existing question.**

- How will the predicted changes in local temperature affect the population distribution of this local species?
- Will the population of a new competing species grow large enough to affect the distribution of this local species?
- If the regional park is made larger, will the distribution of this local species change?
- Will an increase in stormwater runoff during heavy rains affect the distribution of this local species?
- How will the future availability of its primary food source change the distribution of this local species?
- If a species that this local species relies on for food disappears, will the local population be able to adapt to another food source?
- Will the building of a new major road affect the distribution of this local species?

② **Record the scientific question you have about your local species.**

Will an increase in average local temperature reduce the number of deer in urban areas?

ACTIVITY 10

Applying Models to Decisions

CARD-BASED INVESTIGATION

v 1.0

ACTIVITY 10

Applying Models to Decisions

ACTIVITY SUMMARY

Students revisit the fictional frog population of Menanda as they construct models of a frog population. Students apply their knowledge of orders of understanding to build their models. They use their models to construct a Fermi estimate and to inform a decision about which local site would best support the future frog population. The class discusses the role of models in decision-making.

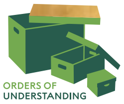
ACTIVITY TYPE
CARD-BASED
INVESTIGATION

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2–3

KEY CONCEPTS & PROCESS SKILLS

1. Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.
2. Different questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.
3. Models are developed based on observations of a system. When modeling a complex system, it is often useful to identify how a system's parts interact and to describe the limitations of the model based on the scientific question being investigated.
4. When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*
5. One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a Fermi estimate—can be used to approximate unknown quantities that are difficult to measure.

CONCEPTUAL
TOOLS



NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (*Science and Engineering Practice: Developing and Using Models*)

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 10.1 "Scoring Guide: Developing and Using Models (MOD)"
- ITEM-SPECIFIC SCORING GUIDE: Activity 10, Build Understanding Item 1

FOR EACH GROUP OF FOUR STUDENTS

- SET OF MENANDA SITE CARDS (4 CARDS)

FOR EACH STUDENT

- STUDENT SHEET 10.1 "Evaluating Sites"
- STUDENT SHEET 10.2 "My Site Model"
- STUDENT SHEET 10.3 "Estimating Factor Impact on Population in 50 Years"
- STUDENT SHEET 10.4 "Writing Frame: Evidence and Trade-Offs" (OPTIONAL)
- SCORING GUIDE: Developing and Using Models (MOD) (OPTIONAL)

TEACHING NOTES

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

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

GETTING STARTED (10 MIN)

1 **Share a real-world example of the use of modeling presented in the Introduction in the Student Book.**

- The Introduction provides a real-world example of a scientific question and the application of a scientific model. You may choose to read it aloud to the class (using a storytelling approach), have individual students read a paragraph aloud to the class while others follow along with the text, have students read it cooperatively in their groups of four, or have students read it individually.
- Highlight the idea that scientists are now working to better understand how wildfires affect birds by developing models to investigate this question. You may want to have students brainstorm the kinds of models that could be constructed to investigate this question or the factors that might best be included in the model.

PROCEDURE SUPPORT (50 MIN)

2 **Present the fictional article found in Procedure Step 1.**

- The fictional 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.

3 **Hand out the Menanda Site cards and support students in rating factors according to their orders of understanding.**

- In Procedure Step 2, hand out a set of 4 Menanda Site cards to each group and Student Sheet 10.1, “Evaluating Sites,” to each student. Each group member will analyze one of the sites, by completing Student Sheet 10.1. Facilitate the engagement of students with learning disabilities and neurodiverse learners by providing targeted support. Consider how to best adapt the activity to the needs of your particular student population. For example, students who need more time processing language (such as students with dyslexia) can be provided with a copy of the cards in advance of the activity.

- Students begin by reading their Site cards and rating the factors listed on Student Sheet 10.1 by their orders of understanding, from 1–3. The rating will vary by site, with cues embedded in the text about which factors have the most impact on the population at the site (with the use of terms such as *serious impact*, *small effect*, *significantly reduce*). There is no single correct answer, and students will share and discuss their ratings in their groups in Procedure Step 5.

- If your student population needs additional support, use the list of word cues associated with each rating you may have developed in Activity 4. For example, factors that have “serious impact/significantly reduce/primary impact” could be rated 1 (greatest impact), factors that are “constant/steady” rated 2 (medium impact), and factors that are “little/no impact” rated 3 (least impact).

4 **Students develop a model based on the two highest impact factors at their site.**

- On Student Sheet 10.1, students circle their site number and the two factors that have the greatest impact on the frog population at their site. They use this information to construct a model on Student Sheet 10.2, “My Site Model,” using the same sample model introduced in Activities 2 and 9. Remind students that they will be using their models as part of their decision about which site to fund. Sample student responses are provided at the end of the activity.

5 **Students make estimates of the future frog population at their site and share them with their group.**

- In Procedure Step 7, hand out Student Sheet 10.2, “My Site Model,” to each student. Students use data from Figure 10.2 to determine the present frog population at each site. Students are provided with information about another frog species that has doubled in size every 25 years. They use that information to predict the future population of the frogs at their sites. This prediction assumes that the population growth rate for the Menanda frogs is the same as the nearby species.

- In Procedure Step 12, hand out Student Sheet 10.3, “Estimating Factor Impact on Population in 50 Years,” to each student. Students make a Fermi estimate to predict the effect of the two high-impact factors on the frog population at the site 50 years in the future. The factors selected and their general trend (increase, decrease, stay the same) are based on information from the Menanda Site cards. Students then make assumptions about how this factor may change in the future (for example, a 25% decrease in rain). Depending on your student population, you may want to model this process for a single site. Remind students to use their models to consider which factors would likely be affected under future conditions and how it might affect their future estimates. These assumptions will vary and can generate new scientific questions and/or class discussions about what is predicted to happen in coming decades to temperature, rainfall, etc. Students record their population predictions in the last column of Table 2 on Student Sheet 10.1. A sample response to Student Sheet 10.2 (for Site 1) is provided at the end of the activity.

