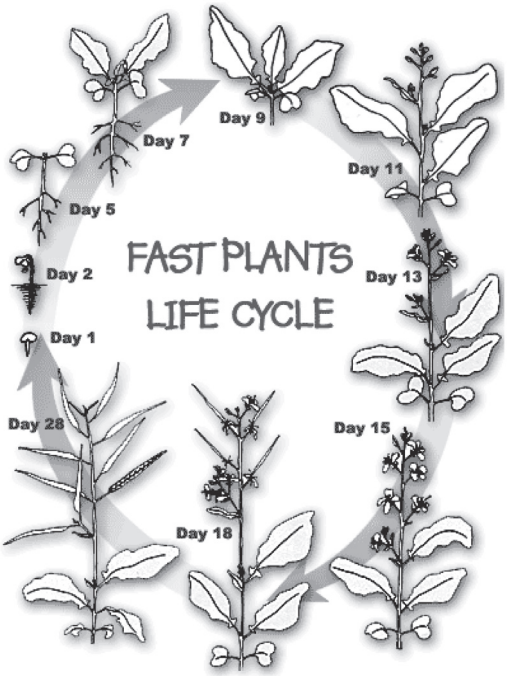
Exploring Variation and Natural Selection with Fast Plants



7th Grade Immersion Unit

Award No. 0227016

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Exploring Variation and Natural Selection with Fast Plants

Please note the following is an overview of a 7th grade Variation and Natural Selection Immersion Unit (extended investigation in science). This unit was developed in partnership with the Los Angeles Unified School District and is being tested and revised by teachers, scientists, and curriculum developers associated with the NSF-funded Math/Science Partnership, System-wide Change for All Learners and Educators (SCALE) and the DOE-funded Quality Educator Development (QED) project at the California State University – Dominguez Hills.

Table of Contents

Navigating the Unit

This Immersion Unit provides a coherent series of lessons designed to guide students in developing deep conceptual understanding that is aligned with the standards, key science concepts, and essential features of classroom inquiry (as defined by the National Science Education Standards). In Immersion Units, students learn academic content by working like scientists: making observations, asking questions, doing further investigations to explore and explain natural phenomena, and communicating results based on evidence. Immersion Units are intended to support teachers in building a learning culture in their classrooms to sustain students' enthusiasm for engaging in scientific habits of thinking while learning rigorous science content.

This Immersion Unit is comprised of several steps; each step contains between one and four lessons. The unit begins with the Unit Overview, which includes a description of the key concepts, evidence for student understanding, assessment strategies and other relevant implementation information. The Unit Overview outlines the conceptual flow and rationale for the structure of the unit.

Each step in the unit begins with an overview, which describes the individual goals and activities of the specific step, and its relationship to the previous and following steps. The title and approximate length of time needed for each lesson is also shown. Within the step, each lesson contains:

- Snapshot
- Background Information
- Implementation Guide
- Student Pages
- Teacher Pages

Snapshots are printed on a single page and provide key information for implementing the lesson. Each snapshot includes the key concept(s), evidence of student understanding, list of materials, procedures for lesson implementation, key words and REAPS—a strategy for assessing student learning. This page is designed to have on hand while you implement the lesson.

The Background Information and Implementation Guide sections provide learning experiences such as investigations, reading research, or other engaging supporting strategies designed to teach a specific concept(s). They include instructions for any advance preparation required, explain the design of the lesson, include strategies for assessing student learning, and provide teacher background information on relevant science content. The Implementation Guide for each lesson addresses teaching methodology, including specific examples and information related to effective teacher implementation. If research identifies common misconceptions related to the content, a detailed explanation of common misconceptions is provided with suggestions for addressing them.

Student pages may include readings, guides, handouts, maps or instructions to engage students during the lesson. These pages assist you as you guide students through the lesson, and are intended to be readily adapted to suit a variety of classrooms with diverse student populations.

Teacher pages may include overheads, maps, data charts and other materials that can help you implement the lesson.

(continued on following page)

Snapshot Page

The information on the Snapshot page includes the following:

- Lesson Title
- Key Concept
- Time Needed
- Materials
- Key Words
- REAPS Questions

This Immersion Unit contains a variety of opportunities for modifying content and methodology based on your students' needs and your classroom situation. The basic structure of the unit is designed to support you in anticipating the particular needs of your students to foster understanding of inquiry, nurture classroom communities of science learners, and engage students in learning key science concepts.

Unit Overarching Concepts

- Naturally occurring variations of traits in a population are influenced by genetic and environmental factors and evolve over generations by selective processes.
- Science knowledge advances through inquiry.

Unit Supporting Concepts

- The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions.
- Individual organisms with certain traits are more likely than others to survive and have offspring. Changes in environmental conditions can affect the survival of individual organisms and entire species.
- Some variation in heritable characteristics exists within every species. One of these characteristics gives individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce.
- New varieties of cultivated plants and domestic animals have resulted from selective breeding for particular traits.
- Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.

Evidence of Student Understanding

- Use experimental evidence to support an explanation for how reproductive success, variation, environmental stress, and adaptations relate to the process of natural selection.
- Interpret illustrations of populations to create a fictional, yet plausible, explanation for how genetic variation and environmental factors are causes of evolution and diversity of organisms and, in some cases, extinction.
- Identify and engage in all aspects of scientific inquiry and the process of keeping a detailed science notebook.
- Explain how studying natural phenomena through scientific inquiry advances knowledge.
- Identify and interpret relationships among variables within data sets and explain how graphing data is useful for seeking patterns in evidence that can lead to scientific explanations.
- Design and conduct an investigation using Fast Plants to collect evidence appropriate for exploring the relationships among environmental stress, inheritance, variation, and reproductive success.
- Apply their knowledge of reproductive success, adaptations, variation, and natural selection to develop an evidence-based explanation for the results of a simulation that is based on multiple sources of evidence (experimental observations, written materials, and audio visual resources).

Unit Preview

This Immersion Unit engages students in an inquiry and a wide variety of supporting activities to explore variation and natural selection. The unit is designed to build deep conceptual understanding of how environmental conditions combined with inheritance influence the distribution of variation for particular traits within a population of organisms over many generations.

Students investigate:

- how variation within a population is influenced by environmental factors
- how environmental factors influence reproductive success in a population

In this unit, evidence from several student investigations using Wisconsin Fast Plants is combined with evidence from a simulation, information from readings, and videotaped interviews with the scientist who developed Fast Plants to support students' understanding of artificial and natural selection. Students learn that natural selection is a gradual process that can cause changes in the distribution of variation within a population over many generations.

There are six steps in this unit, each with an overarching outcome designed to support students to learn the unit's key concepts. Each step is divided into lessons that were developed for one or two 50-minute class periods. Because several investigations involve students in growing plants to gather evidence, some lessons guide the class to design and begin an experiment, then students continue on with other lessons, spending 10 minutes periodically to make and record observations of their plants; then, a later lesson guides the class to analyze results and develop scientific explanations for their investigations. Fast Plants are easy to grow and have a short life cycle (seed to flower in 14 days; seed to seed in 40 days), so they are particularly well suited to the experiments in this unit.

Step 1 immediately engages students in growing and getting familiar with Fast Plants, and it also guides the class to establish expectations for making and recording scientific observations in a science notebook. Step 2 develops both the inquiry process skills and science content knowledge that students need to ask a question and design an investigation to explore how environmental factors can influence variation in traits and reproductive success in a population of Fast Plants. Step 3 focuses on reproduction in flowering plants, which is foundational for students to effectively pollinate and tend their experimental plants as well as to understand what constitutes reproductive success in seed-bearing plants. During Step 4, students' Fast Plants continue to grow while the lessons feature simulations, readings, and activities designed to build content knowledge that is necessary for analyzing investigation results in Step 5.

Lesson 1 in Step 5 provides an opportunity for the teacher to model how to develop a scientifically-oriented explanation. Then, in Lesson 2 of Step 5, students analyze the results of the central Fast Plants investigation conducted in the unit and develop an evidence-based explanation for the variation they observe in their Fast Plants. Students complete Step 5 by communicating and evaluating their explanations, using their scientific inquiry skills and abilities.

Step 6 is divided into two lessons that both provide opportunities for students to apply and demonstrate their understanding of the unit's key concepts. These lessons include activities that involve both small group and individual work with a variety ways for students to reflect on and use what they learned throughout the unit.

Unit Standards

Evolution

3. Biological evolution accounts for the diversity of species developed through gradual processes over many generations. As a basis for understanding this concept:
   a. Students know both genetic variation and environmental factors are causes of evolution and diversity of organisms.
   b. Students know the reasoning used by Charles Darwin in reaching his conclusion that natural selection is the mechanism of evolution.
   e. Students know that extinction of a species occurs when the environment changes and that the adaptive characteristics of a species are insufficient for its survival.

Genetics

2. A typical cell of any organism contains genetic instructions that specify its traits. Those traits may be modified by environmental influences. As a basis for understanding this concept:
   b. Students know sexual reproduction produces offspring that inherit half their genes from each parent.

Structure and Function of Living Systems

5. The Anatomy and physiology of plants and animals illustrate the complementary nature of structure and function. As a basis for understanding this concept:

   5f. Students know that the structures and processes by which flowering plants generate pollen, ovules, seeds, and fruit.

Investigation and Experimentation Strand

7. Scientific progress is made by asking meaningful questions and conducting careful investigations. As for a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

   7a. Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tasks, collect data, and display data.

   7b. Use a variety of print and electronic resources (including the World Wide Web) to collect information and evidence as part of a research project.

   7c. Communicate the logical connections among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from scientific evidence.

Unit Timeline

Step	Lesson	Class Time	Key Concepts
Step 1	**Step 1 Lesson 1** How fast are Fast Plants?	50 minutes	• Fast Plants are a special kind of plant that a creative scientist developed by doing science to produce a plant that grows quickly in artificial conditions.
	Step 1 Lesson 2 Scientific versus Casual Observations	50 minutes	• Scientists' explanations about what happens in the world come partly from what they observe, partly from what they think. • What people expect to observe often affects what they actually do observe. Strong beliefs about what should happen in particular circumstances can prevent them from detecting other results.
	Step 1 Lesson 3 Science Notebooks: Communicating and Recording	50 minutes	• Clear communication and accurate record keeping is an essential part of doing science.
	Step 1 Lesson 4 Science Notebooks: Peer Review	50 minutes	• Clear communication and accurate record keeping is an essential part of doing science. • Results of scientific investigations are seldom exactly the same, but if the differences are large, it is important to try to figure out why.
	Step 1 Lesson 5 Scientific Explanation: How Fast are Fast Plants?	50 minutes	• Communicate the logical connection among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence. • Seeds are the structure from which flowering plants produce new plants.

Step	Lesson	Class Time	Key Concepts
Step 2	**Step 2 Lesson 1** Using Evidence to Explore Similarities and Differences	100 minutes	• Environmental factors are causes of diversity among organisms such as plants • Scientific explanations are different than description; they include explicit references to causes for effects and establish relationships based on evidence and logical argument. • Various forms of display for data sets, including box-and-whisker plot (high-low graph), are useful forms to display a single set of data or to compare two sets of data.
	Step 2 Lesson 2 Investigating Variation: Environmental Factors and Heritable Traits	50 minutes to begin the investigation; 24–26 days evidence until offspring is collected	• Environmental factors are not the only causes of diversity among organisms such as plants; some traits are inherited and others result from interactions with the environment. • Every organism requires a set of instructions for specifying its traits. Heredity is the passage of these instructions from one generation to another. • Scientific investigations may take many different forms; including observing what things are like or what is happening and doing experiments.
	Step 2 Lesson 3 Describing Populations	50 minutes	• Individuals can be described by their characteristics, or traits. • Populations can be described by numerical data describing the traits that exist in the population. • Scientific observations include both things that can be measured and things that cannot.
	Step 2 Lesson 4 Investigating Environmental Stress and Variation	50 minutes to develop question & experiment 50 minutes to design & set up experiment	• Environmental factors influence the traits observed in individuals and populations. • Scientific progress is made by asking meaningful questions and conducting careful investigations.

Step	Lesson	Class Time	Key Concepts
Step 3	**Step 3 Lesson 1** Investigation: Flowers and Pollination	100 minutes	• The flowering plant life cycle includes pollination, which leads to seed production. • Reproductive success in Flowering Plants is when a plant produces flowers that are successfully pollinated and produce seeds that grow into new plants. • Experimental data and observations need to be systematically collected and carefully organized so that they can provide evidence to support claims that can answer the question being investigated.
Step 4	**Step 4 Lesson 1** Selection Simulation	50 minutes	• Individual organisms with certain traits are more likely than others to survive and have offspring. • Simulations can be used in science to simplify a natural phenomenon to make it possible to test and understand.
	Step 4 Lesson 2 Selection Simulation Analysis	90 minutes	• Individual organisms with certain heritable traits are more likely than others to survive and have offspring, and they influence the traits in future generations more than those that do not survive or produce many offspring. • Scientists use appropriate tools and techniques to gather, analyze, and interpret data.
	Step 4 Lesson 3 Artificial and Natural Selection	50 minutes	• Genetic variation provides a population with the potential to reproduce under changing environmental conditions. • Changes in environmental conditions can affect the survival of individual organisms and entire species. • Without variation in a population, changes in environmental conditions can lead to extinction.

Step	Lesson	Class Time	Key Concepts
Step 5	**Step 5 Lesson 1** Building Evidence-based Explanations	50 minutes	• Acquired traits, like the leafless condition acquired by the plant in Step 2, Lesson 2, are not inherited. • Experimental evidence and credible scientific information can be used to support claims that can be logically linked to form scientific explanations. • When fact and opinion are intermingled in a claim, or an explanation does not follow logically from the given evidence, the explanation and/or conclusion is not considered scientific.
	Step 5 Lesson 2 Investigation Explanation	100 minutes	• Naturally occurring variations of traits in a population are influenced by genetic and environmental factors and evolve over generations by selective processes. • Experimental evidence and credible scientific information can be used to support claims that can be logically linked to form scientific explanations. • When fact and opinion are intermingled in a claim, or an explanation does not follow logically from the given evidence, the explanation and/or conclusion is not considered scientific.
Step 6	**Step 6 Lesson 1** Explaining Reproductive success	50 minutes	• Reproductive success occurs when individual organisms pass their genetic information to fertile offspring, influencing the percentage of individuals with similar traits in the next generation.
	Step 6 Lesson 2 Explaining Variation and Natural Selection	50 minutes	• Individual organisms that have certain traits are more likely to survive and have offspring. • Changes in environmental conditions can affect the survival of individual organisms and entire species. • Small differences between parents and offspring can accumulate in successive generations so that descendants are very different from their ancestors.

Variation and Natural Selection
Immersion Unit Planning Timeline

PREP
- Teacher plants, no fertilizer
- Announce need Sci. Notebooks (week before)
- Reserve equipment (week before)
- Planting materials

Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*
	1 Step 1, Lesson 1 Teacher Plant [Plant]	2 Step 1, Lesson 2	3 Step 1, Lesson 3 Science Notebooks [Observations]	4 Step 1, Lesson 4 [Observations]	5 Step 1, Lesson 5 [Observations]	
	8 Step 2, Lesson 1a [Observations]	9 Step 2, Lesson 1b [Observations]	10 Step 2, Lesson 1c	11 Step 2, Lesson 2 [Cut leaves]	12 Step 2, Lesson 3	**PREP** Prepare for pollination
	15 Step 2, Lesson 4a(1)	16 Step 2, Lesson 4a(2) **[Step 2, Lesson 4b is continued after Step 3 in order to have students plant on a Monday]**	17 Step 3, Lesson 1a Step 2, Lesson 2 – Pollinate	18 Step 3, Lesson 1b	19	**PREP** Remind students to bring supplies for their own experiments
	22 Step 2, Lesson 4b [Students' Experiments]	23 [Observations]	24 [Observations]	25 [Observations]	26 [Observations]	
	29 [Observations]	30 [Observations]	31 [Observations]	32 [Observations]	33 [Observations]	
	36 Step 4, Lesson 1a Step 2, Lesson 2 – take plants off water [Observations]	37 Step 4, Lesson 2a [Observations]	38 Step 4, Lesson 2b [Observations]	39 Step 4, Lesson 2c	40 *Step 2, Lesson 2 – Harvest and plant seeds [Last Observations]	*(40) Teacher could replant and harvest on side

Variation and Natural Selection
Immersion Unit Planning Timeline (continued)

Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*
	43	44 Step 5, Lesson 1	45 Step 5, Lesson 2a	46 Step 5, Lesson 2b	47 Step 5, Lesson 2c	
	50 Step 6, Lesson 1	51 Step 6, Lesson 2				

Trouble-Shooting Ideas

Getting Started with Fast Plants

Wisconsin Fast Plants (Rapid-cycling *Brassica rapa*) are a result of 30 years of plant breeding at the University of Wisconsin–Madison. Selected to grow, develop, and reproduce quickly for research, these plants have unique properties that make them ideally suited to short semesters, small spaces, and youthful impatience:

- Rapid growth (40 days seed planting to seed harvest)
- Petite size (15 cm tall and able to grow in 2 cm2 of soil)
- Wide variety of easily recognizable genetic traits

Fast Plants need only water, 24-hour fluorescent lighting, and fertilizer. Today these easy-to-care-for plants are used at all grade levels in classrooms worldwide. For additional information visit the Wisconsin Fast Plants Program website at *www.fastplants.org*.

Unit Level Graphic Organizer

Many lines of evidence work together to explain the effects of variation and natural selection on populations. This unit uses a graphic organizer to help students visualize how all this evidence fits together. In the final step, students use this graphic organizer to gather their learning to explain the effects of the cabbage butterfly on the reproductive success and variation seen in a population of Fast Plants, a situation the students have not previously discussed. The *Unit Level Graphic Organizer* is used throughout the unit, and evolves as students gather more evidence that supports understanding features and processes of natural selection. The headings for the *Unit Level Graphic Organizer* are listed in the following chart (including sample entries for the lesson when it is introduced). Additional sample entries for the chart are provided in the Implementation Guides for the lessons where reference to the chart is made.

What we did	What we know	How we know it
Grew Fast Plants from seed and recorded observations to determine how "fast" they are. Analyzed our observations and measurements from growing Fast Plants	Fast plants emerge from their seeds and grow more quickly than most plants.	• We have data from the class experiment. • We calculated the mean for the number of days to emergence in our class. • We read in the article how many days to emergence Paul reports that Fast Plants take.

Support Materials

Immersion Unit CD

This Immersion Unit comes with a data CD containing multimedia files for use at various points throughout the unit. The CD also includes files for the unit, including the student and teacher pages.

Immersion Unit Toolbox

The Immersion Unit Toolbox is central to this curriculum. It is a separate guidebook thatdiscusses the concepts inherent in teaching science through immersion units. These concepts include engaging in scientifically oriented questions, giving priority to evidence in responding to questions, and formulating explanations from evidence.

The Toolbox also describes several pedagogical approaches (Think-Aloud strategies, for example) that are key to how these units work. Most of the strategies in the Immersion Unit Toolbox support student engagement in scientific inquiry based on the Five Essential Features of Classroom Inquiry (NRC, 2000).

Before starting to teach *Exploring Variation and Natural Selection with Fast Plants*, it is recommended to read and become familiar with the essential features of inquiry and teaching strategies explained in the Immersion Unit Toolbox.

The following is a brief overview of some of the strategies frequently referenced in this unit.

Cooperative Student Groups

In this unit, students often work in groups. When working as a team in a group, the ideal is to have groups no larger than four students. Whatever the group size is, all students in the team need to have a job to do so they are individually accountable for focusing on the current science lesson. When assigning groups, keep in mind that the students will remain in the same groups for the duration of their Fast Plant investigation throughout the unit. More information and suggestions for choosing groups is provided in specific lesson implementation guides.

Science Notebooks

One way that scientists keep a record of their observations, data, explanations, and ideas is by recording them in a notebook. The use of science notebooks for each student is explicitly taught in Step 1 and strongly encouraged for this Unit. Where appropriate, directions are given in the implementation guide to include the use of science notebooks in various activities. Science notebooks can serve not only as an organizing tool, but also as a valuable source of formative feedback throughout the Unit.

Think-Aloud Strategies

Variation and Natural Selection refers to the Think Aloud strategy throughout the unit. The Think Aloud is a teaching strategy whereby the teacher makes important thinking and reasoning processes explicitly clear for learners by describing aloud the thinking process involved in a certain activity. Example Think Aloud dialogs are included in most of the lessons where they are referenced.

Think-Pair-Share

Think-Pair-Share is a cooperative learning technique that allows students to think before they respond to a prompt, to test their response on their partner, and then to share their response (possibly revised) with a larger group. Specific instructions for implementing the Think-Pair-Share strategy are discussed in the Immersion Unit Toolbox. *Exploring Variation and Natural Selection with Fast Plants* uses this technique throughout the unit.

REAPS Questions

REAPS is a method of formative assessment that combines the time-tested ideas of Bloom's Taxonomy with new research on student assessment. The level of thinking increases from basic recall to complex analysis and predictions. On each Lesson Snapshot page is a series of REAPS prompts. This series of prompts is a simple tool that can be used throughout or at the end of each lesson. They can be used individually,

in pairs or in groups to review what students know and are able to do. This provides an opportunity for the teacher to modify instruction as necessary based on student responses. Here are the types of prompts included in the REAPS.

R Recall new knowledge: Determines whether the student has learned the basic knowledge that is related to and supports the key concept including lists, drawings, diagrams, definitions.

E Extend new knowledge: Determines whether the student can organize the basic knowledge related to the key concept such as compare, contrast, classify.

A Analyze knowledge: Encourages the student to apply or interpret what they have learned including developing questions, designing investigations, interpreting data.

P Predict something related to new knowledge: Engages the student in thinking about probable outcomes based on observations and to engage them in a new topic that builds on prior knowledge.

S Self/Peer Assess: Encourages students to take responsibility for their own learning. Includes methods and/or activities for students to assess their own learning and/or that of their peers.

The prompts increase in cognitive difficulty with Recall as the easiest and Predict as usually the most advanced. Students most likely demonstrate confidence and ability when responding to the first few prompts, while demonstrating continuous improvement in responding to the Analyze and Predict prompts. Students are not expected to master all of the skills, but are encouraged to extend their thinking. Suggested responses are included in roman type after the boldface prompts. More detailed responses are included in the implementation guides for each lesson. While these are good responses, other responses may be valid with supportive evidence and reasoning.

The worksheets included in the lessons also provide many opportunities for informal assessment as the students work through the key concepts of the Unit. The worksheets are designed to be collected, reviewed, and used as benchmarks for student understanding.

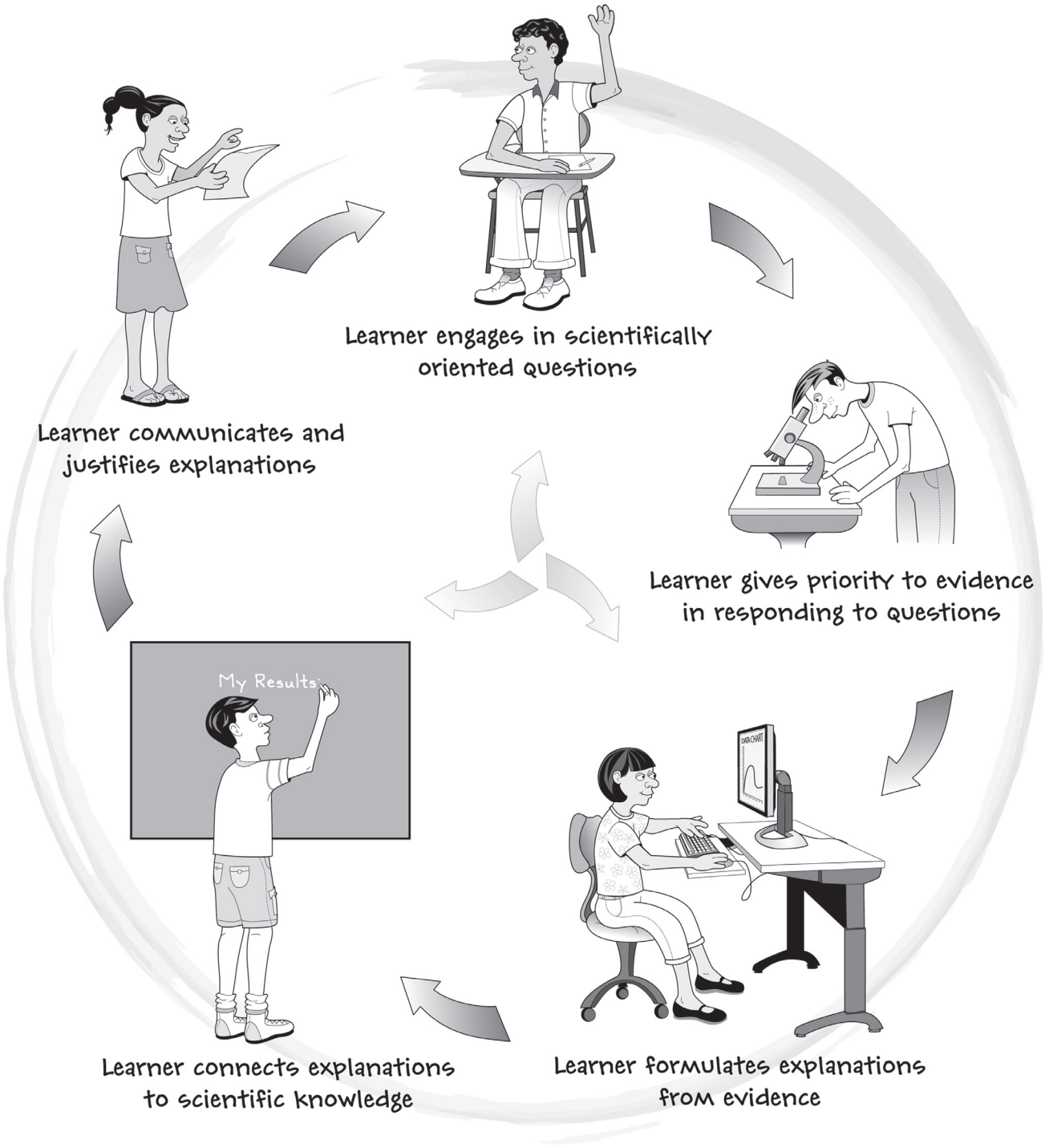
Two summative assessments occur in Step 6 of this Immersion Unit. In this step students apply their knowledge from the unit to explain a scenario in which the results of natural selection can be inferred from provided data.

Science Inquiry Map

The Science Inquiry Map on the following page illustrates the Five Essential Features of Inquiry. You can use this map in your classroom when you introduce Immersion Units to your students. The science inquiry process is dynamic and does not necessarily follow a linear order. For example, a student may develop an explanation that leads to a new scientific question, or that student may revisit evidence in light of alternative explanations.

On some occasions multiple features of an explanation may overlap, or, depending on the type of lesson, some features may have more emphasis than others. These variations allow learners the freedom to inquire, experience, and understand scientific knowledge. The Five Essential Features of Inquiry describe how engaging in science inquiry unfolds in the classroom.

SCIENCE INQUIRY MAP



Adapted from the National Research Council. 2000: Inquiry and the National Science Education Standards. Washington D.C.: National Academy Press

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STEP 1

Overview

In this step, students practice the skills they will need to work as scientists later in the unit when they design and conduct their own investigations on variation in a population of Fast Plants. The opening question, "How Fast are Fast Plants?" provides an opportunity for students to gain experience asking a scientific question, making methodical observations, making and organizing notebook entries, and analyzing data as well as building and communicating evidence-based explanations.

From the opening of lesson one, students are introduced to Paul Williams, a creative scientist whose work with Fast Plants provides the students with background information on the development of the plant. Throughout the unit, students are able to use examples set by Paul Williams as a model to help them conduct their own investigations.

The students and teacher set up the experiment to test "How Fast are Fast Plants?" during one class period and start the investigation over the next day. Then students make observations and complete the first investigation during the first week. Students will continue to make observations and notebook entries on the Fast Plants as they continue to grow and develop in the following weeks as the class progresses through the unit.

Key Concept

Fast Plants are a special kind of plant that a creative scientist developed by doing science to produce a plant that grows quickly in artificial conditions.

Evidence of Student Understanding

The student will be able to:

- explain the origins of Wisconsin Fast Plants
- plant Fast Plants according to the Fast Plants Planting Protocol

Time Needed

50 minutes

Materials

For each student

- 1 copy of Student Page 1.1A ***Fast Plants Planting Protocol***
- 1 copy of Student Page 1.1B ***Petri Dish Germination Protocol***
- 2 note cards (optional: 2 different colors)

For each of 4 students

- one growing quad
- 10 Fast Plant seeds (2 for each quad cell and 2 for the Petri dish)
- potting mix
- lighting
- watering system
- fertilizer pellets
- 1 Petri dish
- paper towel circles cut to fit Petri dish

For the class

- 6–8 quads for the teacher to plant without fertilizer
- 1 copy of Teacher Page 1.1a ***Preparing for Students to Plant Wisconsin Fast Plants***
- 3–4 Petri dishes with paper towel and seeds that will not be moistened (to use in Lesson 2)

How Fast are Fast Plants?

1. To introduce and build enthusiasm for the unit, explain that in this unit students will be working like scientists to understand how important variation is in a population, even designing and conducting their own investigation using Fast Plants. Begin a quick whole-class discussion, posing questions like:

- What kind of variation do we see among the individuals in our class? That is the kind of thing we are going to study for in this unit!
- Why do you suppose the plants we are going to study are called "Fast" plants?
- What do you think of when you think of a plant being "fast"?

2. Remind students that they are going to work like scientists during this unit. Ask the students "What do Scientists do?" Chart responses. Be sure to add or emphasize that scientists communicate with one another to explain their work based on evidence.

3. Briefly explain that throughout this unit the class will hear from the actual scientist who developed Fast Plants. To begin to learn what students already know, have students individually write ***one*** *sentence on a note card* answering:

- How can a scientist "develop" a new type of plant like a "Fast Plant?"

Ask a few volunteers to read their statements. Collect the note cards for use in Step 2 (include students' names on cards).

4. Show the video introducing The Father of Fast Plants, Paul Williams.

(continued on following page)

- After the video, pose the question: **Just How Fast are Fast Plants?** Have students record their predictions on a note card (include names) and collect for use later in Step 1.
- Explain that the class will grow their first crop of plants to learn the answer to that question and to get good at growing the plants for their later investigations.

5. Remind students about how Paul Williams selected for Fast Plants to grow under special conditions that would be handy for his work.

- Brainstorm plants' "needs" for growth and development and how Paul met those needs for selected Fast Plants.
- Emphasize the importance of following the same planting/growing procedures so that the class's plants are all growing under the same conditions.

6. Display the materials for planting and have students review Student Page 1.1A *Fast Plants Planting Protocol*. Allow students to ask questions about the protocol and highlight key points from the planting procedure.

7. Explain to the class that to see what happens to Fast Plants before they emerge from the planting mix, some will be placed on moist paper towel in Petri dishes. Provide a quick demo, and tell each group set up one Petri dish when planting their Fast Plants in planting mix.

- Distribute Student Page 1.1B ***Petri Dish Germination Protocol***.

8. Have groups of four students plant seeds in 1 quad according to the Planting Protocol and prepare 1 Petri dish as previously described.

- Note: *Resist the temptation to provide students with guidance for recording notes or observations until the next lesson.*

See Advanced Preparation section for notes about the different protocol for seeds planted by the teacher.

9. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **What do Fast Plants need to grow and develop well?** Fast Plants do best when they are grown as described in the Growing Protocol with planting mix, fertilizer, water, and light.

E **Compare the growing environment of Fast Plants to another plant you are familiar with—how are they similar and different?** Look for similarities like: they both need fertilizer, light, water; and look for differences like: Fast Plants grow indoors, do best with 24 hour light, and use very little soil.

A Students will analyze their understanding in later lessons.

P **What do you think will be the first change in the Fast Plant seeds?** Use student responses to informally assess their understanding of germination and plant growth.

S **What did you do today that was like what a scientist does?** Look for responses like, "I used a protocol, I wondered about how a plant grows, I made a prediction."

Advance Preparation

Remember to **start the unit on a Monday** so the plants will be ready for student investigations on weekdays when students are in school.

NOTE: On the same day that students plant their Fast Plant seeds, you will need to plant 6–8 quads of Fast Plants yourself using the *Fast Plants Planting Protocol* with one exception: **DO NOT ADD FERTILIZER**. Keep these quads on a separate water reservoir so that they receive no traces of fertilizer. In Step 2 Lesson 1, the class will investigate what may have happened to cause these plants to grow and develop differently than the students' plants. After 9–10 days, the plants without fertilizer will be significantly different; for example, they will be shorter, have paler leaf color, and yet will have similarly-timed life cycle stages.

If you have never planted Fast Plants before, preparing these 6–8 quads will help you to prepare for assisting students as they plant, so we recommend doing this in advance.

Plan the following in advance:

1. Decide how you will group students.

2. Set up video introducing Paul Williams and Fast Plants.

3. Prepare for planting:
   - set up florescent lights
   - organize the materials students need for planting (see Teacher Page 1.1a *Preparing for Students to Plant Wisconsin Fast Plants*)

4. Set out materials needed to grow seeds in Petri Dishes for the first week:
   - Petri dishes
   - Fast Plant seeds
   - paper towels (you may wish to cut Petri dish-sized circles of paper towels in advance to save time)
   - waterproof markers

5. Make copies of Student Page 1.1A ***Fast Plants Planting Protocol.***

6. Set up materials to demonstrate key planting procedures: 1 quad, planting mix, water, fertilizer pellets, Fast Plant seeds.

7. Plant 6–8 quads of Fast Plants yourself without fertilizer (see special NOTE earlier in the Advance Preparation section).

8. Set up materials to demonstrate placing seeds in a Petri dish to germinate: 1 Petri dish, 1 paper towel, 5 Fast Plant seeds, a dish to place the Petri dishes in to wick moisture (see the Petri Dish Germination Protocol).

9. Prepare 3–4 Petri dishes that will not be moistened to use in Lesson 2 so that students can directly observe how the seeds change over night.

NOTE: *The seeds in Petri dishes are intended to be observed only until the seeds emerge from the planting mix in the quads. If some students have poor germination in their quads, seedlings from the Petri dishes can be carefully transplanted into empty cells.*

Teacher Background Information

The plants used throughout this unit are Wisconsin Fast Plants, chosen because of the ease with which they can be grown in the classroom and their quick life cycle. Fast Plants (scientific name: *Brassica rapa*) are rapid-cycling brassicas. They are members of the crucifer family of plants, closely related to cabbage, turnips, broccoli and other cruciferous vegetables. Bred for over 30 years at the University of Wisconsin–Madison by Professor Paul H. Williams, Fast Plants today require little more attention than continuous fluorescent light, water, and fertilizer. The seeds that you grow in your classroom can be immediately planted or stored for up to 10 years in a refrigerator.

The video segment included with this step features Paul Williams. By providing videotaped descriptions of his work developing Wisconsin Fast Plants, this unit takes advantage of this opportunity for students to understand science as an ongoing and dynamic quest to understand the natural world.

Planting Fast Plants on this first day of the unit is designed to accomplish several important and necessary outcomes:

1. Students (and teachers) are immediately introduced to the organism they will be working with throughout the unit.

2. Students learn the planting protocol and practice growing Fast Plants so they are better prepared when they design their own experiments.

3. The Fast Plants needed for Step 2 are planted with sufficient time to grow to the necessary size.

Additional information about Wisconsin Fast Plants—growing options, tending tips, research, and activities—is freely available at *www.fastplants.org*.

This unit involves a great deal of interaction among students and between students and the teacher. So you may want to:

- Set up the classroom so students can quickly and easily shift from working alone to working in groups of four.
- Point out to students that a big part of working as scientists is communicating with other scientists. Scientists are constantly talking with each other and sharing information and learning from each other. **Prepare students to expect an interactive unit—one where they will need to communicate with each other to work through their investigations. As scientists, they will attempt to do problem-solving with other students rather than the teacher.**

NOTE: ***In this lesson, the teacher is instructed to secretly plant 8 quads of Fast Plants WITHOUT any fertilizer. In Step 2, a question about why the teacher's plants are different will be posed to students, and the teacher will provide a situation where students must use experimental data to develop an explanation for what happened.***

Implementation Guide

1. Quickly engage students in understanding that during this unit they will work as scientists to conduct their own investigations with a cool plant known as Fast Plants.

They will also learn about variation. Begin a quick whole-class discussion, posing questions like:

- What kind of variation do we see among the individuals in our class? That is the kind of thing we are going to study for in this unit!

Encourage students to look around the classroom at the many different heights of their classmates, the many different hair colors, hair curliness or straightness. These are variations of traits. Briefly mention to students that they will design their own investigation to look at the variation of traits in Fast Plants. Ask the class:

- Why do you suppose the plants we are going to study are called "Fast" plants?
- What do you think of when you think of a plant being "fast"?

2. Remind students that they are going to work like scientists during this unit. Ask the students "What do Scientists do?" Chart responses. In order to begin to set the tone for how this unit will be executed in the classroom add or emphasize that scientists communicate with one another to explain their work based on evidence. In addition, mention that the students are the ones who will be discussing the work and the teacher is the facilitator of the discussions. Post the chart paper on the wall for the duration of the unit. Refer to and add to the list as necessary.

3. Explain to students that they will have an opportunity to hear from the actual scientist who developed the Fast Plants—the plants they are using in their investigations. To begin to learn what students already know, have students individually write ***one*** *sentence on a note card* answering:

- How can a scientist "develop" a new type of plant like a "Fast Plant?"

Collect the note cards for use in Step 2 (include students' names on cards).

Ask a few volunteers to read their statements. As students offer explanations, resist the temptation to explore their ideas at this time. This is only intended to assess students' current understandings. Encourage students to keep what they wrote in mind as they watch the video and investigate Fast Plants.