- For students who investigated the same site, you may want to have them compare Fermi estimates by recording their estimates on the board. Point out that it is expected that there will be a range of values. Evaluate the estimates based on scale by discussing the powers of 10 of the Fermi estimates for the same site. While exact estimates may vary based on assumptions, students should feel more confident in their estimates if they all arrived at estimates at the same scale (i.e., powers of 10). Have students share how they made their calculations and what assumptions they made. They can make revisions to their estimates as needed.
- Students share and discuss their population models and predictions for their sites in their groups. Students' responses will vary based on their models and their sites. A sample response to Student Sheet 10.3 (for each site) is provided at the end of the activity.

SYNTHESIS OF IDEAS (15 MIN)

6 **Students decide which site to recommend funding to protect and improve frog habitats.**

- Based on their models and future population estimates, students decide which site to fund. They do not need to agree, but they should be able to support their decisions with evidence from the activity, in particular their models and estimates.
- Highlight the idea that multiple models can offer different insights into the same question.
- Note that the use of models and the resulting Fermi estimates will strongly influence students' decision. Site 4 currently has the largest frog population. In the sample student response on Student Sheet 10.1 Table 2, the Fermi Estimate for Site 4 shows the greatest predicted population decline. Based on this estimate, students might choose to protect the frog habitat at Site 4.
- Encourage students to look at the difference in the scale of predicted population numbers and not simply to a particular value. For example, in the sample student response for Student Sheet 10.1, Sites 3 and 4 have different predicted populations that are at the same powers of 10.
- For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 10.4, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use optional Student Sheet 10.4 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.

7 Facilitate a discussion by using a Walking Debate in Procedure Step 16.

- Use the literacy strategy of a Walking Debate in Procedure Step 16 to encourage students to discuss their opinions about which site to fund. You may want to post signs with each site number (Site 1, Site 2, etc.) and begin by having students walk to their recommended site. 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.

8 Assess student growth using the Developing and Using Models Scoring Guide for Build Understanding item 1.

- Build Understanding item 1 provides the opportunity for students to transfer their knowledge of modeling to a different context. Remind students of the Developing and Using Models Scoring Guide. You may wish to project Visual Aid 10.1, "Scoring Guide: Developing and Using Models (MOD)," 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 1) 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 development, use, and analysis of models, and they may want to review their responses to the assessment in Activity 3 (Build Understanding item 4) and/or Activity 5 (Build Understanding item 4).

- 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 each other's work for revision prior to turning in the work to you for scoring. Alternatively, consider having students turn in a rough draft to you for feedback and revision.

- End the activity by revisiting the Guiding Question, *What role can models play in making a conservation decision?* Use this as a chance to revisit and summarize the key concepts and process skills of the unit.

9 **Revisit the Unit Driving Question, *How can scientific models be used to investigate changes in the distribution of species?***

- Over the course of the unit, students have been introduced to the role of scientific modeling in understanding, explaining, and predicting changes in species distribution over time, particularly in response to changes in climate. They have constructed and analyzed models to predict changes in population size and range, including different approaches to population estimation.

- Have a class discussion about what students have learned about scientific modeling, especially in terms of assumptions, limitations, and revisions of models. Scientific models simplify reality to explain complex systems and make testable predictions, and they must be refined as they are approximations of systems. Emphasize that errors, inaccuracies, and limitations of models do not mean that they are not useful or reliable. Rather, the process for designing models includes evaluating and improving them over time. Encourage students to recognize that they may need to interpret scientific models in their everyday lives, such as when voting on local issues, or they may even consider careers that incorporate modeling as an essential tool.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **MOD Scoring Guide**

In Procedure Step 7, you constructed a model and described it. Complete Student Sheet 10.2 by:

- **identifying the two most high-impact factors affecting the population at this site.**
- **explaining what your model predicts about the effect of the two factors on the frog population at your site.**
- **describing at least one source of uncertainty in your model.**

Sample Level 1–4 responses (for Site 1) for Student Sheet 10.2 can be found at the end of this activity.

② **Which site do you recommend for funding to protect and improve Menanda frog habitats? Support your answer with evidence from the activity and identify the trade-offs of your decision.**

Student answers will vary. A sample response is provided.

I recommend Site 4. It has the highest population of the 4 sites. But according to my group's models, it is likely to experience the greatest population decline due to changing temperatures and predation. Building a pond will also provide a habitat for other species. The trade-off is that one of the other sites will not get funded. Someone who disagrees with me will likely question my model.

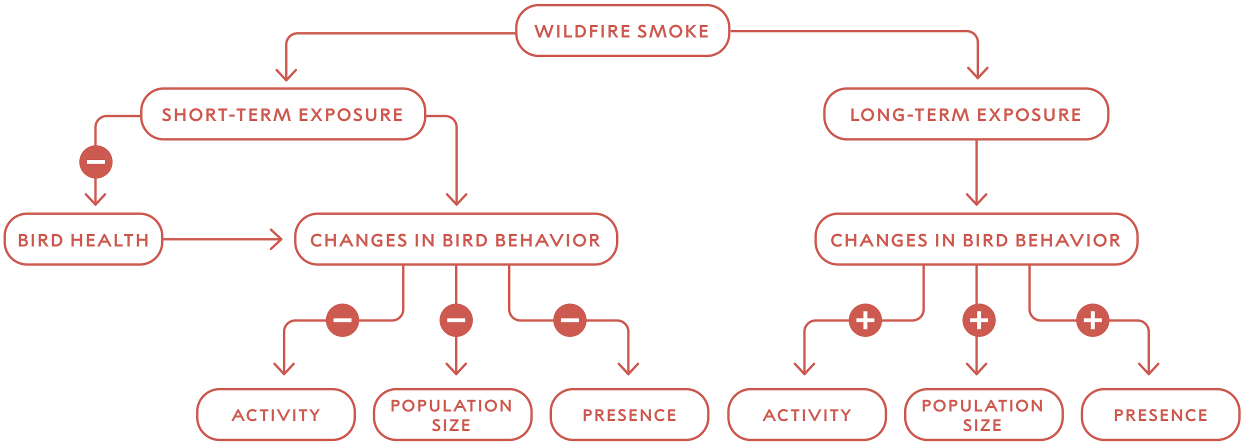
③ **A researcher creates a model to predict the local deer population over the next 5 years. At the end of the first year, the model's prediction for the population size was 40 deer, but the actual count was 25. Should the researcher revise the model? Explain what you think the researcher should do and why.**

Yes, the researcher should revise the model because it is very inaccurate. The researcher should make sure that the factors having the greatest impact on the deer population, such as predator population and disease, are included in the model. This will likely improve the model's accuracy.