4. Show the class the video introducing The Father of Fast Plants, Paul Williams. In his last words on the video, Paul begins to talk about how short the life cycle is for Fast Plants. After the video, give each student another note card and pose this question to the class:

- ***Just How Fast Are Fast Plants?***
- Then have students write a one-sentence prediction on the note card and put their name on the card.
- Collect and keep these cards for use later in Step 1, Lesson 3, when students will add them to their science notebooks and then refer back to them in Lesson 5.

Explain to students that it is now time to plant their first crop of Fast Plants. They will use them to answer the question, ***How Fast Are Fast Plants?*** and to get practice growing these plants, because later they will be using them in their own investigations.

5. Bring students back to the idea that Paul Williams mentioned in the video. Remind students that when he developed his line of Fast Plants, he selected plants that would grow under special conditions that would be useful for his work.

Facilitate a discussion to help students explore how he met the needs of Fast Plants in his laboratory and compare it to how plants typically get their needs met in nature.

Brainstorm with students about what plants need to survive. Draw a three-column table and work with the whole class to fill in the table. For example:

Environmental needs of plants	How the natural environment meets needs of wild type Fast Plants	How the artificial environment in Paul William's lab meets the needs of Fast Plants
sunlight	sunlight	florescent light/commercial light
soil	soil	commercial planting mix
water	rainfall, groundwater, etc.	water from faucet
nutrients	nutrients in soil	fertilizer
air	air	air

Explain that students will use the same protocol that Paul Williams used to grow Fast Plants so that their specific needs are met. A ***protocol*** is a detailed plan for how to perform a task.

Emphasize the importance of following the same planting/growing procedures so that the class's plants are all growing under the same conditions. This way we will know that any differences we see among plants probably are not due to differences in how the plants were raised.

6. Display the materials for planting in the front of the classroom, and distribute copies of Student Page 1.1A *Fast Plants Planting Protocol*. Have students read the instructions and talk with a neighbor about any questions they have.

With the class, highlight these key points in the planting procedure:

- Make sure that the wick extends enough to make contact with the mat on the water reservoir. The wick also needs to be saturated with water.
- DO NOT pack the planting mix. Sprinkle the mix in place; it will settle when it is watered.
- Notice that the fertilizer pellets look like seeds; however, Fast Plant seeds are much smaller.
- There is a layer of planting mix between the fertilizer pellets and seeds so that young roots do not get burned by the fresh fertilizer.
- Cover seeds lightly with a thin layer of planting mix.

7. Explain that to see what happens to the Fast Plant seeds before they emerge from the planting mix, some will be placed on moist paper towel in Petri dishes.

Direct each group of four students to start seeds in one Petri dish after they plant their seeds in potting mix (one quad per group). Provide a quick demonstration of how to set up the Petri dish. Distribute Student Page 1.1B *Petri Dish Germination Protocol.*

- These will be used only during the first week of the unit. However, seedlings can be carefully transplanted from the Petri dishes into quads late in the week if needed.

8. Have students in groups of four plant seeds in 1 quad according to the Planting Protocol and prepare one Petri dish with seeds to germinate. As students plant, travel from group to group to ensure students are following the details of the protocol. Direct students to label their plants and place the quads under the florescent lights.

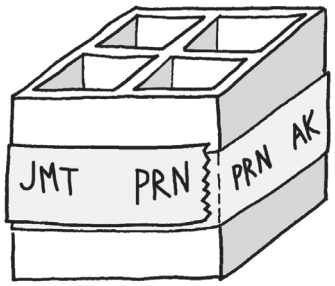
Resist temptation to provide students with guidance for recording notes or observations until the next lesson. During the next lesson, they discover for themselves why keeping a detailed and accurate science notebook is critical.

9. Use the REAPS questions throughout the lesson where appropriate.

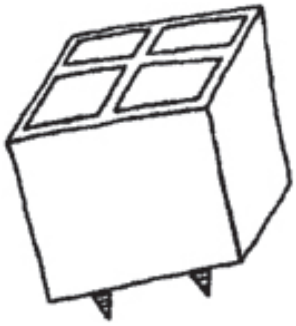
On the same day, plant 6–8 quads yourself using the same Fast Plant Planting Protocol with one exception: add NO fertilizer. In Step 2 Lesson 1, the class will investigate what may have happened to cause these plants to grow and develop differently than the students' plants. See the ***Advance Preparation*** section for more details.

Student Page 1.1A: Fast Plants Planting Protocol

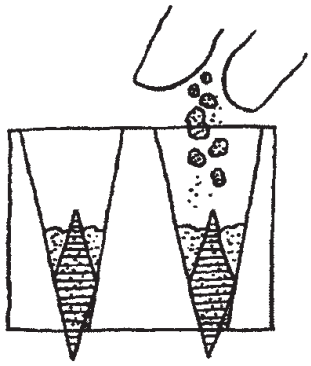
1. Label each cell as your teacher directs so that every student will know which plant is hers or his.



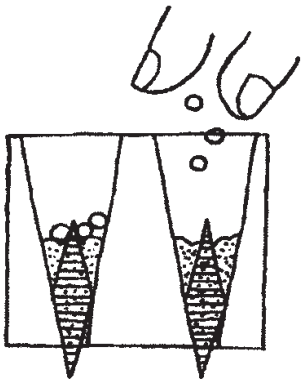
2. Drop one wet wick into each cell so that the tip extends 2 cm out of the hole in the bottom.



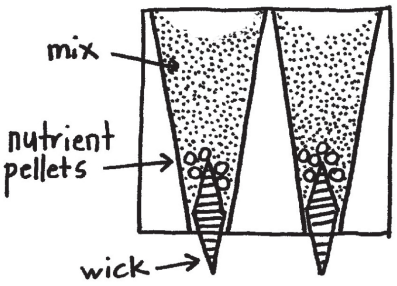
3. Fill each cell halfway with slightly moistened planting mix.



4. Add 3 pellets of fertilizer to each cell.

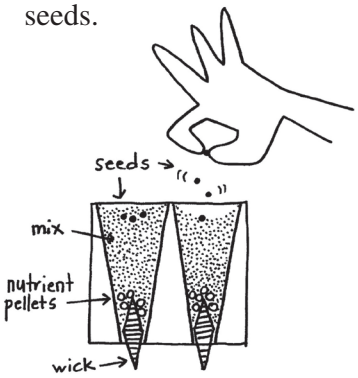


5. Fill each cell nearly to the top with planting mix.

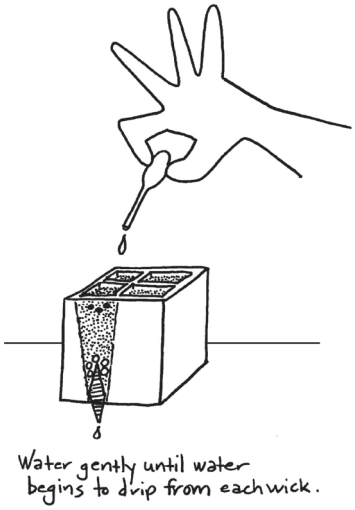


6. Drop 3 seeds on top of the planting mix.

- Fill to the top of each cell with mix to just cover the seeds.

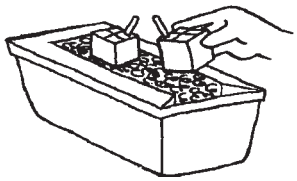


7. Water very gently with a pipette or dropper.

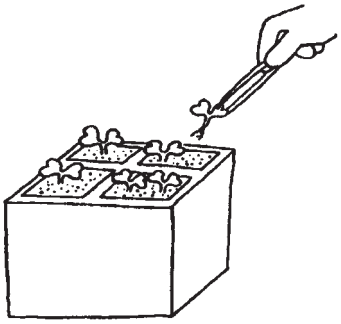


8. Put your group's quad on a water reservoir as your teacher directs.

- The class quads (on their reservoirs) will all be placed under fluorescent lights that are on 24 hours/day and kept 5–10 cm from the top of the plants.

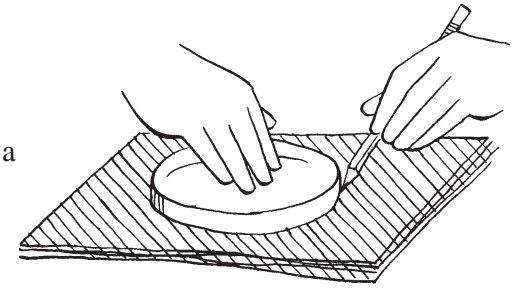


9. Use tweezers or scissors to thin to one plant per cell when your plants have just pushed through the planting mix.



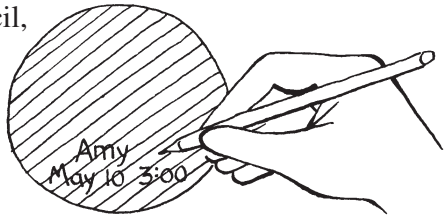
Student Page 1.1B: Petri Dish Germination Protocol

1. From a paper towel or a piece of filter paper, cut a circle 8.5 cm in diameter to fit in the cover (larger half) of a Petri dish.

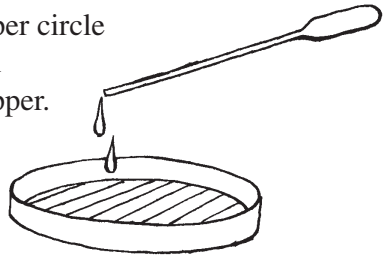


2. Fold the paper towel circle in half. Use a pencil to draw a straight line where you folded the circle in half.

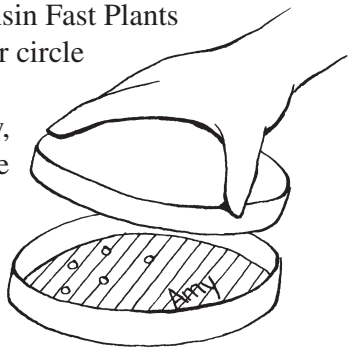
3. With a pencil, label the bottom of the paper circle with your name, the date and the time.



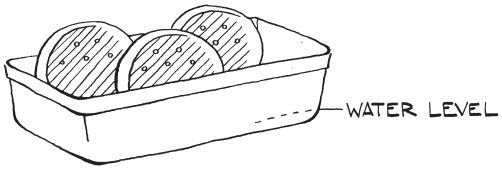
4. Moisten the paper circle in the Petri dish with an eyedropper.



5. Place five Wisconsin Fast Plants seeds on the paper circle along the middle line that you drew, and cover with the bottom (smaller half) of the Petri dish.

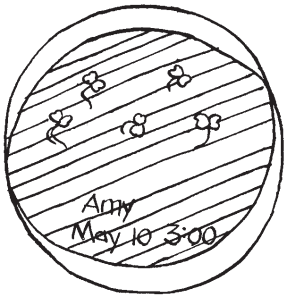


6. Place the Petri dish at a steep angle (80˚– 90˚) in shallow water in a tray so that the bottom two centimeters of the paper is below the water's surface.



7. Set the experiment in a warm location (optimum temperature: 65–80˚F). Check the water level each day to be sure the paper circle stays wet.

8. Over the next 3–4 days observe the germinating seed and seedlings using a magnifying lens.



NOTE: Germinated seedlings can be carefully transplanted into quads at Day 5 and grown to maturity. This may slow the developmental cycle by a few days.

Materials for planting and growing Wisconsin Fast Plants using The Wisconsin Fast Plants Growing System

The growing system components and lighting are ordered from Carolina Biological Supply Company, and include everything you need to successfully grow Fast Plants. Unless otherwise specified, Classroom Kits are designed for use by up to 32 students working in pairs. Planting and growing instructions for the Wisconsin Fast Plants Kits are provided with purchase.

The following materials are included in the growing system:

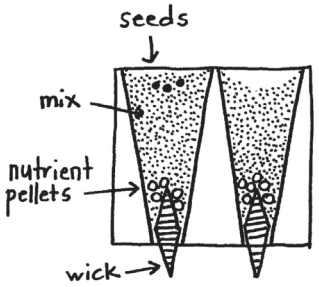
- Wisconsin Fast Plants seeds, rapid-cycling *Brassica rapa* (Rbr). (Seeds are small and need to be handled with care.)
- quads—4-celled planting units in which you will grow one plant to maturity in each cell
- planting mix (NOT planting soil)
- diamond wicks—conduct water from water mat to planting mix in cell of quad
- water mat—conducts water from reservoir to wicks
- fertilizer pellets—slow-release source of nitrogen (N), phosphorus (P) and potassium (K). Pellets are larger than the seeds.
- plant labels—to record student name, planting date and experiment *(note: see comments in #6 of Advance Preparation Table)*
- pipettes or droppers—to water cells from above when necessary
- dried honeybees—to make beesticks for pollinating
- algae-squares (tinged blue)—contain copper sulfate to prevent algae growth in reservoir
- water reservoir
- wooden stakes and plastic support rings—to support the plants if necessary *(use at the very first sign of plants leaning)*

(continued on following page)

Advance Preparations for Planting

1. Obtain seeds and growing system materials:

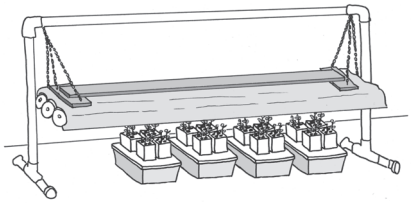
- 2–3 seeds per student
- 1 quad for each group of four students
- 4 wet wicks for every quad
- 1 water reservoir for every 8 quads



2. Assemble lighting system if necessary.

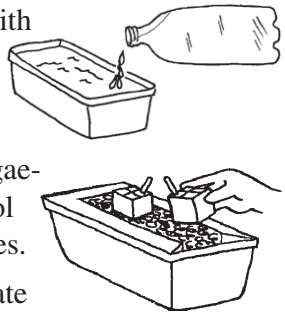
Determine how you will adjust the distance from the light to the plants.

- You must either raise/lower the water system with quads or raise/lower the lights.

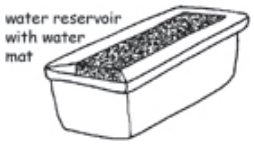


3. Prepare water reservoirs:

- Fill with water and drop in algae-control squares.

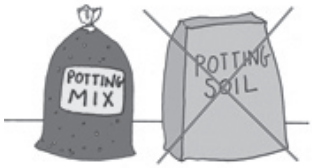


- Saturate the water mat and lay it on the reservoir lid with one end of the mat extending into the water through the slot cut in the lid.



4. Pre-moisten a large container of planting mix for use during planting.

- Planting mix needs to be just moist enough to feel wet and not clump together.
- Prepare to give each group of four students a Pipette or dropper to water their cells gently after planting.

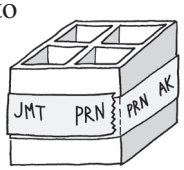


5. Determine how you will dispense seeds to students to minimize loss and waste.

- You may wish to hand seeds out individually to students just as they are ready to place seeds in the quads during planting.
- Also, plan for distributing fertilizer pellets and making it very clear to students that the fertilizer pellets are NOT the seeds (they may look like seed to a novice).

6. Determine how students will label the quads so that they know which plant is theirs. This is important for making accurate observations and building interest in tracking their own plant. Recommended:

- Wrap the quad in masking tape several times so it stays in place when wet, and have students write initials on the masking tape with permanent marker or pencil. (This is easy to remove later to re-use the quad.)



Key Concepts

- Scientists' explanations about what happens in the world come partly from what they observe, partly from what they think.
- What people expect to observe often affects what they actually do observe. Strong beliefs about what should happen in particular circumstances can prevent them from detecting other results.

Evidence of Student Understanding

The student will be able to:

- explain the difference between making scientific and casual observations

Time Needed

50 minutes

Materials

For each group of 4 students

- 1 planted quad (labeled) from the previous lesson
- 1 Petri dish with seeds (labeled) from the previous lesson

For each student

- 1 note card

For the class

- 3–4 Petri dishes with paper towel and seeds that were not moistened (to look as they did in Lesson 1)

Scientific versus Casual Observations

1. Remind students that in the previous lesson they started exploring questions such as:

- How can a scientist "develop" a new type of plant like a "Fast Plant?"
- Just How Fast are Fast Plants?

2. Encourage curiosity about what has happened to the seeds planted yesterday. On a note card, have students individually write one sentence about what they think has happened to the seeds from the previous lesson.

- Reinforce that the class is growing this first crop of plants to learn the answer to the question **Just How Fast are Fast Plants?** and to improve their skills at growing the plants for their later investigations.

3. Allow student groups 4–6 minutes to observe and discuss the changes in the quads and Petri dishes. Refrain from giving directions about recording data or being systematic about observations.

4. Remove the quads and Petri dishes so they cannot be seen, and ask the class a series of probing questions that will be difficult to answer without carefully made and recorded observations today and during the previous lesson. Ask questions like:

- How have the seeds changed since yesterday (color, size, position, moistness)? How do you know?

5. Ask students what would have made it easier to make reliable observations of what ***changed*** during the past day. Have students provide specific examples of difficulties they had trying to respond to the questions you posed based on their current observations.

(continued on following page)

6. Use a Think-Pair-Share strategy to develop a class list of criteria for making and recording good observations. Guide the discussion to include criteria such as:

- some observations need to be repeated every time for comparison
- drawings made to record scientific observations are realistic and made to scale
- (see the Implementation Guide for more suggestions)

7. Hand the plant materials back out to groups so they can make observations to more accurately answer the questions, ***How have the seeds changed since yesterday (color, size, position, moistness)? How do you know?*** Circulate among groups and check for accuracy and improved observing.

8. Use the REAPS questions either as a written exercise or oral discussion, and guide students to compare their own experience with observations to what scientists experience.

REAPS Questions

R **What is growing from the Fast Plant seeds?** Newly developing plants are growing from the seeds.

E **Compare what happens when scientists make observations and they already have a strong idea what they are looking for to when they don't have any idea what will happen?** When scientists make observations when they have strong ideas what to look for, those ideas may influence what they see, and their interpretations may be wrong because of that. Scientists try to be aware of their preconceived notions so that they can make observations without be influenced by their prior ideas.

A **Look at the sentence that you wrote before making any observations that described what you expected would have happened to the seeds. How did what you expected influence what you observed?** Students may realize that their ideas about what was likely to happen during germination may have influenced what they observed.

P **What difference do you expect to see between the seeds growing in planting mix and the seeds growing on paper towel?** Students may predict whatever they think with a reason.

S **How do you work differently when you make careful observations compared to when you make casual observations?** Look for responses such as, "I used a protocol, I wondered about how a plant grows, I made a prediction, I take notes in my science notebooks, I draw things to scale and the right colors, I measure things.)

Implementation Guide

In the first part of the lesson, students are directed to make observations of the Fast Plants and seeds in Petri dishes; however, they are not given instructions about how to make observations or to make notebook entries. After making observations, they are given questions that are likely to be difficult to answer from casual observations.

The goal of this experience is to make a strong case for setting standards for how observations are made and recorded. The class will then develop criteria for observations, setting expectations for how observations will be made throughout the unit. Using these criteria, the students will repeat the observation and questions.

1. Bring students back to where they left off by raising two questions that were posed the previous day:

- How can a scientist develop a new type of plant?
- Just how fast are fast plants?

Remind students to keep these questions in mind as they continue.

2. Raise the students' curiosity about how the Fast Plants may have changed since they were planted the previous day, by holding up one of the Petri dishes and asking, ***What do you expect to see when you look at the seeds today?***

- Pass out note cards and direct students to write one sentence about what they think happened during the past 24 hours.
- As students write, travel around the room and read over the shoulder of students to see if you can get an indication of what students understand about seed germination.
  - Resist the temptation to tell students what they ought to expect to see, and do not validate incorrect responses. Rather, acknowledge that this is just a prediction and may or may not be supported by what is observed.
  - Make a mental note if some students need additional instruction about how plants emerge from seeds. It will be important to support their learning this so that they can grasp in this unit how the environment influences growth and development for individual and populations of plants.
- Instruct students to keep their note cards for now because they will use them again in a few minutes.
- Reinforce that the class is growing this first crop of plants to learn the answer to the question **Just How Fast are Fast Plants?** and to improve their skills at growing the plants for their later investigations.

3. Pass out the quads and Petri dishes to the groups and instruct students to make observations. **Remember**: Allow students to make and record observations however they choose; later you will instruct them on how to make systematic observations.

- Allow 3–5 minutes for students in groups to observe and discuss their observations.

4. Next, remove the quads and Petri dishes from the students' sight and ask students a series of probing questions that would be challenging to answer without making methodical observations and records. The purpose of this is to allow students to experience the difficulty of remembering details accurately when making casual observations. This experience is intended to build awareness of the value and importance of scientifically oriented observations. Ask the questions:

- How have the seeds changed since yesterday (color, size, position, moistness)? How do you know?

Have students write their answers to these questions on the opposite side of the note card they wrote on earlier.

- Students need to keep these note cards for students to revise in #7 below, and in Lesson 3, they will add them to their science notebooks.

5. Ask students what would have made it easier to make accurate statement about what changed during the past day.

- During the discussion, have students refer to specific examples of challenges they faced trying to recall details.
- Make sure that students understand that it would have been easier to make a comparison of the seeds on the two days if they had careful observations from both days to compare.

Explain that you have several Petri dishes with seeds and no water added from yesterday that the students could use to repeat their observations after the class establishes criteria for making observations.

6. Use the Think-Pair-Share strategy for students to develop a class list of criteria for good observations. Prompt students to think about what makes a good observation by asking such questions as "How can you make and record observations so that days or weeks later you will still remember what you saw?" Guide the class discussion about what makes an observation reliable so it includes such criteria as:

- Observations are made and recorded the same way each time so students know that any differences are not due to how observations were made.
- Measurable traits, such as height and weight are measured using the same guidelines every time. For example, how do you measure the height of plant? From the planting mix to the top of the plant? Or from the roots up to the top of the plant?
- Traits that cannot be measured, such as the hardness of a seed, are compared to the same standard. For example, the hardness of seeds can be compared to the hardness of the same dry seeds every time. This way, differences probably are not due to inconsistent comparisons.
- Notes include comments about whether an observation is casual or methodical.
- Notes include comments on whether something is described from an actual observation or is an inference.

Save the class-generated criteria for making and recording high quality scientific observations as a reference.

> ***Evidence*** in science is gathered directly when we make observations of the natural world using any or all of our five senses. Evidence can also come from credible accounts of direct observations that were made and recorded by others. When evidence is gathered directly, it is considered primary source evidence. When evidence is collected and reported by someone else, it has then gone through their interpretation and is no longer considered primary source evidence.
>
> An ***Inference*** is an interpretation of evidence. We make inferences by comparing and judging evidence against our past experiences.

7. Pass out Fast Plant Petri dishes and Fast Plant growing quads again to their respective groups for students to practice methodical observing to answer the questions, ***How have the seeds changed since yesterday (color, size, position, moistness)? How do you know?*** Circulate around the room and check for improved observation techniques.

8. Use the REAPS questions either as a written exercise or an oral discussion and guide students to compare their own experience with observations to what scientists experience.

Key Concepts

- Clear communication and accurate record keeping is an essential part of doing science

Evidence of Student Understanding

The student will be able to:

- make science notebook entries using the class criteria effectively

Time Needed

50 minutes

Materials

For each group of 4 students

- their 1 quad of growing Fast Plants
- their Petri dish with growing Fast Plants

For each student

- science notebook
- 1 copy of Student Page 1.3A *Sample Science Notebook Pages*

Science Notebooks: Communicating and Recording

1. Explain to students that in this lesson the class will explore how scientists use scientific notebooks and focus on the question, **Why is a science notebook such an important tool that nearly every scientist uses one?**

2. Use a Think-Pair-Share strategy to learn what prior experiences students have had with keeping a notebook for science.

- Have students individually write three things that are important to include in a science notebook.

3. Explain that nearly all scientists keep a science notebook. Share the sample notebook pages on Student Pages 1.3A: *Sample Science Notebook Pages* for students to observe individually.

4. Have students brainstorm a list of similarities and differences among the three notebook samples. Discuss why they might have similarities.

5. Remind the class how they have videos from The Father of Fast Plants, Paul Williams, and one is about his science notebook. Show the video.

- After the video, pose the question: How does Paul Williams' science notebook help him do his scientific work?

6. As a class, reflect back on the brainstorm list about similarities among the science notebooks, and compare that list to what Paul Williams said in the video to look for similarities that could be the start of class criteria for notebook entries.

7. Remind the class that they are working like scientists to answer the question, ***How fast are Fast Plants?*** and explain how they will benefit from having an agreed upon criteria for notebook entries so that entries are similar enough to make sharing observations and evidence more effective.

- Hold a discussion to add to the brainstorm list everything the class can think of that is important to include in a science notebook.

(continued on following page)

- As appropriate, refine the class list to the most important factors to include, and have students further explain how each factor will look if it is done well.

8. Have each student begin a notebook, and tape the note cards and observations from previous lessons into the book.

- Add dates as appropriate and place entries in chronological order.

9. Have students make Fast Plant observations, and record them in their science notebooks using the class-established criteria for entries.

10. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **Draw in your notebook how your seeds have changed since you placed them on the paper towel to germinate.** Look for students to be able to accurately represent both growth and development of a Fast Plant from seed.

E **Compare a seed to a flowering plant. How are they related?** The seed is the offspring or baby of the fully-grown plant.

A **Explain how a TV guide or artist's sketchbook is similar to a science notebook. How are they different?** A TV guide, like a science notebook, gives specific times when things happen, includes short descriptions, and organizes information so that it is easy to retrieve. An artist's sketchbook is a record of ideas and work that is usually organized so the artist knows when sketches were made, and it may include labels and/or short descriptions. A TV guide does not document the study of natural phenomenon, and an artist can record anything he or she imagines; it does not focus on evidence.

P **Predict if you will see more variations or differences in the speed of growth when Fast Plants are in planting mix or in a Petri dish. Explain your prediction.** Look for recognition by students that there are probably more variables in the potting mix environment that might affect the rate of germination (depth of planting, amount of water, how hard the mix was packed, etc.).

S **What will be most difficult about keeping a science notebook that meets the criteria we established in class today? What strategies do you think might help you with that?** Help students recognize that a systematic approach—always taking out the science notebook at the start of class and recording notes neatly and with organization are two key strategies for using this tool well.

Teacher Background Information

What are Science Notebooks?

One way that scientists keep a record of their observations, data, explanations, and ideas is by recording them in a notebook. Using science notebooks is a standard practice in all science disciplines. Whether in a university, government, or private industry research laboratory or in the field, scientists use notebooks to record their questions, observations, data, explanations, and predictions about whatever phenomenon they are studying. These notebooks are then used to compare new and old data; formulate explanations, models, or theories; and develop presentations to communicate results to others.

Using Science Notebooks

Research on how people learn and the use of science notebooks in the classroom provides good reasons for using science notebooks in the classroom. These include substantial improvements in student learning and writing skills. They also provide students with an organizing tool for the unit and are a valuable source of feedback for teachers about students' understandings.

The use of science notebooks for each student is strongly encouraged for all science lessons, particularly those throughout this unit. Specific opportunities for using science notebooks in this unit are explicitly described where appropriate. A bound notebook works well for a science notebook because its pages cannot easily be torn out or replaced, handouts and other loose pieces of paper can easily be taped in, and it is inexpensive.

Key features for science notebook entries that other teachers recommend to both help the learner stay organized and make reading/ assessing student-notebooks manageable include:

- student's name on the outside cover of the notebook—all student's names in the same location so it is easy to locate any one notebook in a stack
- a title for each new entry (you may want to have students begin a new page for each new lesson and/or use a highlighter to highlight the titles where new lessons begin to make navigation easier)
- the date (placed in an agreed upon location, such as the left hand margin, so it is easy to find)
- captions and/or titles for observations—drawings, written descriptions, tables with data
- location (if not in the classroom)
- written responses to all REAPS questions assigned to be recorded
- class notes from discussions and mini-lectures
- all mathematical computations (not just the answers)
- partners' names when working in small groups

Additional items:

- empty space to write additional notes later (in some cases teachers use a strategy in which one type of record is kept on the right page and a different type of record, such as notes taken during class, are kept on the left page)
- environmental/weather conditions
- specific types of descriptive words
- units of measure and/or references about relative size
- drawings that are accurate representations with colors and labels

There is additional information about using science notebooks in the ***Immersion Unit Toolbox***.

Advance Preparation

This lesson includes a video segment featuring Paul Williams talking about keeping a science notebook; plan in advance, how you will project this for your class (computer/projector, TV/player). Also, make a sufficient number of copies of *Student Page 1.3A Sample Science Notebook Pages* for your class.

Implementation Guide

1. Explain to students that in this lesson the class will explore how scientists use scientific notebooks, focusing on the question, **Why is a science notebook such an important tool that nearly every scientist uses one?**

Share with the class that because in this unit students work like scientists, they will need to keep science notebooks, too. At this time you could mention how observations up until now haven't been as well organized as they would be if they were in a science notebook.

2. Use a Think-Pair-Share strategy to help students reflect on their previous experiences keeping notebooks for science.

- Have students individually write three things that are important to include in a science notebook.

3. Explain that one way to learn more about what is important to include in a high quality science notebook is to look at examples from successful scientists. Distribute Student Page 1.3A *Sample Science Notebook Pages* to each student, and instruct students to spend a few minutes looking at the notebook pages. There are examples from Jane Goodall's observations during her early studies, a page from Paul William's notebook, and a page from an entomologist's field notebook, studying insects. Encourage students to imagine what each scientist was looking at when he or she wrote the entries.

4. Organize students in groups of four and have them brainstorm a list of similarities and differences between the scientists' notebook pages. Have one volunteer from each group share with the class their observations about similarities and differences among the notebooks. Encourage questions and speculations from students about why scientists keep their records the way they do.

Guide the discussion to draw students' attention to two science notebook features:

- There is more than one way for scientists to organize their science notebooks and record their observations.
- Entries include dates, observations, comments, and other basic kinds of information that provide both context and detail.

5. Let students know that you also have information on video about how Paul Williams uses his science notebook. After viewing the video, pose the question:

- How does the way Paul Williams' organizes the information in his science notebook help him do his scientific work?

6. As a class, reflect back on the brainstorm list about similarities among the science notebook pages, and compare that list to what Paul Williams said in the video to start a discussion about the class's criteria for notebook entries.

Point out to students that, even though the three scientists were investigating gathering very different data, they all recorded their observations and comments regularly and organized their notebooks so that it is easy to read and useful.

7. Bring students back to thinking about what their own science notebooks will look like. Explain that as a class you will work together to describe the criteria for what makes a good science notebook and then use that criteria. Point out how having the same criteria for making science notebooks will make it easier for students to communicate with one another and you by sharing observations and evidence.

- Hold a discussion to add to the brainstorm list everything the class can think of that is important to include in a science notebook.
- As appropriate, refine the class list to the most important factors to include, and have students further explain how each factor needs to be completed for highest quality.

If necessary, provide some guidance by asking questions such as:

- What kinds of entries will we make in a science notebook?
- What needs to be in each entry?
- What would make our science notebooks useable for us? For others?

Possible criteria include:

For investigations:

- name of the investigation
- procedure for investigation
- observations and measurements
- comments about observations, thoughts, the process
- how measurements are taken each time
- when entries are made (day, month, year, and time)
- where investigation is performed

General criteria:

- new lesson or project always starts on a new page
- entries are readable
- entries are objective observations, unless specified as thoughts and speculations, opinions.
- use a pen (or pencil) and draw line through changes instead of erasing or crossing them out.
- organized
- calculations included
- explanations include reasoning

8. Explain to students that they will now begin their own science notebooks using the criteria the class established. Have students start their notebooks by taping the notes and note cards they collected in the first two lessons.

- Add dates as appropriate and place entries in chronological order.

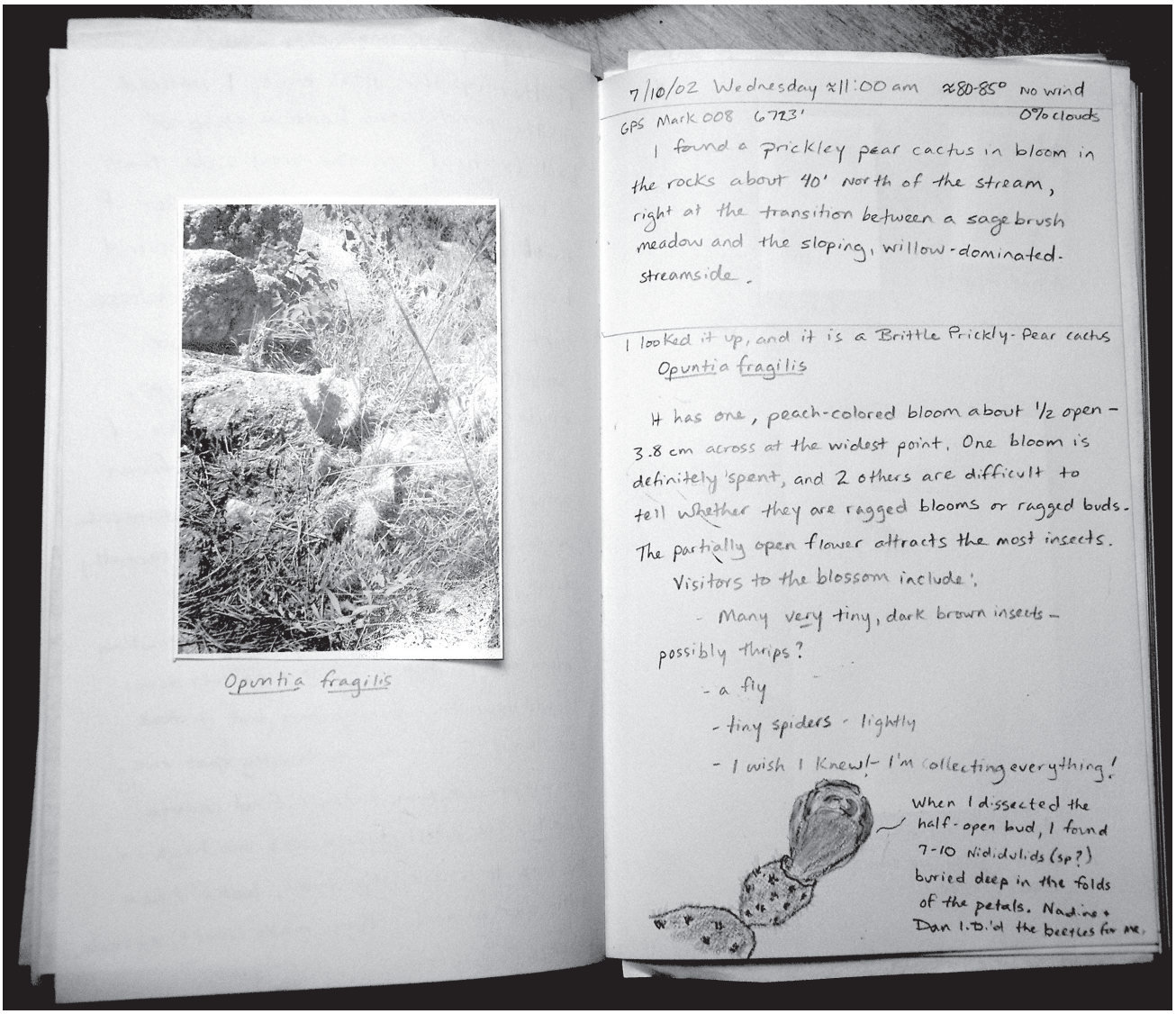
NOTE: Save the class-generated criteria for science notebook entries. Before the next lesson, use this list to revise the rubric provided on the Unit CD so that it reflects your class criteria to use in the science notebook peer review (and future assessments you conduct).

9. Have students make Fast Plant observations, and record them in their science notebooks using the class-established criteria for entries. What students include in the science notebooks and how they include it will provide valuable information that can be used to assess student understanding.

Travel around the room and reinforce students who are following the criteria carefully and in detail. Clarify any criteria established by the class that seem to be challenging for students as they set up their notebooks.

10. Use the REAPS questions throughout the lesson where appropriate.

Student Page 1.3A: Sample Science Notebook Pages



Opuntia fragilis

7/10/02 Wednesday ≈11:00 am ≈80-85° No wind

GPS Mark 008 6723' 0% clouds

I found a prickley pear cactus in bloom in the rocks about 40' north of the stream, right at the transition between a sagebrush meadow and the sloping, willow-dominated streamside.

I looked it up, and it is a Brittle Prickly-Pear cactus Opuntia fragilis

It has one, peach-colored bloom about 1/2 open - 3.8 cm across at the widest point. One bloom is definitely spent, and 2 others are difficult to tell whether they are ragged blooms or ragged buds. The partially open flower attracts the most insects.

Visitors to the blossom include:

- Many very tiny, dark brown insects - possibly thrips?
- a fly
- tiny spiders - lightly
- I wish I knew! - I'm collecting everything!

When I dissected the half-open bud, I found 7-10 Nididulids (sp?) buried deep in the folds of the petals. Nadine + Dan I.D.'d the beetles for me.

Table 1: 3/2/00 PHW

Fast Plants Growth, Development & Reproduction

Your name: PHW Date of sowing 5/28/00

Plant Variety: Rbr, C1-33, LUT96

Standard environment: PLH#1, FCS, 150 µM, PAR

Variable environment: 1/8 x Peters nutrient

Plant #	Plant Trait Measured					
	height (mm) 18das	# of leaves on stem	# hair, 1st leaf margin	# flowers pollinated	# seeds	other
1	262	6	22	29		
2	279	6	56	15		
3	253	5	0	13		
4	242	7	1	17		
5	301	7	6	21		
6	311	6	0	16		
7	267	7	18	25		
8	302	5	21	22		
9	254	7	16	21		
10	264	6	26	20		
11	230	6	26	12		
12	315	7	31	21		
n	12	12	12	12		
$\bar{x}$	273	6.3	19	19		
s	28	0.8	16	5.0		
r	65	2	56	17		

n = number of plants measured

$\bar{x}$ = average measure = sum of measures ÷ n

r = range of variation = highest - lowest value

s = standard deviation, = average variation around the average, $\bar{x}$. (use statistical calculator)

Fifi.