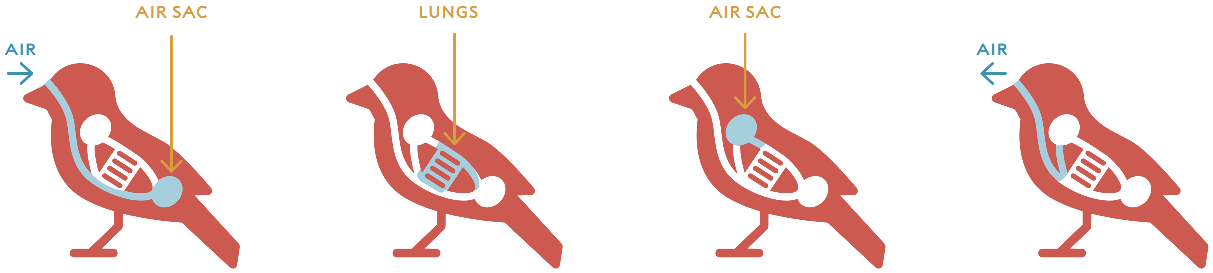
④ **In the Introduction, you learned that scientists are constructing models to explore the effects of wildfire smoke on house sparrows. Explain how each of the two models in Figure 10.3 might be used to begin to investigate this question.**

FIGURE 10.3
Two House Sparrow Models: Wildfire Effects (Model 1) and Respiration (Model 2)

MODEL 1



MODEL 2



1. **FIRST BREATH IN:** air (blue) moves into the air sac
2. **FIRST BREATH OUT:** air moves into lungs
3. **SECOND BREATH IN:** air moves into front air sac
4. **SECOND BREATH OUT:** air leaves the body

Model 1 has a lot of factors and predicts how a bird might respond to short-term and long-term exposure to smoke. It could be used to investigate how smoke exposure affects bird behavior.

Model 2 explains the biology of the bird and how it breathes. This model could be used to investigate how birds inhale wildfire smoke and how different organs in the bird might absorb smoke and lead to bird death.

CONNECTIONS TO EVERYDAY LIFE

⑤ **This activity explored *population dynamics*—the study of how and why the size, structure, and distribution of a population change over time. Consider the ways in which people rely on and interact with different populations of organisms such as for food, recreation, conservation, and so on.**

a **Create a question about population dynamics that investigates a relationship between humans and an organism's population.**

Student responses will vary. Sample questions include:

To what extent do loud repetitive sounds, such as cars honking, reduce the native bird population?

How does the use of weed killer affect the butterfly population?

Which bird species most benefits from birdhouses?

b **List the factors that would be most relevant to creating a model to investigate this question.**

Student responses will vary. The most relevant factors to the question *Which bird species most benefits from birdhouses?* include:

The present size of the bird population, the number of birdhouses, their locations, and the size of different bird species.

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STUDENT SHEET 10.1	EVALUTING SITES	NAME

Table 1: Orders of Understanding for Each Site

	SITE 1	SITE 2	SITE 3	SITE 4
Food availability				
Predation				
Yearly rainfall				
Average annual temperature				
Traffic				

Table 2: Present and Future Frog Populations for Each Site

	PRESENT FROG POPULATIONS	FUTURE FROG POPULATIONS BASED ON NEARBY SPECIES	FERMI ESTIMATE OF FUTURE FROG POPULATIONS
SITE 1			
SITE 2			
SITE 3			
SITE 4			

STUDENT SHEET 10.1 | EVALUTING SITES | NAME SAMPLE STUDENT RESPONSE

Table 1: Orders of Understanding for Each Site

	SITE 1	SITE 2	SITE 3	SITE 4
Food availability	*1*	*2*	*2*	*3*
Predation	*3*	*3*	*2*	*2*
Yearly rainfall	*1*	*3*	*1*	*3*
Average annual temperature	*2*	*3*	*1*	*1*
Traffic	*3*	*1*	*3*	*3*

Table 2: Present and Future Frog Populations for Each Site

	PRESENT FROG POPULATIONS	FUTURE FROG POPULATIONS BASED ON NEARBY SPECIES	FERMI ESTIMATE OF FUTURE FROG POPULATIONS
SITE 1	*50*	*200*	*50 (10^1)*
SITE 2	*500*	*2,000*	*1,250 (10^3)*
SITE 3	*200*	*800*	*250 (10^2)*
SITE 4	*1,000*	*4,000*	*300 (10^2)*

STUDENT SHEET 10.2 | MY SITE MODEL | NAME

Site Number: 1 2 3 4

Construct your model:

Description of the relationships in the model:

Two of the most high-impact factors affecting the population at this site:

What does your model predict will happen to the frog population at this site? Explain how the factors will affect the population.

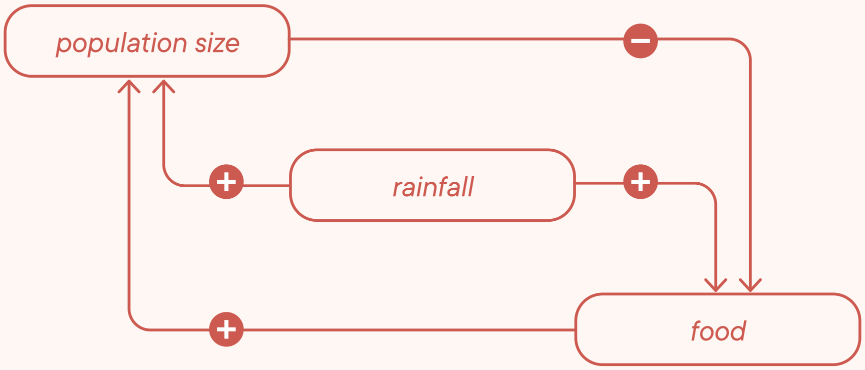
Describe at least one source of uncertainty in your model.