4 June (14) 292 Then Ff reach F. Ff again. Stops and ←.
Takes Ff's hand. Grin Fg. Later pulls his foot.
Pulls him quite away. Flo looks
Ff sits up + puts arms around him. Ff push up
+ nearly looks over F sh. Flo lifts him away (1')
4 293 Ff (later) waves his arm around. hits + his imp.
Ff grin Flo' Pulls at Ff.
4 294 Ff touch Ff. Flo push Ff head > foot (both lying)
298 Pulls him away for moment only. Flo pulls back. 9.15
Pulls his foot. DD on it.
Ff reaches + him. Ff sleeps. Flo push Ff ←
5 301 Ff pulls him away. Holds on lap. Sl. whimp. Flo pulls
him back.
Ff then seems + reach ⊆ F. Grabs leaf > one x.
Ff picks twig of leaf, + pulls both his x > + hr.
Flo pulls him back. Flo → Ff.
Then Ff kicks Ff > heel.
Goes up to play > Ff. Flo twice gathers him as
Ff rough + Ff whimp. He whimp as Ff DD foot.
Ff crawls up Ff. Ff held. He whimps.
Flo takes back.
Ff DD 3 more times.
Ff takes Ff away. Ff after no crawls back up Flo.
Ff grabs his x > play face. Then → Flo.
Touch Ff again. → Fg.
302 Ff grabs leg + waves (Ff has ant in lip)
Ff takes. Ff whimp + creep low Flo who grabs
1st x then chest as Ff keeps hold. ~~Ff lets~~ go.
Flo lets go. Ff hangs out Flo Ff lets go.
holds foot. Ff → Ff.
303 Ff pl. Ff. Flo push > foot.
304 Ff pulls under arms + gets Ff away. As she holds
Ff Flo → Ff. Then after 1½' Flo removes. (4.30)
Then → Ff again.
Ff pulls his chin. He whimp. Flo takes back (4.43)
Ff plays > Ff.
Ff pulls at + gets Ff. Turns away from Flo > him.
Fg appr. Ff hip. Goes first ~~of~~ trip + then
quad > Flint. dirtying + down. Flo poll.
calmly. Ff has him 3'
5 305. Ff tries twice + take Ff. Then gets. Rolls 3 feet
from Flo + sits by Fg. Flo gives her 'hoo'
sounds (6) Reaches + takes Ff back.
Twice Ff grabs such Ff - Flo moves.
Then Ff follows. Gets Ff. Rolls out back. Sits up
+ nuzzles. (Back + Flo) 'Bounces' him on hr lap.
He stretch arms + Flo. Flo reach for
him - Ff hangs on + fell.
Ff can't + pull He pants. Whimp. Flo detach as
Ff x. Turns from Ff. Ff can't + nuzzle this
(37) head. Pulls. Bites hard. Jerks arm up + down.

Key Concepts

- Clear communication and accurate record keeping is an essential part of doing science
- Results of scientific investigations are seldom exactly the same, but if the differences are large, it is important to try to figure out why.

Evidence of Student Understanding

The student will be able to:

- evaluate a peer's science notebook entries using the class criteria effectively.

Time Needed

50 minutes

Materials

For each group of 4 students

- their 1 quad of growing Fast Plants
- their Petri dish with growing Fast Plants

For each student

- science notebook
- 1 copy of Student Page 1.4A *Science Notebook Rubric*

Science Notebooks: Peer Review

1. Explain to students that if everyone is doing a good job with their science notebooks they will be able to trade notebooks and understand the entries. Pose two questions to the class and discuss briefly,

- **What is probably the easiest part of your science notebook for someone else to read and understand?**
- **What is probably the most difficult part of your science notebook for someone else to read and understand?**

2. Distribute and explain Student Page 1.4A *Science Notebook Rubric* to remind students about the class expectations for science notebook entries.

(continued on following page)

REAPS Questions

R **What is one reason for scientists to create science notebooks that others can read and understand?** There are many reasons including, so others can repeat your investigation and check the accuracy, so others can understand your thinking process and the evidence you based your explanations on.

E **What evidence would you have to demonstrate that you have done a good job on your science notebook?** Other students would be able to read and understand the entries.

A **How can you tell if others will be able to understand what you did when they read your science notebook?** Students can apply the Science Notebook Evaluation Rubric to determine how easy it is for others to understand entries in your notebook.

P **Predict: Which features of science notebook entries are the most difficult things for others to understand?** Predictions will vary. The important part of student predictions is the logic that students use to make their predictions.

S **After receiving feedback from others about your science notebook, how have you made it stronger?**

3. Explain that after the observations today are recorded, classmates will exchange notebooks as you direct and read entries to give feedback about improving how they are written.

4. Have students make Fast Plant observations, and record them in their science notebooks using the class-established criteria for entries.

5. Direct students to exchange notebooks according to your plan.

- Have students apply the notebook entry rubric on the number of entries determined in advance. Travel around the room as students review notebooks, and assist with applying the rubric and giving feedback.
- Use this as an opportunity to informally assess students' work.
- Provide time for the reviewers to give feedback to the science notebook authors.
- Allow students additional time to make improvements before collecting the notebooks yourself to read and assess.

6. Use the REAPS questions throughout the lesson where appropriate.

Teacher Background Information

This lesson features a peer review to help students improve the quality of their science notebooks. Teachers using science notebooks often report that students respond particularly well to knowing that their peers will be trying to understand what they record in their notebooks. In addition, the experience of trying to understand someone else's notebook entries can clarify for students the amount of detail and organization that is necessary to include in their own entries.

This peer evaluation is intended only to be used as an informal assessment. Do not have students assign grades; it defeats the purpose of the lesson to provide informal feedback. One goal for having students engage in the thoughtful development of criteria and a common approach to keeping science notebooks is to encourage collaboration in a way similar to how scientists work together.

Advance Preparation

NOTE: Before this lesson, use the class's criteria for science notebook entries to revise the rubric provided on the Unit CD so that it reflects your class criteria to use in the science notebook peer review (and future assessments you conduct). A Word file for the rubric is available on the Unit's CD to be customized for your class.

Decide in advance on a strategy for having students exchange science notebooks. Rather than having students choose whom to trade with, it is suggested that you make the exchange more random and consider having students generally be seated away from each other so that the notebook must speak for itself (not have its author nearby to interpret).

One method for exchange is to walk a path through your classroom collecting all the notebooks into a stack in your arms, then repeat the same path handing out notebooks so that the last one collected is the first one handed out. If you use this technique, keep in mind that near the middle of the path you will need to either shuffle the notebooks a little or change your path slightly so that students don't receive either their own or a near-neighbor's notebook.

Implementation Guide

1. Invite students to imagine that years from now, a scientist will find their Fast Plant science notebooks. Ask the class, could someone figure out what you did in your investigation, just by reading your science notebook?

Explain that students don't need to wait for years to see if someone else can understand their science notebook entries. If they are doing a good job with their science notebooks, they will be able to trade notebooks with someone else and understand each other's entries. Ask students to reflect on what it would be like for someone else to read the notebook entries they made the previous day. Discuss the following questions briefly:

- What is probably the easiest part of your science notebook for someone else to read and understand?
- What is probably the most difficult part of your science notebook for someone else to read and understand?

Emphasize that one of the main goals in keeping a science notebook is to document your work so that others can evaluate and even try to duplicate it if needed. In addition, it is important that students communicate sufficiently with their teacher what they are doing and learning so that it can be accurately assessed (and sometimes graded).

2. Explain to students that later in this lesson they will use a rubric to evaluate each other's notebooks for giving feedback to help improve entries. Distribute and explain Student Page 1.4A *Science Notebook Rubric* to remind students about the class expectations for science notebook entries (discussed and outlined in Lesson 3).

Provide an overview of the work to be completed today. In this lesson, students will do three things:

a. record their observations of Fast Plants in their science notebooks.
b. exchange notebooks with a classmate according to directions.
c. read each other's notebook entries and give feedback about how the entries can be improved.

Be sure that students understand that the goal of the notebook exchange is for students to help each other improve their notebook entries. Do not have students *grade* their peers' notebooks.

4. Have students make their daily observations of Fast Plants and record observations in their science notebooks according to the criteria discussed and established in class during Lesson 2.

5. Direct students to exchange notebooks according to the process decided upon before class. Explain to students that when looking at their neighbor's notebook, they will:

- evaluate how well the entries meet the criteria for good science notebook entries.
- make recommendations for how entries can be improved.

Have students apply the notebook entry rubric to today and yesterday's science notebook entries. Explain how a rubric can be used to point out where improvements can be made.

- Have students give feedback to each other by using a highlighter to highlight descriptions on the rubric that align with the quality of work shown in the science notebook being reviewed. In addition, feedback can be given by writing comments on the rubric.
- Travel around the room as students review notebooks, and assist students with applying the rubric and giving feedback.
- Use this as an opportunity to informally assess students' work.

When students finish their peer evaluations, have students return the notebooks to their owners. Then allow the notebook authors additional time to revise their notebook organization before the notebooks are collected for teachers to review.

6. Use the REAPS questions throughout the lesson where appropriate.

Student Page 1.4A: Science Notebook Rubric

Performance Criteria	Attribute	Exemplary 5	Learning 3	Beginner 1
The science notebook is organized and includes the headings, labels and dates that reader needs to follow. • *Name of investigation on each page* • *Dates next to each entry or group of entries* • *New lessons and projects start at the top of a page* • *Entries are in the order observations or comments were made (chronological order)*	Breadth Completeness	Science notebook is well organized. Includes headings, dates, and labeling needed to follow organization of notebook; it is easy for the reader to open the notebook to any page and figure out what was done.	Science notebook shows some features of being well organized. Is missing some of the headings, dates, and labeling that is needed for reader to fully understand what was done.	Science notebook not organized. Does not include all of the headings, dates, and labeling needed to be organized so that it is difficult or not possible for a reader to understand what was done.
Entries in the science notebook are accurate. • *Author makes clear which entries are observations and which are comments or thoughts of author* • *Measurements are in appropriate units* • *Measurements are reasonable and/or explained* • *Statements are accurate: not overstated*	Accuracy	Notebook entries are accurate and use appropriate units Measurements are reasonable or explanations are suggested for unusual data Statements are accurate/ not overstated	Notebook entries are complete and generally accurate and include units Measurements are reasonable Statements are brief but accurate/ not overstated	Notebook entries are incomplete or not accurate, may incorrectly use or not include units Measurements are not reasonable or insufficient for the task Statements are overly brief or not accurate or reasonable
The science notebook communicates information clearly. • entries are readable and make sense • handwriting is easy to read	Clarity	Information in the notebook is extremely clear in at least 90% of the entries	Information in the notebook is clear in substantially more than 50% of the entries	Information in the notebook is not communicated clearly in 50% or more of the entries

Rubric format based on rubric design by Tierney, Robin & Marielle Simon (2004). What's still wrong with rubrics: focusing on the consistency of performance criteria across scale levels. *Practical Assessment, Research & Evaluation*, 9(2). Retrieved May 13, 2006 from *http://PAREonline.net/getvn.asp?v=9&n=2*

Key Concept

- Communicate the logical connection among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence.
- Seeds are the structure from which flowering plants produce new plants.

Evidence of Student Understanding

The student will be able to:

- develop an explanation for how fast Fast Plants are, based on experimental observations and evidence from a written resource.
- reflect on their own learning and accuracy of their original prediction in light of evidence.
- draw a diagram showing how new plants emerge from seeds.

Time Needed

80–100 minutes

Materials

For each student

- 1 copy of Student Page 1.5A *How Fast are Fast Plants compared with Other Plants*
- 1 copy of Student Page 1.5B *The Development of Fast Plants*

For the class

- 2 transparencies of Teacher Page 1.5A *Fast Plant Data*

Scientific Explanation: How Fast are Fast Plants?

1. Take 5–10 minutes before starting this lesson for students to conduct their daily observations and record notebook entries on Fast Plants.

2. Explain to students that they are working like scientists by deciding how to analyze how fast Fast Plants are. At this point, they have conducted an entire investigation to answer the question about how fast these plants are.

3. Remind students that the original question they asked before planting their plants was "**How Fast are Fast Plants?**" Ask students to explain their current ideas about how to respond to this question. Record students' responses on the board.

- Be sure that students include evidence for their ideas.
- Instruct students to identify if they are describing individual plants or a population.
  - NOTE: Several plants in the same quad or all the quads on the same water reservoir are considered a population.

4. Conduct a whole class discussion to define what the question "How Fast are Fast Plants?" means. Instruct students to:

- Make a list of possible criteria for what fast could mean.

5. Explain to students that, as a class, they will develop an explanation for how fast Fast Plants are according to two sets of criteria:

- when the first plant FIRST appears above the soil surface.
- a second set of criteria selected by the class

Guide students to work together as a class to select the second criteria from their list of possible criteria.

6. Have students work in pairs to review their own records to see if they have the evidence they need to describe when their Fast Plants first emerged above ground. They will need to calculate how many days based on the date they planted the Fast Plants and the date they emerged.

- Record the number of days it took each plant to emerge from each team on a transparency of Teacher Page 1.5A *Fast Plant Data—Days to Emerge*

(continued on following page)

- Ask students to look for patterns in the class data.

7. Use a Think-Pair-Share strategy to find out how students would calculate **the mean number of days until the class's plants emerged from the soil**.

8. Repeat sections 6 and 7 with the second criteria the class chose to determine how fast Fast Plants are.

9. Introduce students to Student Page 1.5A *How Fast are Fast Plants Compared with Other Plants*.

- Have individual students add Fast Plants to the graph.
- Invite students to describe how fast the Fast Plants are compared to other plants.

10. An article, Student Page 1.5B *The Development of Fast Plants*, provides information from Paul Williams about his work developing and analyzing data about how fast Fast Plants are, and that can be used as additional evidence.

- After students read *The Development of Fast Plants*, hold a whole-class discussion to see how evidence from that article could be used to strengthen their explanation.

11. Have students reflect back on their original predictions for how fast they thought Fast Plants would be and explain how it compares to what they now know.

- Highlight how scientists revisit their original predictions throughout their investigations.
- Direct students to review the *Unit Level Graphic Organizer* and contribute new concepts they learned by conducting this investigation.

12. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **Draw and label a diagram showing what happens when a flowering plant makes seeds and its seeds are planted.** This drawing ought to show understanding that a flower produces seeds and a new plant emerges from a seed.

E **Looking at your team's plants, explain if they look like all their needs were met or not. If not, what do you need to do differently to meet their needs when you grow Fast Plants again?** Answers will vary. Use this question to help students recognize if they planted correctly and tended their emerging plants well (right number of seeds, good depth of soil, plenty of moisture throughout, thinned to one plant/cell etc.).

A **Why is it useful to calculate the mean number of days until the class's plants emerged from the soil?** The mean is more valuable to know when analyzing traits in a *population*.

P **Give at least three examples of other types of plants you might expect scientists to be working with to develop faster growing types. Explain your list.** Work to breed trees that grow quickly for shade or wind protection, grasses that grow quickly to cover disturbed ground, all kinds of fruits and vegetables to produce early crops, and flowers that grow quickly to provide early blooms are all examples.

S **Look at the first note card you wrote in Lesson 1, and compare your response to the question, *How can a scientist "develop" a new type of plant like a "Fast Plant?"* to your current understanding of how a scientist like Paul Williams can do this. How has your thinking changed so far?** At this point, students need to be developing an understanding of the idea that variation in plants can be influenced by the environment and selected for by a plant breeder (or nature).

Advance Preparation

Lesson 1.5 is particularly important for setting the expectations in this unit and in your class for evidence-based explanations. It is important that students experience in this lesson how to decide what evidence is important, analyze experimental results for patterns, and use logic and reasoning to develop an explanation for those results. Additional resources for preparing to teach these inquiry skills and abilities to students can be found in the *Immersion Unit Toolbox*.

Implementation Guide

1. Have students conduct their daily observations of Fast Plants and make notebook entries before the lesson.

2. Explain to students that they are working like scientists by deciding how to analyze how fast Fast Plants are. At this point, they have conducted an entire investigation to answer the question about how fast these plants are.

3. Remind students that the original question they asked before planting their plants was "How Fast are Fast Plants?" Ask students to explain their current ideas about how to respond to this question. Record students' responses on the board.

- Be sure that students include evidence for their ideas. Consider asking questions like "What makes you say that?" and "How do you know that?" when a student makes a claim without sharing the evidence that supports their claim. Also, encourage students to question each other about the evidence on which they are basing their claims.
- Use this opportunity to have students start recognizing when they are describing individual plants or a population. Throughout this unit, students will need to distinguish when they are talking about individuals and when they are talking about populations.

4. Ask students if they think the question, "How Fast are Fast Plants?" is a scientific investigation question. Prompt them to recognize that the question does not make it clear what is meant by fast. Point out that scientists are extremely careful to write questions that clearly indicate what they are asking. Ask the class to work together to define what the question "How Fast are Fast Plants?" really means. To guide this discussion, suggest making a list of criteria that would help explain what they mean by fast. For example,

Does fast refer to the number of days until the plant:

- grows the first root?
- develops the first flower?
- first cotyledon opens?
- germinates?
- breaks through the soil?
- flowers?

5. Explain to students that, as a class, they will develop an explanation for how fast Fast Plants are according to two sets of criteria:

- when the plants first appear above the soil surface
- a second criterion that class selects from their list

Guide students to work together as a class to select the second criterion from their list of possible criteria (the list that was generated by the class in #4). Explain that the class will use these two pieces of evidence to begin to explain just how fast Fast Plants really are.

6. Have students work in pairs to review their own records to see if they have the evidence they need to describe when their Fast Plants first emerged above ground. They will need to calculate how many days based on the date they planted the Fast Plants and the date they emerged.

- Next, have one student from each quad group share the number of days it took for each of their Fast Plants to emerge from the soil. Allow other group members to agree or disagree with the calculation.
- Once the team has agreed upon the correct number of days for each plant, record the number of days for each of their plants on a transparency of Teacher Page 1.5A *Fast Plant Data.* In the blank at the bottom of the Teacher Page, record "emerged from the soil" and title the graph appropriately.

- Explain that whenever scientists have data one of the first things they do with the data is begin to look for patterns, and since they are developing a scientific explanation for just how fast Fast Plants are, looking for patterns is a logical next step. Prompt students to study the patterns with questions like:
  - Do all Fast Plants emerge after the same number of days?
  - Do you see any patterns in the differences in the data among groups?
  - Does any data seem to be extremely different from the rest of the data?

7. Explain to students that scientists that work with lots of data (like their graph displays) often use math to summarize the data. This is especially useful when they are talking about populations, instead of individuals. Share that instead of trying to talk about the number of days that each plant took to germinate, the class can summarize the data by calculating the mean number of days that the class's Fast Plants take to emerge from the soil. Use Think-Pair-Share for students to calculate the mean number of days until the class's plants emerged from the soil.