STUDENT SHEET 10.2 | **MY SITE MODEL** | **NAME** SAMPLE STUDENT RESPONSE

LEVEL 4 RESPONSE

Site Number: [✓ 1] 2 3 4

Construct your model:



Description of the relationships in the model:

Frogs need food. More food means more frogs. Lots of frogs reduces the amount of food available. Increased rainfall has a positive effect on the size of the frog population and the availability of food.

Two of the most high-impact factors affecting the population at this site:

Food availability and rainfall.

What does your model predict will happen to the frog population at this site? Explain how the factors will affect the population.

My model predicts that when there is increased rainfall, there is more food and an increase in the size of the frog population. Large frog populations reduce the availability of food (because they eat it).

Describe at least one source of uncertainty in your model.

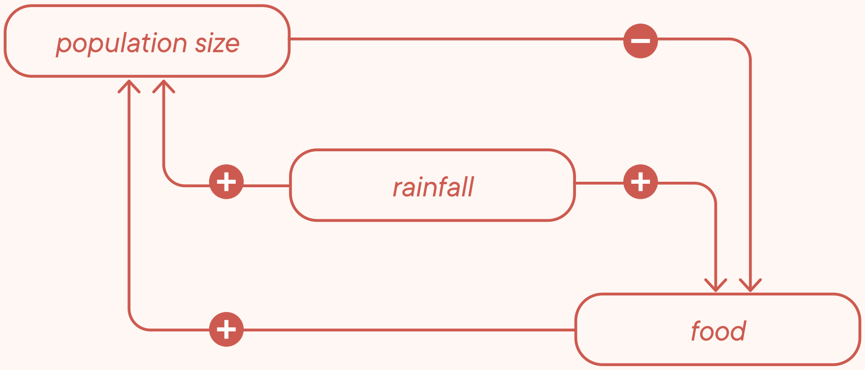
The effect of rainfall assumes a steady amount of rain over time. It does not take into account a severe thunderstorm or flooding, which could result in frog deaths and decreased population.

STUDENT SHEET 10.2 | **MY SITE MODEL** | NAME SAMPLE STUDENT RESPONSE

LEVEL 3 RESPONSE

Site Number: [✓ 1] 2 3 4

Construct your model:



Description of the relationships in the model:

If there is not enough food, frogs will die. Rain means there is more food and more frogs.

Two of the most high-impact factors affecting the population at this site:

Food availability and rainfall.

What does your model predict will happen to the frog population at this site? Explain how the factors will affect the population.

More rain and more food increases the frog population.

Describe at least one source of uncertainty in your model.

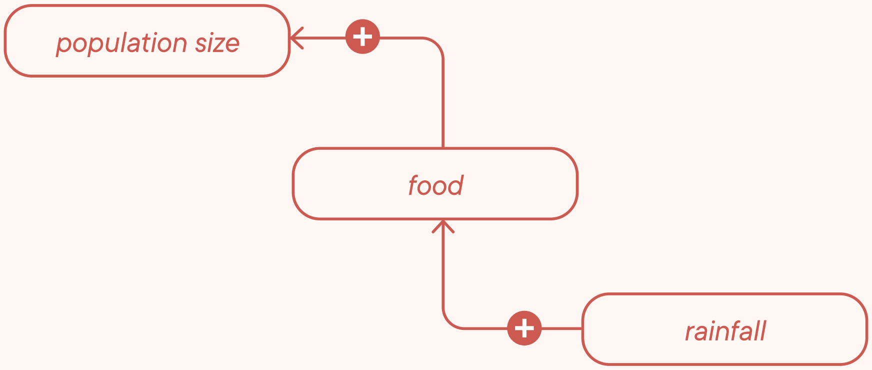
Rainfall varies.

STUDENT SHEET 10.2 | **MY SITE MODEL** | **NAME** SAMPLE STUDENT RESPONSE

LEVEL 2 RESPONSE

Site Number: [✓ 1] 2 3 4

Construct your model:



Description of the relationships in the model:

Rainfall increases food availability for the frogs.

Two of the most high-impact factors affecting the population at this site:

Food and rainfall.

What does your model predict will happen to the frog population at this site? Explain how the factors will affect the population.

The population will increase because of food and rain.

Describe at least one source of uncertainty in your model.

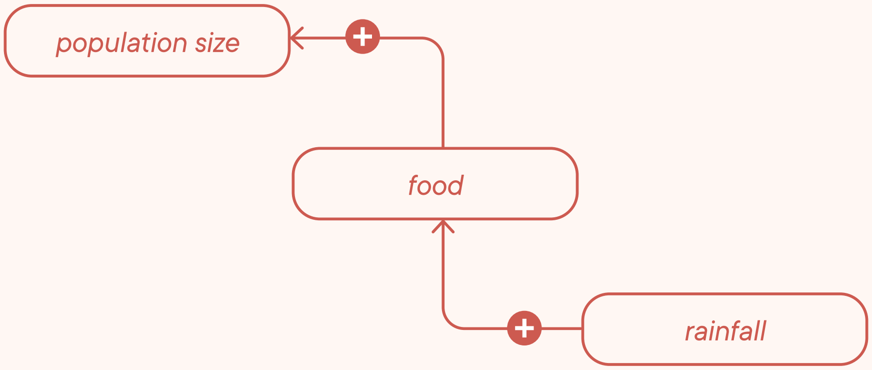
Frogs.

STUDENT SHEET 10.2 | **MY SITE MODEL** | **NAME** SAMPLE STUDENT RESPONSE

LEVEL 1 RESPONSE

Site Number: [✓ 1] 2 3 4

Construct your model:



Description of the relationships in the model:

Food and rainfall affect frogs.

Two of the most high-impact factors affecting the population at this site:

Food and frogs.

What does your model predict will happen to the frog population at this site? Explain how the factors will affect the population.

Goes up.

Describe at least one source of uncertainty in your model.

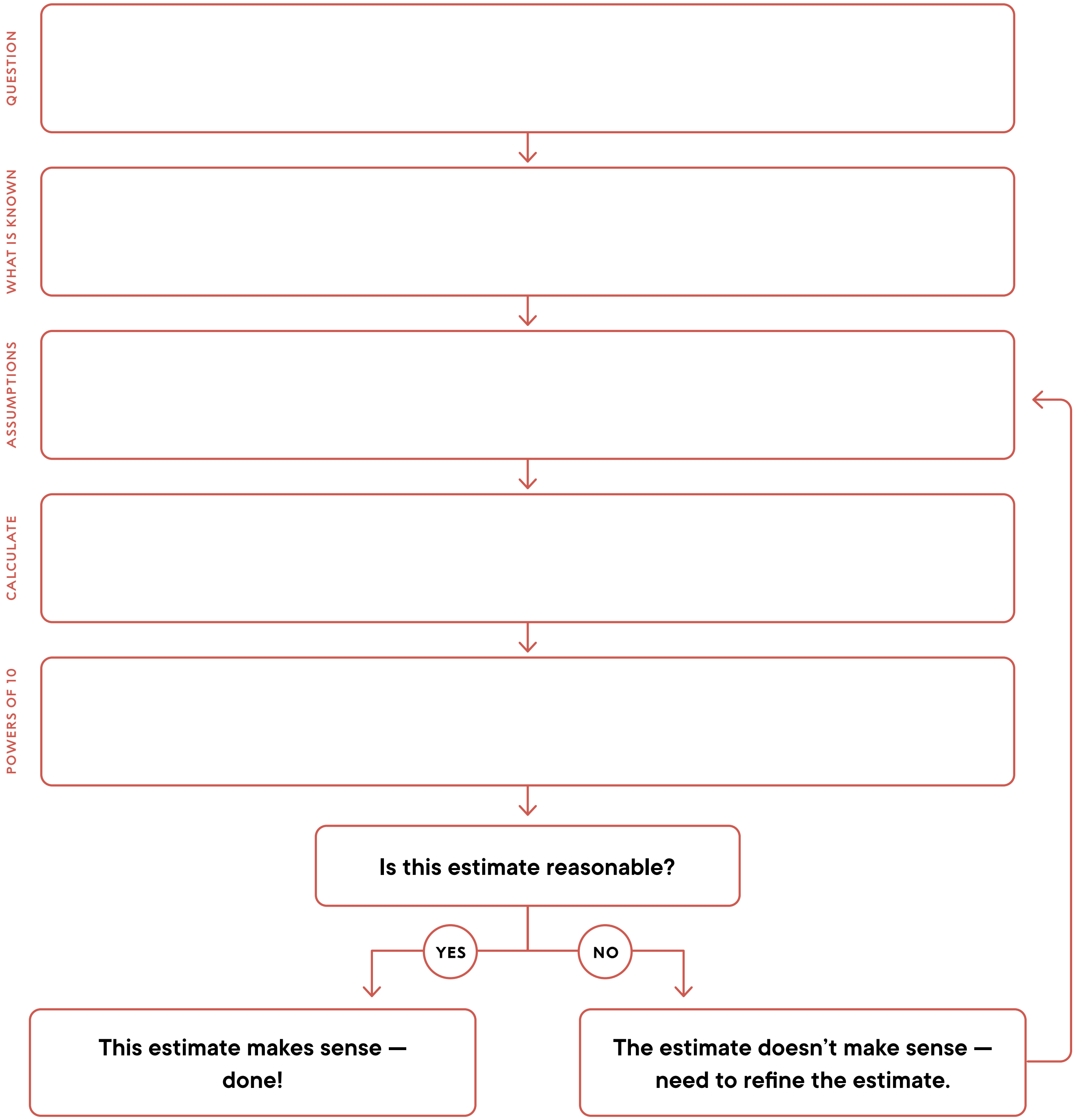
Factors.

STUDENT SHEET 10.3

ESTIMATING FACTOR IMPACT ON POPULATION IN 50 YEARS

NAME

Site Number: 1 2 3 4



STUDENT SHEET 10.3 | **ESTIMATING FACTOR IMPACT ON POPULATION IN 50 YEARS** | NAME SAMPLE STUDENT RESPONSE 1

Site Number: [✓ 1] 2 3 4

QUESTION

What is the likely effect of changing food availability and yearly rainfall on the future frog population at Site 1?

↓

WHAT IS KNOWN

Current frog population of 50 frogs.
If population doubles every 25 years, there will be 200 frogs in 50 years.
The 2 factors most likely to impact the population are food and rainfall.

↓

ASSUMPTIONS

I predict future droughts, so 50% less rainfall.
This will decrease food availability by 50%.

↓

CALCULATE

200 frogs x ½ due to less rain = 100 frogs
100 frogs x ½ due to less food = 50 frogs

↓

POWERS OF 10

50 frogs, or 10^1, in 50 years.

↓

Is this estimate reasonable?

YES → **This estimate makes sense — done!**

NO → **The estimate doesn't make sense — need to refine the estimate.** → ASSUMPTIONS

STUDENT SHEET 10.3

ESTIMATING FACTOR IMPACT ON POPULATION IN 50 YEARS

NAME SAMPLE STUDENT RESPONSE 2

Site Number: 1 [✓ 2] 3 4

QUESTION

What is the likely effect of changing traffic patterns and food availability on the future frog population at Site 2?

WHAT IS KNOWN

Current frog population of 500 frogs.
If population doubles every 25 years, there will be 2,000 frogs in 50 years.
The 2 factors most likely to impact the population are traffic and food.

ASSUMPTIONS

I predict more traffic, which will kill about 50% of the frogs.
I predict 25% more frogs because of more food from backyard ponds.