- Have students first individually think about how they would go about calculating the mean, and then individually calculate the mean.
- Then, allow students to work in pairs to discuss how they calculated the mean and compare their answers.
- Conduct a class discussion to formalize the correct way to calculate a mean.
- Determine the correct mean number of days that the class's Fast Plants took to emerge from the soil.

8. Repeat sections 6 and 7 with the second criteria the class chose to determine how fast Fast Plants are. Students will need to review their science notebook records to calculate the number of days each plant took to reach the criteria and then provide data for the second transparency of Teacher Page 1.5A *Fast Plant Data*. In the blank at the bottom of the Teacher Page, record the criteria and title the graph appropriately. Finally, they will need to calculate the mean number of days for the class's Fast Plants for that criterion.

NOTE: *If students decide the second criterion ought to be number of days to flowering or some other factor that has not yet occurred, repeating sections 6 and 7 can be delayed until after the data is collected.*

9. Explain to students that based on these two lines of evidence they have developed an initial idea for explaining how fast Fast Plants are. Remind students that evidence is key to making a strong scientific explanation. Explain that you have another piece of evidence that might help them with their explanation about how fast Fast Plants are. Introduce students to Student Page 1.5A *How Fast are Fast Plants Compared with Other Plants*.

- Have individual students add Fast Plants to the graph, which shows the number of days different plants take to emerge.
- Invite students to describe to their neighbor how fast the Fast Plants emerge compared to how fast the four other plants emerge.

10. Explain that since they now have three solid pieces of evidence to help them explain how fast Fast Plants are, there explanation is stronger. Describe that when scientists are developing explanations they often turn to the work of other scientists to see how it fits with their own explanation.

Share that you have an article about the work of a scientist, Student Page 1.5B *The Development of Fast Plants* that the class can use as additional evidence. It provides information from Paul Williams about his work developing and analyzing data about how fast Fast Plants are.

- Use an appropriate reading strategy for your students to understand the story.

After students read *The Development of Fast Plants*, discuss the story, and emphasize the points in the story that define, explain, or refer to the following key concepts:

- Flowering plants reproduce by developing seeds, which develop into new plants.
- Reproductive success is defined by the number of offspring that a parent produces. **Note**: *To truly be successful the offspring must be able to reproduce and continue to pass down the parents' genetic code*.
- Selection is a process (natural or artificial) in which some plants are allowed to survive and reproduce based on their traits.
- Environmental stresses are conditions that challenge the health and well-being of individuals living in the environment with those conditions.

Next, guide the discussion to use all the evidence that the class has gathered (from the reading as well as the experiment) to develop a well-formed logical explanation for how fast Fast Plants are.

- Remind students that they will be developing explanations that use this same type of structure when they conduct their own experiments in the next weeks.

11. Have students reflect back on their original predictions for how fast they thought Fast Plants would be and explain how it compares to what they now know.

- Highlight how scientists revisit their original predictions throughout their investigations.
- Direct students to review the *Unit Level Graphic Organizer* and contribute new concepts they learned by conducting this investigation.

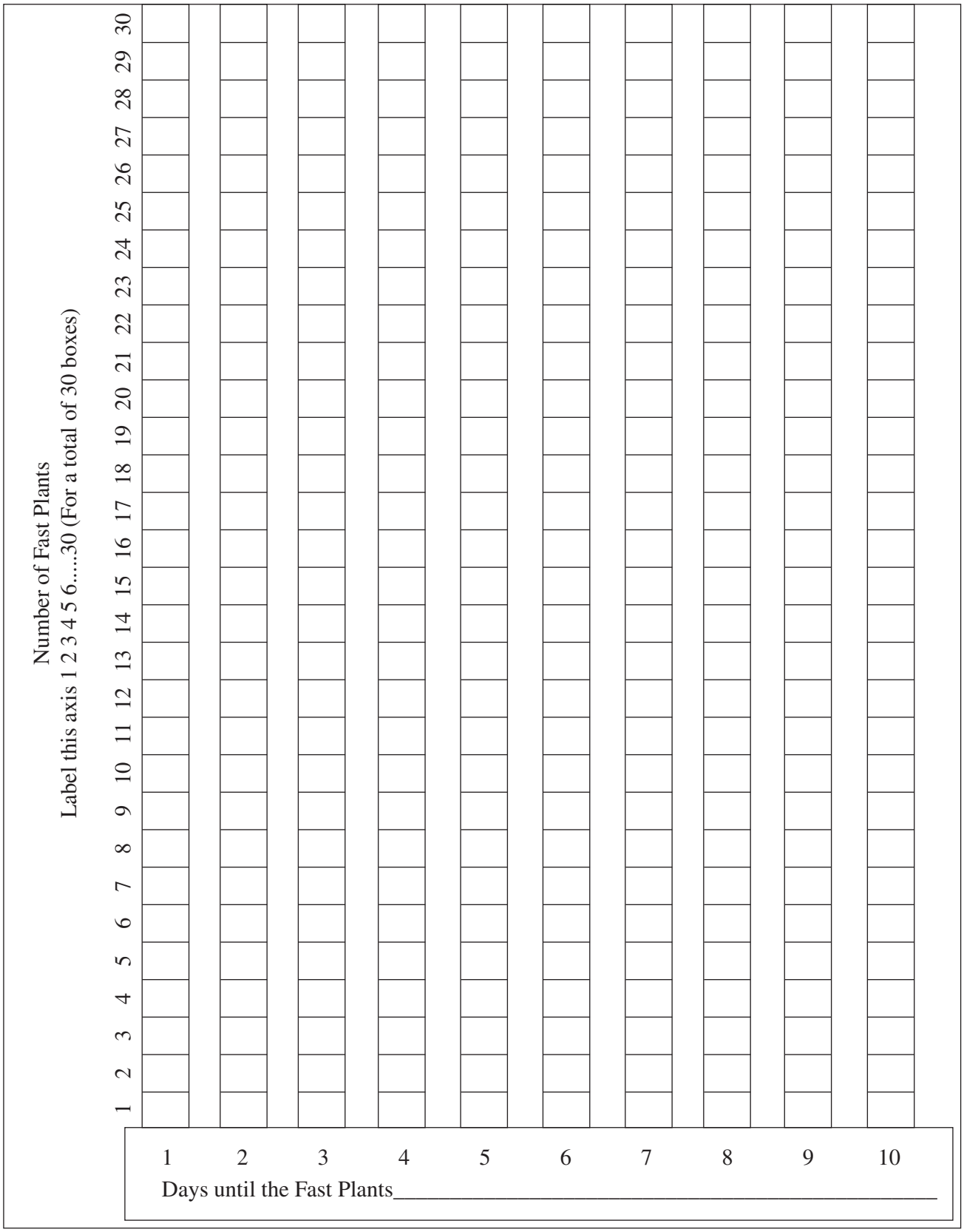
A sample entry for the Graphic Organizer is shown below.

12. Use the REAPS questions throughout the lesson where appropriate. The **S**elf reflection question asks students to compare their response to one of the first questions asked in Lesson 1, How can a scientist "develop" a new type of plant like a "Fast Plant?" to their current understanding.

- At this point, students need to be developing an understanding of the idea that variation in plants can be influenced by the environment and selected for by a plant breeder (or nature).

What we did	What we know	How we know it
Grew Fast Plants from seed and recorded observations to determine how "fast" they are. Analyzed our observations and measurements from growing Fast Plants.	Fast plants emerge from their seeds and grow more quickly than most plants.	• We have data from the class experiment. • We calculated the mean for the number of days to emergence in our class. • We read in the article how many days to emergence Paul reports that Fast Plants take.

Teacher Page 1.5a: Fast Plant Data



Student Page 1.5A: How Fast are Fast Plants Compared with Other Plants?

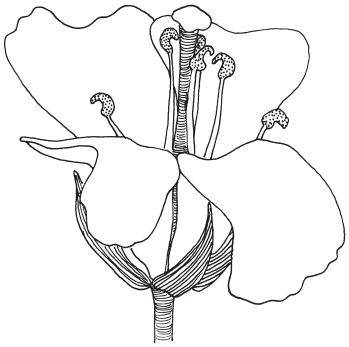
Type of Plant	Number of Days Until the Seedling Emerges From the Soil
Sunflower 	10 – 14 days
Cherry Tree 	7–21 days
Corn 	5–7 days
Peppers 	10–12 days
Fast Plants 	

Student Page 1.5B: The Development of Fast Plants

The story of the Fast Plants begins many many years ago in the kingdom of Nepal. High up on a rugged mountainside of the Himalayas, a farmer walked out to check his newly planted field of barley.

It was late in the spring. The snow had recently melted and the ground was becoming warm again. The barley grass he had planted a week ago would grow and provide grain for cereal, and for the fried bread that he liked to eat. The farmer was intending to just check the field, as farmers do. He didn't expect to see any plants yet.

Imagine his surprise when he spotted patches of weedy looking *Brassica* plants, growing sturdily in the early spring sunlight. These weeds must have sprouted very fast. The farmer thought for a bit. It had been a long winter and a long time since his family had had any fresh vegetables to eat. It would also be three months before the barley he had just planted could be harvested. So instead of pulling up the weedy plants and throwing them away, he took some home for a salad for the family's supper.



Brassica Flower

In a few days, the farmer went back to his field. By this time, the little plants were flowering. The bright yellow flowers looked like sunshine on the mountainside. Each time he visited the field, the farmer took a few plants home for his family to eat. The remaining plants attracted many hungry honeybees. The honeybees spread pollen from one flower to the next, and that is how flowering plants reproduce. Soon the bright yellow flowers produced pods with plump seeds. The farmer and his wife pressed some of the seeds for oil that they could use in cooking. The farmer wisely kept the rest of the seeds to plant the following year. He knew that new plants come from seeds.

The next spring he scattered his field with two kinds of seeds, the *Brassicas* and the barley. Both of the crops grew fairly quickly, but the weedy *Brassica* plants came up first and were already flowering while the barley was still spreading its shoots across the ground. These little plants had high ***reproductive success*** because they produced many healthy offspring. The farmer harvested the *Brassicas* before the barley was tall enough to shade them from the sun. He was able to produce two crops on one piece of land, providing enough food for his family, and for the farm animals, the yaks.

Year after year, the farmer saved and replanted some of the *Brassica* seeds. The little weedy *Brassica* was an easy plant to grow, and required no special fertilizer. It was well-adapted to survive there on the mountainside.

Time passed. Soon, the farmer's grandchildren were farming the same crops on the terraced mountain field. And so it continued, generation after generation.

One day early in the twentieth century an American plant explorer visited the mountainside farm in Nepal. When she saw the field of weedy little plants, she recognized them as a kind of *Brassica*. She knew about the family of plants called *Brassicas*. Many common vegetables such as broccoli and cabbage are members of this family. Other *Brassicas* are mustard and canola oil plants.

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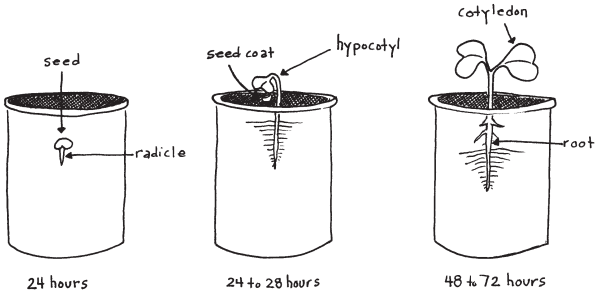
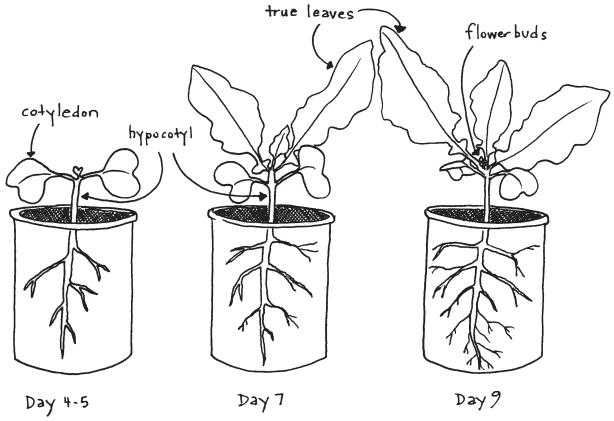
The little *Brassicas* on the Nepalese farm had been grown for hundreds of years in the same location. Because of their isolation, they represented a unique plant stock. That is, these plants had genetic information that was different from other *Brassica* plants anywhere else. The scientist considered them a new plant variety. The explorer knew the importance of saving this different plant type. It is important because different varieties of plants might have the genetic code for variations in traits that can survive environmental stresses. She collected some of the seed of this *Brassica* variety to take home to the US. The seed was stored in the United States Department of Agriculture's *Brassica* seed bank at Iowa State University in Ames. The seed was stored in the collection for many years, though no one seemed particularly interested in it.

However, in the late 1980's a plant scientist at the University of Wisconsin was seeking new genetic material for his research on *Brassicas*. He was trying to discover how to breed vegetable *Brassicas* like cabbage, broccoli, and turnips so that they wouldn't get particular diseases. Plants in the *Brassica* family can get diseases with names like "black leg," "soft rot," and "yellows." These diseases are caused by fungi, bacteria, and viruses. Plants that don't get these diseases are called ***disease resistant***.

The scientist heard about the *Brassica* seed collection in Iowa and wrote to the curator, asking for samples of different kinds of *Brassica* seed varieties. When the seeds arrived, he planted them outside in a field called a research plot. There, in the middle of the research plot, appeared the little, weedy *Brassica* from the mountains of Nepal. That scientist was Paul Williams.



STAGES IN THE LIFE CYCLE



Paul noticed the little *Brassica* right away because it flowered much more quickly than any other *Brassicas*. Some *Brassica* plants are slow to flower, and don't grow very quickly. This means that if a scientist is trying to crossbreed different plants with one another, the research can take a long time. For example, it can take a year to crossbreed cabbages. But this *Brassica* grew very quickly, and from this, Paul got an idea. What if he could use this plant in his research to develop a really fast flowering plant that he could use to test for disease resistance?

He knew he would have to change the plant's environment to discover how quickly he could make the plant grow. Paul saved the seeds of these first plants, then planted those in a

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greenhouse. He grew the new plants under constant light, and with only a small amount of soil. Changing the amount of light and soil introduced an environmental stress. For some of the plants with particular traits, these conditions encouraged plants to grow quickly.

Paul selected from everything he grew the plants that were shortest and sturdiest, that flowered the fastest, and that produced the most seed. He saved seeds from those plants. He was selecting plants with the greatest *reproductive success*. Then he planted those seeds, and grew more plants.

Paul continued to grow generations of *Brassica* plants until he created a "model plant" that he could use to crossbreed with disease-resistant *Brassicas*, and test his results quickly. He called his model plants "Fast Plants." After thirty years of selecting and breeding Fast Plants, Paul developed a new type of plant that germinates in just one to two days. His plants produced flowers in just fourteen days!

In the same way that he had learned about *Brassicas* from the work of other people who came before him (the Nepalese farmer, and the plant collector), this scientist passed on the knowledge of Fast Plants to other scientists. These other scientists discovered different uses for the plants in their research. Today, scientists, students, and teachers are all working with Fast Plants. They are studying how plants grow, and how they produce new generations of plants. Thus the weedy little *Brassica* from Nepal became the great, great…grandmother of the Fast Plants.

Some students will go on to become plant geneticists, molecular biologists, and plant breeders, and they will write the next chapter in the story of Fast Plants.

How do you think it will end?

STEP 2

Overview

All four lessons in this step focus attention on investigating variation and its relationship to environmental factors and heritable traits in a population of Fast Plants. In the first lesson, students work to unravel an explanation for why the teacher's plants that were started in Lesson 1.1 are very different than the students' plants started at the same time. This leads to investigation of various types of data collected by Paul Williams in an experiment about the affect that different amounts of fertilizer had on Fast Plants' growth and development.

In the second lesson, the class designs an investigation to find out if environmental factors change heritable traits. This lesson both introduces students to the difference between inherited and acquired traits and sets the class expectations for experimental design. Students analyze the results of this investigation in Step 5.

In the third lesson, students begin to recognize that the influence of environmental factors has a different type of significance for individuals than for populations of Fast Plants. Understanding the implication of this concept is foundational for students to design an investigation into how an environmental stress could affect variation in reproductive success and future generations of a Fast Plants population.

Lesson 2.4 supports students to pull together everything they have learned in the unit so far to work in small groups and design investigations to test the influence of an environmental factor on the variation of traits in Fast Plants. Students then make and record observations as their plant populations grow over the next two weeks. In Step 5, Lesson 2, they will analyze experimental results and develop explanations for these investigations.

Key Concepts

- Environmental factors are causes of diversity among organisms such as plants
- Scientific explanations are different than description; they include explicit references to causes for effects and establish relationships based on evidence and logical argument.
- Various forms of display for data sets, including box-and-whisker plot (high-low graph), are useful forms to display a single set of data or to compare two sets of data.

Evidence of Student Understanding

The student will be able to:

- compare and contrast similarities and differences among variations of a Fast Plant trait and suggest plausible causes.
- use a variety of resources to collect information and evidence to develop an explanation for why the teacher's plants are smaller and appear less healthy than the students' plants.
- identify and interpret relationships among variables within data sets.

Time Needed

100 minutes

Materials

For each group of 4 students

- 1 quad of Fast Plants grown by the teacher without fertilizer
- their 1 quad of growing Fast Plants

For each pair of students

- 1 copy of Student Page 2.1A *What Happened?*

(continued on following page)

Using Evidence to Explore Similarities and Differences

1. Place quads of student and teacher plants out to be observed, and remind the class of any instances in which students wondered why these plants are different. Pose the question to the class and discuss as a class, ***What do you think caused the differences in some of the traits that we see in my plants and yours?***

2. Have students work in pairs to complete Student Page 2.1A *What Happened?*

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REAPS Questions

R **What is a trait?** A distinguishing feature that can be observed.

E/A ***Note: Graphic organizers on the student pages support students to extend, apply, and analyze their work in this lesson.***

P **What would happen to a species if an environmental stress was introduced that was so severe that NO individuals in the population could produce offspring (seeds or babies)?** The population would go extinct if the stress continued for more than a generation.

S **What did you do during this lesson that helped you to understand how the environment affects the plants growing in that environment?** Look for students to recognize some aspect of the lesson that helped their learning. Use this information to use the best strategies in future lessons.

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- 1 copy of Student Page 2.1C *Observing Differences and Similarities*

For each student

- 1 copy of Student Page 2.1B *Paul's Growing Protocols for Populations A and B*
- 1 copy of Student Page 2.1D *Paul's Data: Pressed Plants*
- 1 copy of Student Page 2.1E *Paul's Data: Graphical Data*
- 1 copy of Student Page 2.1F *Paul's Data: Data Tables*

3. Review the question the class is addressing. Collect students' brainstormed ideas and questions.

- Organize the ideas while recording them on the board during the brainstorm so that **questions**, **observations**, and **possible causes** are kept as separate lists.

4. In the list of observations, point out that what the class is observing are differences between the students' and teacher's plant populations.