CALCULATE

2,000 frogs x ½ due to less rain = 1,000 frogs
1,000 frogs x 1¼ due to less food = 1,250 frogs

POWERS OF 10

1,250 frogs, or 10^3, in 50 years

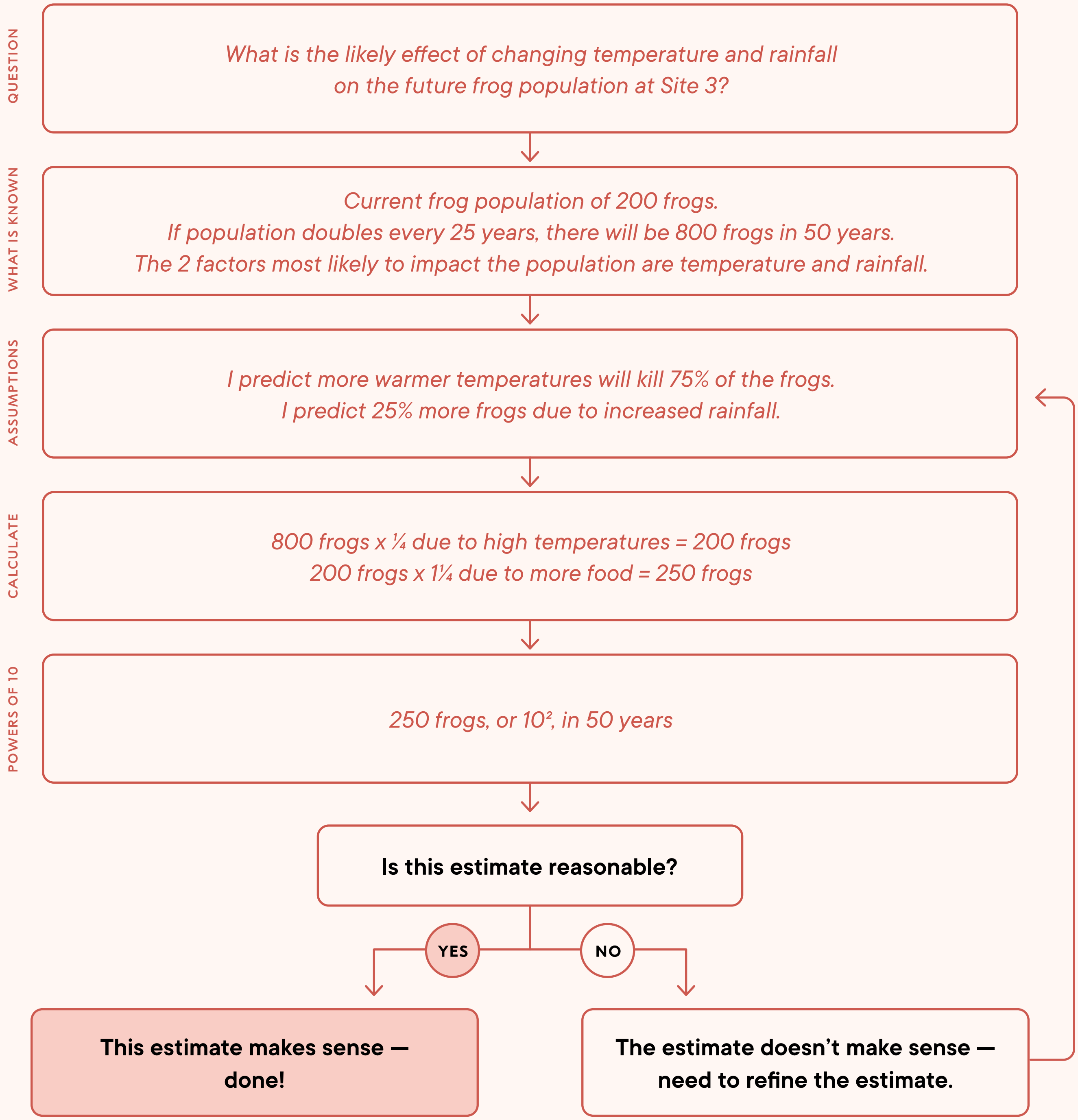
Is this estimate reasonable?

YES → **This estimate makes sense — done!**

NO → **The estimate doesn't make sense — need to refine the estimate.**

STUDENT SHEET 10.3 | **ESTIMATING FACTOR IMPACT ON POPULATION IN 50 YEARS** | **NAME** SAMPLE STUDENT RESPONSE 3

Site Number: 1 2 [✓ 3] 4



QUESTION

What is the likely effect of changing temperature and rainfall on the future frog population at Site 3?

WHAT IS KNOWN

Current frog population of 200 frogs.
If population doubles every 25 years, there will be 800 frogs in 50 years.
The 2 factors most likely to impact the population are temperature and rainfall.

ASSUMPTIONS

I predict more warmer temperatures will kill 75% of the frogs.
I predict 25% more frogs due to increased rainfall.

CALCULATE

800 frogs x ¼ due to high temperatures = 200 frogs
200 frogs x 1¼ due to more food = 250 frogs

POWERS OF 10

250 frogs, or 10^2, in 50 years

Is this estimate reasonable?

YES

This estimate makes sense — done!

NO

The estimate doesn't make sense — need to refine the estimate.

STUDENT SHEET 10.3 | **ESTIMATING FACTOR IMPACT ON POPULATION IN 50 YEARS** | **NAME** SAMPLE STUDENT RESPONSE 4

Site Number: 1 2 3 [✓ 4]

QUESTION

What is the likely effect of changing temperature and predation on the future frog population at Site 4?

WHAT IS KNOWN

Current frog population of 1,000 frogs.
If population doubles every 25 years, there will be 4,000 frogs in 50 years.
The 2 factors most likely to impact the population are temperature and predation.

ASSUMPTIONS

I predict warmer temperatures will kill 90% of the frogs.
I predict that predation will kill another 25% of the remaining frogs.

CALCULATE

4,000 frogs x 0.1 due to high temperatures = 400 frogs
400 frogs x 0.75 due to predation = 300 frogs

POWERS OF 10

300 frogs, or 10^2, in 50 years

Is this estimate reasonable?

[✓ YES] NO

This estimate makes sense — done!

The estimate doesn't make sense — need to refine the estimate.

STUDENT SHEET 10.4 | 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 10.4 | **WRITING FRAME: EVIDENCE & TRADE-OFFS** | NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

which site to fund to protect and improve Menanda frog habitats.

My decision is that

Site 1 should be funded.

My decision is based on the following evidence:

First,

Site 1 has the smallest frog population of 50. This makes it vulnerable to completely disappearing.

Second,

our group's Fermi estimates predict that this site will continue to have the smallest frog population.

Third,

the population at this site is very affected by rainfall, and some years there is little or no rainfall, which means the population declines.

The trade-off(s)

is that the other sites will not get funded, and their frog populations may also decline.

People who disagree with my decision might say that

their group's estimates predicted a different population outcome, and they recommended a different site.

VISUAL AID 10.1 | SCORING GUIDE: DEVELOPING AND USING MODELS (MOD)

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION
Level 0 **Missing or off task**	The student's response is missing, illegible, or irrelevant.
X	The student had no opportunity to respond.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students develop their own models or use established models to describe relationships and/or make predictions about phenomena and/or systems.

WHAT TO LOOK FOR:

- Response accurately represents the phenomenon and/or system.
- Response includes an explanation of relevant ideas and concepts represented by the model or a prediction based on the relationships between ideas and concepts represented by the model.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system, AND the student uses it to develop a complete and correct explanation or prediction.	The student response: • contains a complete model and includes a detailed description of it. • identifies the two most impactful factors and logically predicts their likely effect on population. • provides a thorough, logical explanation of a source of uncertainty in the model.

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* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 3 **Almost there**	The student's model* completely and accurately represents the components, relationships, and mechanisms of the phenomenon/system AND includes a mostly correct use of the model to create an explanation or prediction.	The student response: • contains a complete model and includes a description of it. • identifies the two most impactful factors and predicts their likely effect on population. • identifies a source of uncertainty in the model.
Level 2 **On the way**	The student's model* represents components of the phenomenon/system AND includes a partially correct representation of the relationships or mechanisms associated with the phenomenon.	The student response: • contains a model with some description of it. • identifies the two most impactful factors BUT may not logically predict their likely effect on population.

* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 1 **Getting started**	The student's model* represents components of the phenomenon/system BUT provides little or no evidence of the relationships or mechanisms associated with the phenomenon/system.	The student response: • contains an incomplete model AND/OR it has little or no description. • identifies the two most impactful factors BUT predicted effects on population are vague, illogical, or missing. • identifies a source of uncertainty in the model, BUT it is vague, illogical, or missing.
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.	

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* A model can be a diagram, drawing, physical replica, diorama, dramatization, storyboard, or any other graphical, verbal, or mathematical representation. It may include labels or other written text as required by the prompt.

MENANDA SITE 1

This frog population lives in a seasonal pond, which is now mostly dependent on yearly rainfall. Years when there is little or no rainfall results in very few frogs. Yearly rainfall affects the food availability, which is also having a serious impact on the population. In years with less rainfall, higher than average annual temperatures can also contribute to a declining population. Predation remains constant over time. There is little traffic nearby.

Local residents would like to re-establish natural water flows that will better support seasonal ponds and wetland areas.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 10: Menanda Site Cards

MENANDA SITE 2

New homes are being built near this site. Increased traffic is significantly reducing the local frog population. It is also reducing the predator population, so predators are only having a small effect on the frog population. Residents would like to build a tunnel under the busiest local road to provide a wildlife crossing between the site and a nature area on the other side of the road.

Many local residents have built backyard ponds, increasing food availability and helping to measurably increase the population. Changes in average local temperature and yearly rainfall amounts do not appear to be having an impact on the frog population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 10: Menanda Site Cards

MENANDA SITE 3

This site is on the sheltered side of a mountain, resulting in much less yearly rainfall than the surrounding areas. This is the primary cause of a much smaller frog population in this area. The average annual temperature is also much warmer than the surrounding areas, further reducing the frog population. Food availability and predation are constant over time. There is only one road and little traffic in this area.

A nearby hiking trail attracts people who sometimes accidentally damage the habitat. Local residents would like to place wildlife-friendly fencing and signs around the site to protect the area.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 10: Menanda Site Cards

MENANDA SITE 4

As the average annual temperature increases, the size of the frog population at this site is significantly declining. Yearly rainfall amounts are staying steady, resulting in a steady amount of food availability, which is helping keep the population steady. These factors have also resulted in an increase in the predator population, causing declines in the frog population. There is no traffic nearby.

Residents would like to create a more frog-friendly habitat by building a pond at this site with native plants.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: Scientific Modeling, Activity 10: Menanda Site Cards

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?