- During this discussion, check for students' understanding of the terms *trait* and *variation*.
- Circle on the board any observations that are examples of variation.

5. Guide the whole class to identify those suggested causes that are environmental factors.

- Emphasize that the amount of fertilizer available in the planting mix is an environmental factor, and wonder aloud if you forgot the fertilizer.

6. Explain how more evidence would strengthen any explanation that the class suggested, and offer data from an experiment that Paul did.

- Comparing Paul's data with a known environmental stress may help.
- Hand out Student Page 2.1C *Paul's Growing Protocols for Populations A and B*, and have students find and discuss the experimental variable.

7. Introduce each of the 3 sets of data from Paul's experience. Guide pairs of students to analyze and compare it to class observations.

8. Have students work in pairs to complete Student Page 2.1C *Observing Differences and Similarities* based on the class's and Paul's data.

9. Summarize the status of the class's explanation for what happened to the teacher's plants, and emphasize the importance of evidence and reasoning to make it as strong as possible.

10. Use the REAPS questions throughout the lesson where appropriate.

Teacher Background Information

This lesson is built on letting students compare the class experiment that you began in Step 1, Lesson 1 (without disclosing what you were doing) to a similar experiment conducted by Paul Williams. By allowing students to unravel the mystery about the difference between your plants and theirs, this lesson allows for important practice with using evidence and many different types of data to support a hypothesis (about what happened to cause the difference).

In Paul's experiment, two crops of Fast Plants were grown. Population B was grown under an optimal growth environment for Fast Plants. In Population A, Paul introduced a single environmental variable by providing no nutrients (fertilizer).

In his experimental procedure, individual plants in each population of 12 plants were numbered and observed, and selected traits representing growth (height), development (# of leaves, # of hairs) and reproduction (# of flowers pollinated and # of seeds produced) were measured and recorded. After summarizing and graphing the data collected, Paul was able to determine the degree that the various parts of the growing plant are affected by the nutrient deprived environment.

Advance Preparation

There are six types of student pages for this activity that need to be photocopied in advance. If possible, Student Page 2.1D *Paul's Data: Pressed Plants* and Student Page 2.1E *Paul's Data: Graphical Data* are best viewed in color. You may want to make and laminate a class set of color copies so they can be used repeatedly.

Implementation Guide

Note: You have a chance to do some acting in this lesson when you pretend not to know why the Fast Plants that you planted two weeks ago look different from the students' plants.

Allow 5–10 minutes for students to make observations and notebook entries.

1. Prompt students to notice differences between Fast Plants by placing all 8 quads of the teacher and students' Fast Plants next to each other. By now, the students' Fast Plants will be considerably taller and more robust than the teacher's plants, which did not receive fertilizer.

Pose the question: ***What do you think caused the differences in some of the traits that we see in my plants and yours?*** Allow a few minutes for students to comment on and raise questions about the differences between the two groups of plants. Collect student responses but resist going further with discussing causes for now.

2. Have students work in pairs to complete Student Page 2.1 *What Happened?* Circulate around the room, and observe what students write to confirm that all students understand what the "mystery" or question is.

3. Repeat the question and have students brainstorm ideas and questions: "What do you think caused the differences we see between my plants and yours?"

Organize student responses into three separate categories on the board: Keep the three categories separate:

- questions
- observations
- possible causes of differences

Collect and record students' brainstormed ideas and questions under the appropriate headings. For example: under possible causes: write "too little water." Under observations, write "one plant is taller than the other?" Under questions, write "why is my plant taller than the teacher's plant?"

4. During this discussion, check for students' understanding of the terms *trait* and *variation*.

Trait: A distinguishing feature that can be observed; discuss when differences can be called variations.

Variation: A difference in two or more versions of a particular trait.

Explain to students that the differences in height between the teacher's and students' Fast Plants are examples of variation. Point out how the different variation of heights within a population of plants is much like the variation of heights between the students in the class,

Have students point out and circle examples of variation listed under observations.

Note: Many students may be familiar with the term diversity. You may want to use a Think-Pair-Share for students to come up with explanations of how the meaning of "variation" differs from "diversity" and "differences."

- Diversity is being made of many different elements, forms, kinds, or individuals
- Difference is to be unlike or dissimilar
- Variation is the presence of two or more versions of the same trait such as different versions of height.

(*Population will be defined later in the unit when it is a more central focus.*)

5. Guide students to look at the list of possible causes and highlight those that are environmental factors.

Tell students that you wish you had kept notes during the first day you planted the Fast Plants seeds so you would know what environmental factor influenced how your plants developed.

Wonder aloud if you left out an environmental factor such as fertilizer. Point out that fertilizer is both an environmental factor and an

environmental stress because by using it or leaving it out, we influence how plants grow and develop.

6. Explain how more evidence would strengthen any explanation that the class suggested, and offer data from an experiment that Paul did to investigate an environmental variable and its affect on Fast Plants' growth and development.

- Explain how comparing Paul's data with a known environmental stress may help. **NOTE: Let students figure out what the environmental stress in Paul's experiment was to help prepare them to design their own single-variable experiment.**
- Point out that one way scientists extend their data, is to compare data with data that other scientists collected when doing the same investigation. Explain that, similarly, Paul Williams' data can be a source for extending the class's data.
- Hand out Student Page 2.1C *Paul's Growing Protocols for Populations A and B*, and have students find and discuss the experimental variable.
- Students will quickly find that the variable was whether the populations received fertilizer or not. The environmental stress tested was the absence of nutrients (fertilizer).

7. Explain to students that they will compare their Fast Plant records with the actual records that Paul Williams kept when he investigated Fast Plants. Introduce students to the three kinds of evidence that Paul Williams used to analyze the evidence he collected.

- Press plants: photo copies of the plants he grew in the investigation.
- Raw data: the data that Paul Williams recorded in his notebook during the investigation.
- Graphs – special graphs called box-and-whisker (high-low) graphs that show the variation of a trait among the plants in each population.

Explain that students will compare their records with each kind of evidence Paul Williams used. Organize students in pairs, and work as a class to compare one type of data at a time so that students are not overwhelmed.

Compare Paul Williams' pressed plants; then compare Paul Williams' raw data

Pass out copies of the data set (first pressed plants, then raw data) to each student. Explain to students that these are photocopies of the two populations of plants that Paul Williams used in his investigation. Then follow these steps to compare data:

- Direct individual students to analyze and compare Paul Williams' pressed plants with observations from their own Fast Plants.
- Have individual students write down one key observation and one question in their notebooks.
- Next, have students discuss their observations and questions with their partners.
- Engage the entire class in a discussion of similarities and differences between students' plants and Paul Williams pressed plants.
- Practice linking evidence to inferences with sound reasoning to consider if Paul's data supports any of the explanations that were brainstormed about why the teacher's and class' plants are different.

Compare Paul Williams' graphed data

Pass out copies of Paul Williams' graphs to each student. Then, use a Think Aloud to help students interpret Paul Williams whisker graphs.

- Explain that you want to be sure that you understand what a whisker graph is and

how Paul Williams plotted his data on the graphs. Otherwise you may not know where to plot your own data.

- Talk about what Paul Williams' whisker graph is showing—the range of heights of his plants. This means that each short horizontal line represents the height of one or more of his plants. And the dark line is the mean height. That means that half of all of his plants were this height or taller and half were this height or shorter than this height.
- Explain that you wonder how you can use his graph to compare your plants with his. You wonder if you could add your plants to the same graph to see how the points compare. You decide to indicate the height of each of your plants next to the same height marker on the graph, so you show the measurements for the teacher's plant heights and mark a line on the graph for each plant.
- Next, you wonder what you will compare. Maybe you could compare different features, such as whose plants have the greatest difference between the tallest and shortest plants. Or which has the highest and which has the lowest mean.

After the Think Aloud:

- Instruct individual students to use colored pens, pencils or markers to add their data into Paul Williams' graphs.
- Have individual students analyze and compare the pattern of plants on Paul Williams' graphs with their own Fast Plants data.
- Have individual students write down one key observation and one question in their notebooks.
- Next, have students discuss their observations and questions with their partners.
- Engage the entire class in a discussion of similarities and differences between students' plants and Paul Williams' pressed plants.
- Practice linking evidence to inferences with sound reasoning to consider if Paul's data supports any of the explanations that were brainstormed for why the teacher's and class's plants are different.

8. Have students work in pairs to complete Student Page 2.1 C. *Observing Differences and Similarities* based on the class's and Paul's data.

9. Summarize the status of the class' explanation for what happened to the teacher's plants, and emphasize the importance of evidence and reasoning to make it as strong as possible. Have students explain whether they have the evidence they need to support an explanation.

Explain that the class cannot be certain of what happened to the teacher's plants unless a chemical analysis is done to see if there is any fertilizer in the soil the teacher's plants are growing in. However, there is still strong evidence to support the explanation that the teacher left out fertilizer because these observations and Paul Williams' observations of Fast Plants raised without fertilizer are similar.

10. Use REAPS questions throughout the lesson where appropriate.

Student Page 2.1A: What Happened?

Questions *Choose 2 or 3 "W" words to begin questions you have or heard about what happened.*	**Who** **What** **Where** **When** **Why** **How**

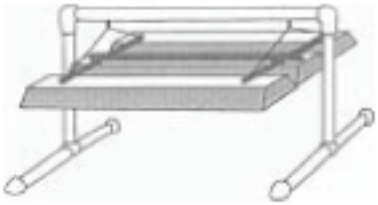
Observations that caused the questions to be asked	***What we noticed*** **1.** **2.** **3.**	***What we wondered*** **1.** **2.** **3.**

Results: What we did or are doing to answer our questions	

Fast Plants Planting Protocol for Population A

Fast Plants (*Brassica rapa*) are fast-growing plants that are related to crucifers (plants in the mustard family, such as broccoli, cabbage, and turnips). Fast Plants complete an entire life (from seed through flowering to seed production) cycle in 40-45 days.

All materials for protocol are provided in kits.



Plant Light Bank

1. Continuous Fluorescent Light

- **Fluorescent lights should be on 24 hours a day.**
- **Construct or assemble the light system** according to the instructions, then plug it in and leave it on, 24 hours a day.

2. Preparing to plant

- Place a wet wick through the hole in the bottom of each quad section
- Fill each section of the quad full with potting mix.
- Water the quad thoroughly, soaking the potting mix throughout.

Quad with wicks

3. Planting the seeds

- In each section of the quad, place 1-2 seeds on top of the potting mix and cover lightly with soil.
- In 2-3 days, after the seedlings have emerged, thin the number of plants to 1 plant per section.

4. Continuous Water

- Place the Fast Plant quads on the self-watering system to keep the plants watered continuously.

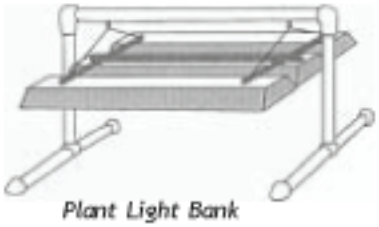
5. Place under lights

- Keep top of plants as they emerge 10 -15 cm below the light source
- Optimal room temperature: 65-83°F (18-28°C)

Fast Plants Planting Protocol for Population B

Fast Plants (*Brassica rapa*) are fast-growing plants that are related to crucifers (plants in the mustard family, such as broccoli, cabbage, and turnips). Fast Plants complete an entire life (from seed through flowering to seed production) cycle in 40-45 days.

All materials for protocol are provided in kits.



Plant Light Bank

1. Continuous Fluorescent Light

- **Fluorescent lights should be on 24 hours a day.**
- **Construct or assemble the light system** according to the instructions, then plug it in and leave it on, 24 hours a day.

2. Preparing to Plant

Quad with wicks

- Place a wet wick through the hole in the bottom of each quad section
- Fill each section of the quad half-full with potting mix.
- Place 6 fertilizer pellets in each quad section and cover with potting mix, filling each quad to nearly the top.
- Water the quad thoroughly, soaking the potting mix throughout.

3. Planting the seeds

- In each section of the quad, place 1-2 seeds on top of the potting mix and cover lightly with soil.
- In 2-3 days, after the seedlings have emerged, thin the number of plants to 1 plant per section.

4. Continuous Water

- Place the Fast Plant quads on the self-watering system to keep the plants watered continuously.

5. Place under lights

- Keep top of plants as they emerge 10 -15 cm below the light source
- Optimal room temperature: 65-83°F (18-28°C)

Student Page 2.1C: Observing Differences and Similarities

Interesting trait that you observed	List of at least 3 different variations in the trait that we observed	List at least 3 similarities you see among the variations of this trait?	What you think may have caused the variations you observed	What evidence do you have to support your ideas about what caused the variations you observed?
	1. 2. 3.	1. 2. 3.		
	1. 2. 3.	1. 2. 3.		
	1. 2. 3.	1. 2. 3.		

☆ **Which of the traits that you observed might affect how many seeds a Fast Plant produces? Explain your reasoning.**

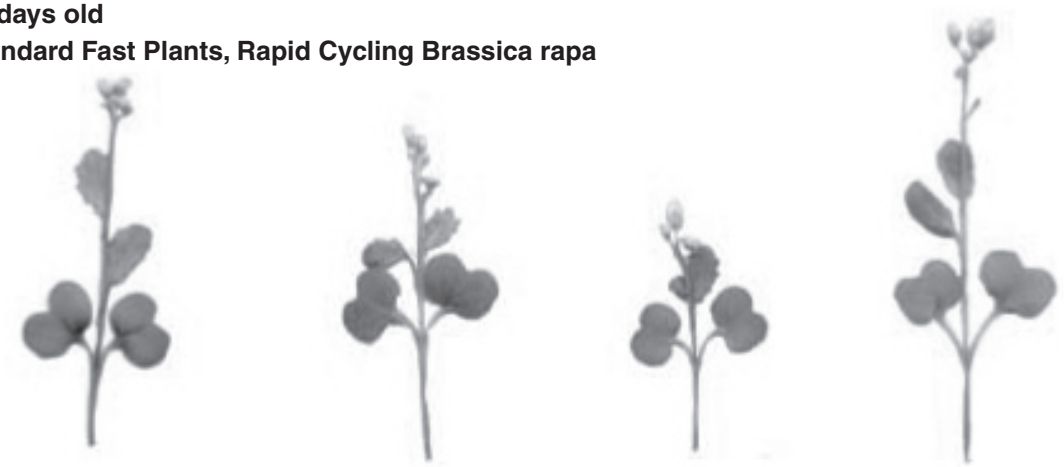
Student Page 2.1D: Paul's Data – Pressed Plants

Population A
7 days old
Standard Fast Plants, Rapid Cycling Brassica rapa

Population B
7 days old
Standard Fast Plants, Rapid Cycling Brassica rapa

Student Page 2.1D: Paul's Data – Pressed Plants (continued)

Population A
13 days old
Standard Fast Plants, Rapid Cycling Brassica rapa



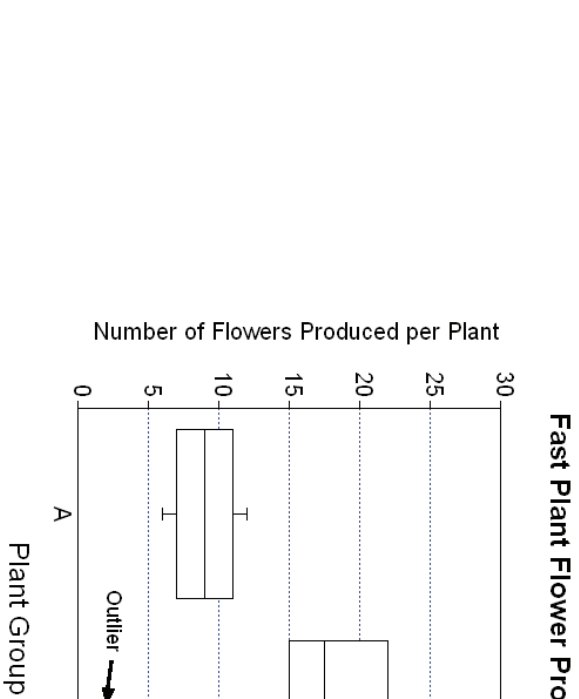
Population B
13 days old
Standard Fast Plants, Rapid Cycling Brassica rapa

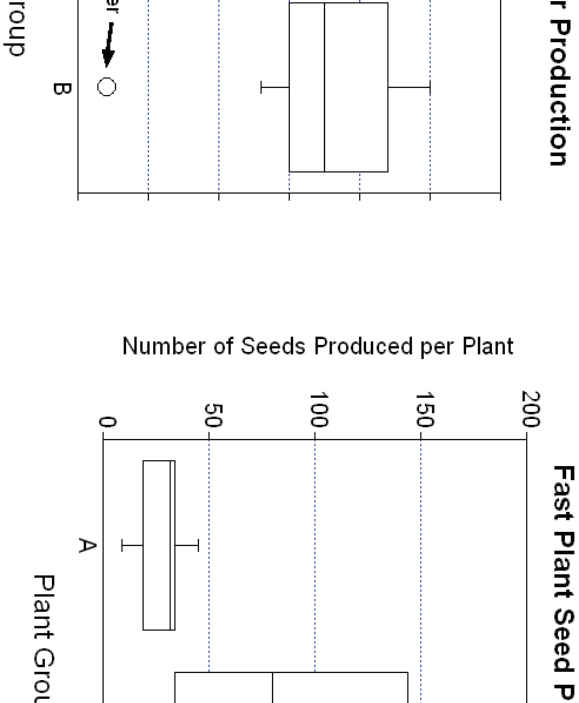
Student Page 2.1D: Paul's Data – Pressed Plants (continued)

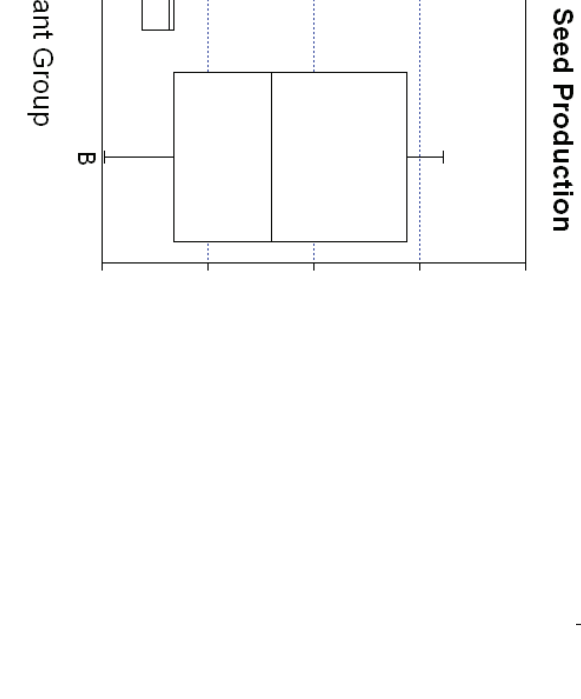
Population B
22 days old
Standard Fast Plants, Rapid Cycling Brassica rapa