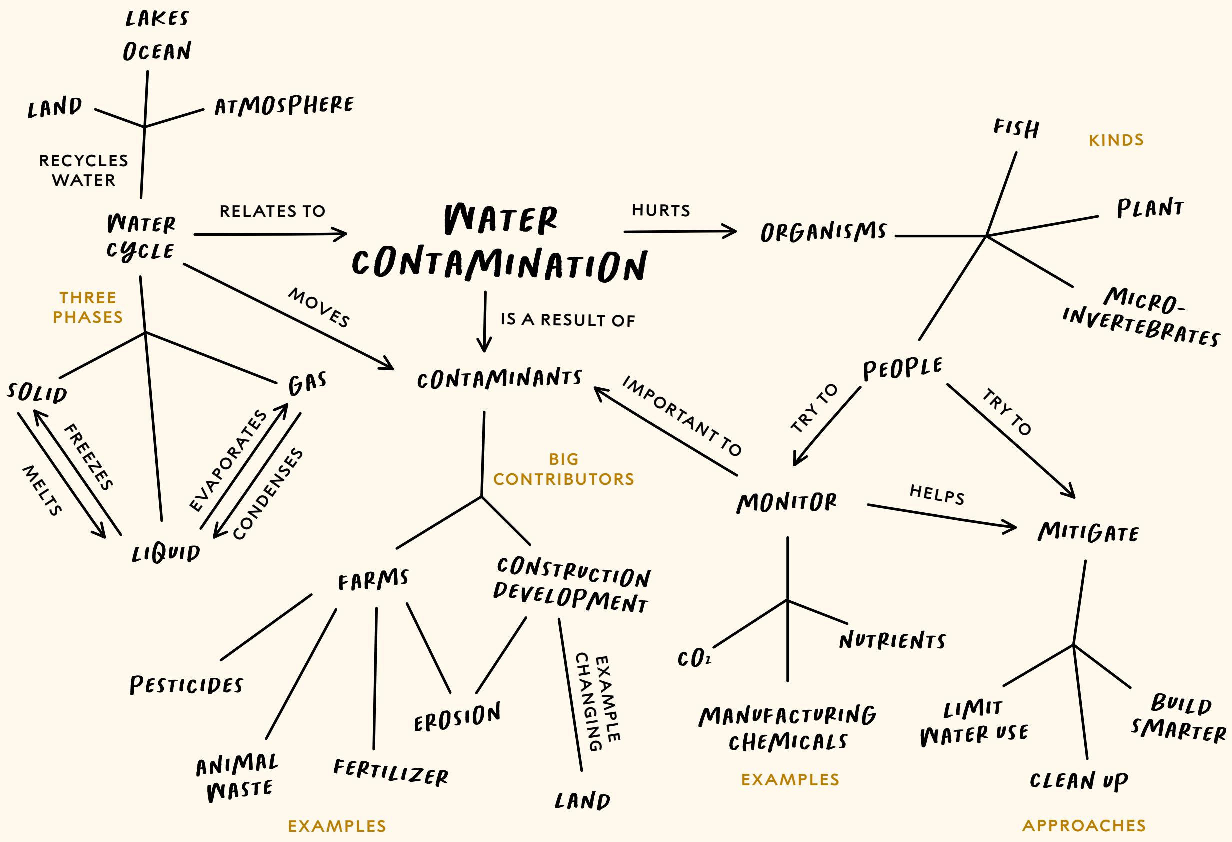
Concept maps demonstrate students' understanding of the connections between topics in a spatial manner. They also allow students to expand their knowledge related to a topic.

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.

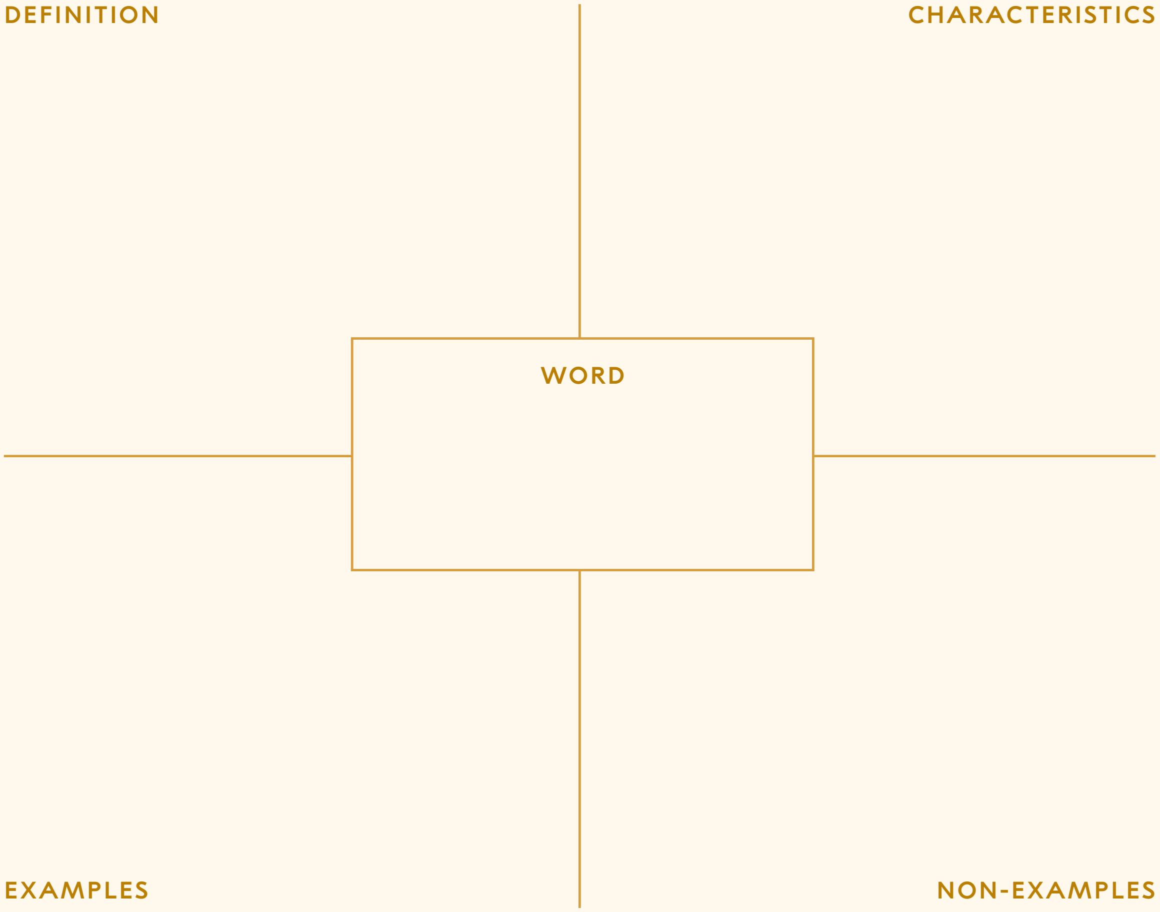
Where It Is

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 tradeoffs 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 **Skills to Evaluate Thinking**	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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