Population A
22 days old
Standard Fast Plants, Rapid Cycling Brassica rapa

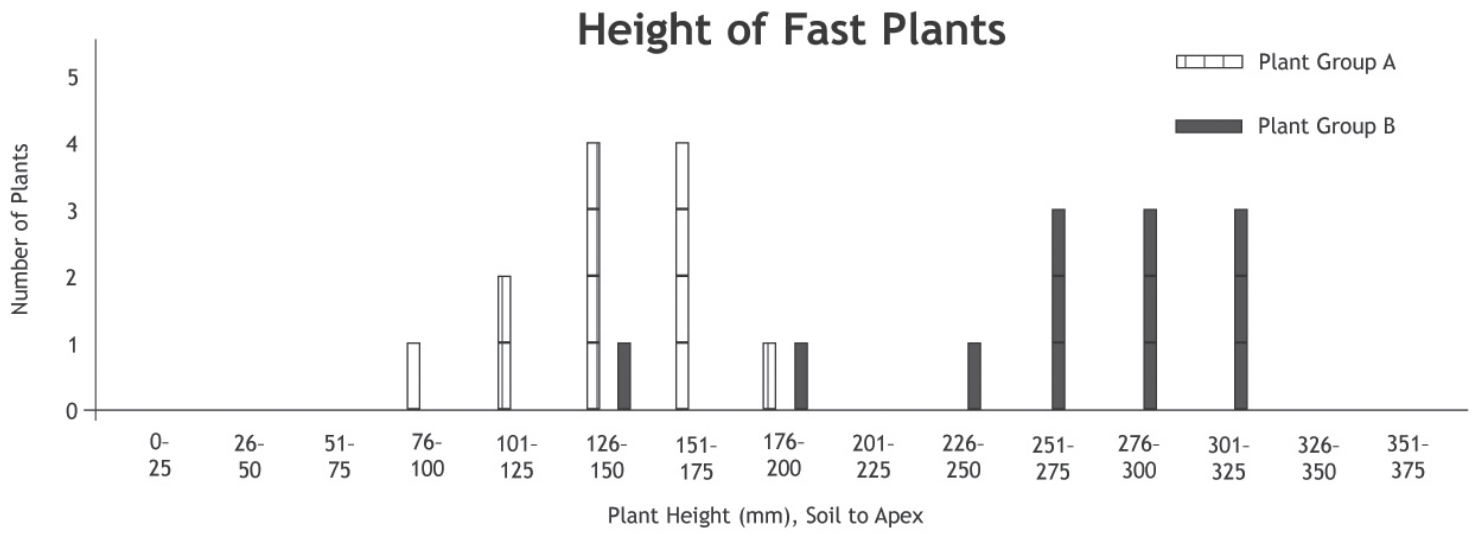
Student Page 2.1E: Paul's Data – Graphical Data

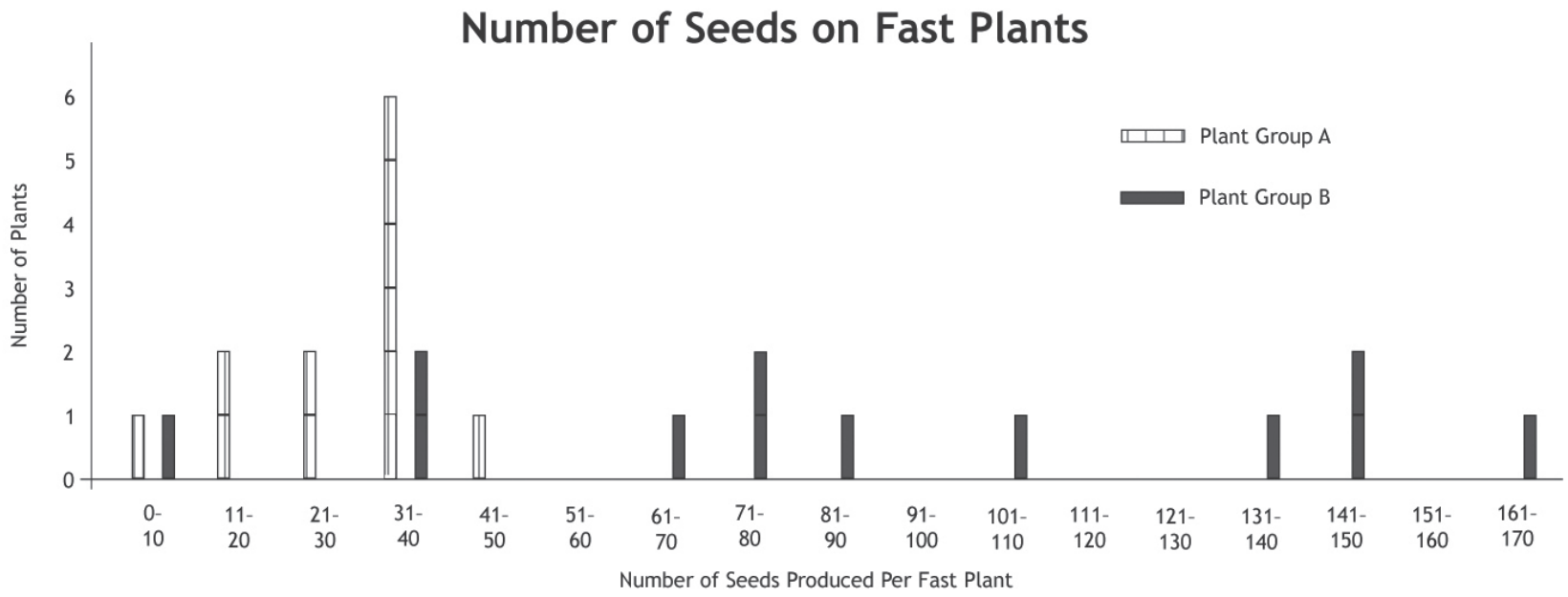






Student Page 2.1E: Paul's Data – Graphical Data (continued)





Student Page 2.1F: Paul's Data – Data Tables

Population A
Your Name: Paul Williams Today's Date: 12/8/99
Date of Sowing: 10/23/99
Plant Variety: Standard Fast Plants, rapid cycling *Brassica rapa*

Plant #	Plant Trait Measured: Height (mm)	# of Leaves on Stem	Hairs on 1st Leaf	Flowers Pollinated	Seeds Produced
1	109	6	7	9	16
2	162	6	19	12	33
3	156	6	30	7	34
4	166	6	7	10	40
5	129	6	1	10	31
6	90	6	11	7	19
7	139	6	15	7	33
8	148	6	19	9	27
9	178	7	13	11	9
10	146	6	8	12	45
11	154	5	13	9	24
12	112	7	14	6	32

Population B
Your Name: Paul Williams Today's Date: 12/8/99
Date of Sowing: 10/23/99
Plant Variety: Standard Fast Plants, rapid cycling *Brassica rapa*

Plant #	Plant Trait Measured: Height (mm)	# of Leaves on Stem	Hairs on 1st Leaf	Flowers Pollinated	Seeds Produced
1	308	6	15	18	72
2	278	6	21	18	83
3	290	5	38	15	34
4	267	6	55	25	108
5	229	7	18	15	140
6	138	6	21	2	1
7	200	6	2	13	61
8	304	6	0	17	32
9	312	5	1	22	148
10	276	6	2	22	161
11	262	7	4	17	144
12	265	6	6	21	77

Summary Table
Your Name: Paul Williams Today's Date: 12/8/99
Date of Sowing: 10/23/99
Plant Variety: Standard Fast Plants, rapid cycling *Brassica rapa*

n = number of plants measured or counted
x = average measure or count (sum of measurements or counts/n)
r = range of variation (highest measure or count - lowest measure or count)

Plant Trait Measured	Population A: n	x	r		Population B: n	x	r	
Height (mm)	12	141	88		12	261	174	
# Leaves on Stem	12	6.1	2		12	6.0	2	
Hairs on 1st Leaf	12	13	29		12	15	55	
Flowers Pollinated	12	9	6		12	17	23	
Seeds Produced	12	29	36		12	88	160	

Key Concepts

- Environmental factors are not the only causes of diversity among organisms such as plants; some traits are inherited and others result from interactions with the environment.
- Every organism requires a set of instructions for specifying its traits. Heredity is the passage of these instructions from one generation to another.
- Scientific investigations may take many different forms, including observing what things are like or what is happening and doing experiments.

Evidence of Student Understanding

The student will be able to:

- complete a sequence of events chart to describe the experimental process and purpose.
- explain a Venn diagram depicting how heredity and environmental factors together cause the traits we observe in organisms.

Time Needed

50 minutes to begin the investigation;

24–26 days until evidence from offspring is collected (see Unit Timeline)

Materials

For the class

- overhead transparency or large chart of Teacher Page 2.2c *Unit Level Graphic Organizer*

(continued on following page)

Investigating Variation: Environmental Factors and Heritable Traits

1. Introduce the *Unit Level Graphic Organizer*. Explain to students that in Lesson 2, they will:

- work together as a class to plan a well-designed scientific investigation about a Fast Plant trait and inheritance.

2. Pose the question from Lesson 2.1 to the class: **Other than environmental factors, what determines how an organism such as a plant or human looks?**

- Guide a class discussion to focus students' attention on both environment and heredity as factors that determine traits
- Check for students' understanding that a ***trait is a distinguishing feature that can be observed***.

3. Have students work in pairs to complete Student Page 2.2A *Venn Diagram of Traits*.

- Use student diagrams to reemphasize that both heredity and environment influence the traits we see.

(continued on following page)

REAPS Questions

R **What is an inherited trait?** A distinguishing, observable feature.

E/A/P ***Note: Graphic organizers on the student pages support students to extend, apply, and analyze their work in this lesson as well as to predict the experimental outcome.***

S **What did you do during this lesson that was like what a scientist does?** Look for students to recognize that asking questions, designing experiments, using logic and reasoning, and organizing their ideas are all work like scientists do.

(continued from previous page)

- 1 copy of Teacher Page 2.2d *Fast Plants Pollination Protocol*
- 1 copy of Teacher Page 2.2e *Leafless Experiment Calendar*
- two quads of growing Fast Plants
- scissors

For each pair of students

- 1 copy of Student Page 2.2A *Venn Diagram of Traits*

For each student

- 1 copy of Student Page 2.2B *Experimental Sequence*

4. Ask students: If we made a new trait—leaflessness—by clipping the leaves from Fast Plants, would the plants' offspring inherit the leafless trait?

- Focus both on the question AND on discussing how a scientific experiment can be designed to answer this question.

5. Use Think-Pair-Share strategy for students to fill out Student Page 2.2B *Experimental Sequence* to guide students to think, discuss and record the thinking processes involved in asking a scientifically-oriented question, predicting the answer, and designing an experiment to gather evidence.

- Remind students that they will design their own experiments soon so they need to understand how the class designs this experiment.

6. Use a Think Aloud strategy to highlight the key points to consider when designing an experiment. Emphasize the logic and reasoning that go into planning and carrying out an experiment.

- Engage the students as a whole class throughout the Think Aloud to help you design the investigation to answer the question about inheriting leaflessness, *If we made a new trait—leaflessness—by clipping the leaves off of a Fast Plant, would the leafless plant's offspring inherit the leaflessness trait?*

- Have students work in pairs to complete Student Page 2.2B *Planning an Experiment to Answer a Question* as needed.

7. Conduct the experiment as designed by the class as a demonstration. Finish up by assigning students in pairs to work every-other-day to tend to the experimental and control plants (see the Implementation Guide).

8. Use the REAPS questions throughout the lesson where appropriate.

Advance Preparation

Teacher Page 2.2e *Leafless Experiment Calendar* provides a timeline for the simple procedures you will need to either complete yourself or assign students to complete during a few minutes of class time periodically (when you will model how to develop an evidence-based explanation for the results from this investigation).

Keep in mind that the plants in this investigation need to produce seeds, so it will be necessary to pollinate them. The procedure for pollinating Fast Plants is included in the Teacher Page 2.2d *Fast Plants Pollination Protocol*.

For this lesson, also prepare materials and a simple outline of key reasoning that you will model during the Think Aloud to teach students about high quality scientific experimental design. This will prepare students to design their own experiment, investigating the affect of an environmental stress on variation in reproductive success (flowering/seed production) in Fast Plants.

Also, consider looking for insights into what students are already thinking about how heredity and environmental factors influence how traits are expressed by reading what students wrote on Student Page 2.1C *Observing Differences and Similarities*. Prepare instruction accordingly.

In this lesson, you have the option to have students work on a Venn Diagram on chart paper, an overhead transparency, or individual copies for students to keep in their science notebooks (or a combination). Students will use graphic organizers from this point on to develop a visual understanding of natural selection. In this lesson, students will use a graphic organizer (Venn Diagram) to view how

- traits are determined by genetics or environmental stresses or both
- acquired traits are not inherited

Implementation Guide

1. Introduce students to the Unit Level Graphic Organizer and compare it to how scientists use graphs, tables and other visual tools to help them visualize what is happening. Instruct students to keep the Unit Level Graphic Organizer in the back of their notebooks, where they can pull it out each time they need it.

Tell students that in this lesson, they will:

- work together as a class to plan a well-designed scientific investigation about a Fast Plant trait and inheritance.

Bring the class back to thinking about variation in different traits by asking students to point out examples of variation in traits of living things they see around the classroom and from Paul Williams' investigations. List the examples on the board. Then invite students to work together to reflect on:

- what they already know about variation.
- questions students may have about variations in traits.

The Unit Level Graphic Organizer entry at this point may look something like the chart below.

2. Pose the question: **Other than environmental factors, what determines how any organism, such as a plant or human, looks?** Make sure that students understand the terms:

- **environmental factor** – any living or nonliving feature of an organism's surroundings and experiences, such as diet and air temperature. This can include anything from the fertilizer that the students added to the soil to the temperature of the soil.
- **environmental stresses** – All environmental stresses are environmental factors, but not all environmental factors are environmental stresses. Environmental stresses and other environmental factors are also possible causes for the variation between plants.
- **trait** – A distinguishing feature that can be observed.

Allow a few minutes for students to engage in a discussion about what determines the traits we observe (appearance). Encourage students to apply the question to specific traits, such as "Other than environmental factors, what determines how tall a person is, or the color of a flower?

As students propose answers, ask them for evidence supporting their suggestion. Ask questions such as "*How* do you know that?" As the discussion progresses, guide the class to focus on how both environment and heredity determine the traits we see.

3. Direct students to work in pairs to complete Student Page 2.2A *Venn Diagram of Traits*. Have students choose traits from the class's and Paul's experiments to fill in the diagram.

What We Did	What We Know	How We Know It
We used Paul's data and our own observations to try to figure out why the teacher's and students' plants are so different.	We know that plants like those in Paul's experiment that don't receive any fertilizer look similar to the teacher's plants. The teacher might have forgotten to add fertilizer.	We compared all of Paul's experimental observations and graphs to our class's observations, and our evidence aligns. The teacher said that because we didn't keep a science notebook on the first day, there is no record that fertilizer was added for sure.

When they finish the diagrams, ask students to share traits listed in the overlapping parts of their diagrams.

- Point out to students that by listing traits in the overlapping part of the diagram, they are suggesting that both heredity and environment influence these traits.

4. Ask students: ***If we made a new trait—leaflessness—by clipping the leaves off of a Fast Plant, would the leafless plant's offspring inherit the leaflessness trait?*** Allow a few minutes to clarify and discuss the question. Accept student responses, but resist the temptation to reach an answer; an explanation can be made about the question after the experimental evidence is gathered.

- If students seem sure that the leafless trait cannot be inherited, ask, "How do you know?" Emphasize the need for evidence when answering scientifically.
- Focus discussion on both the question AND on discussing how a scientific experiment can be designed to answer this question.

5. Use a Think-Pair-Share strategy for students to complete the first two entries (question and prediction) in Student Page 2.2B *Experimental Sequence*. The goal of this step is to guide students to think about and record the thinking processes involved in

- asking a scientifically-oriented question,
- predicting the answer.

Remind students that they will design their own experiments in one of the next lessons so they need to understand how the class designs this experiment to know what will be expected.

See the Immersion Unit Toolbox section, *Giving Priority to Evidence—When there is an Experiment* for general information about designing an investigation.

6. Use the Think Aloud strategy to highlight the key points of designing an experiment.

- Emphasize the logic and reasoning that goes into planning and carrying out an experiment.
- After the Think Aloud is completed, provide time for students to record their ideas in the Student Page 2.2B *Experimental Sequence.*

The following paragraphs provide an example of how a Think Aloud may look in this specific investigation.

- I am wondering if I could develop a Fast Plant that grows without leaves. How could I set up an investigation to try? If we made a new trait—leaflessness—by clipping the leaves off of Fast Plants, would the leafless plants' offspring inherit the leaflessness trait? To test this idea I was thinking that I could create two leafless plants by cutting their leaves off, then breed them to see if their offspring would or would not have leaves.
- I think that this experiment could work because the only factor I would change in this experiment is whether I do or do not cut off leaves. When designing an experiment it is always important to know that if a difference occurs in an investigation, the investigator will know what caused it. As much as possible, scientists keep their experiments simple, which makes it easier to make strong evidence-based explanations.
- The results I am looking for are also simple. The offspring will either be leafless or have leaves. To design the experiment, I need to plan the procedure—how I will conduct this investigation. Sometimes it's easiest if I try to imagine what each step will look like. I know that I need to:
  - cut the leaves off of two parent plants,
  - breed the parent plants with each other,
  - then take the seed that develop from the parent plants

- and plant them to see if their offspring would or would not have leaves.

- I also need to plan for a "control" in my experiment. Does anyone know what is meant by a control? In this case, I need to have plants that I do not perform our experimental procedure on—I need to have two plants that don't get their leaves snipped off and are pollinated and grown to produce seed just like those that we are experimenting with. What else will I need to keep the same between the experimental and control plants during the procedure?

- I'm thinking that I want to be sure that the environmental conditions are just the same as I dry, harvest, and plant seeds for the next generation. If there was a difference in the environment, then that could be the cause of any differences I might observe between the offspring. I want to be as sure as I can that any differences I see in the offspring are caused by having snipped the leaves off the experimental plants.

- Now that I have a design for my experiment, there are several things I need to do before getting started. I need to write down my experimental procedure so that I can follow it carefully and plan what materials I need. Then I need to gather them. I also need to set up a schedule for when I will do each step in the investigation.

See the ***Immersion Unit Toolbox*** section, Supporting Student Inquiry: The *Think Aloud Strategy* section for general information and a description of the characteristics of the Think Aloud strategy.

- Engage the students as a whole class throughout the Think Aloud to help you design the investigation to answer the question about inheriting leaflessness, *If we made a new trait—leaflessness—by clipping the leaves off of a Fast Plant, would the leafless plant's offspring inherit the leaflessness trait?*

7. Conduct the experiment as designed by the class (as a demonstration), while you continue explaining your thought processes using the Think Aloud strategy.

Explain that during the next five weeks the two leafless experimental plants and the two plants with leaves that are the control will flower, be pollinated, produce seed, and then the seed will be harvested and planted.

Finish up by assigning students in pairs to work every other day to tend to the experimental and control plants. Refer to Teacher Page 2.2e *Leafless Experiment Calendar* for approximate dates for the following procedures.

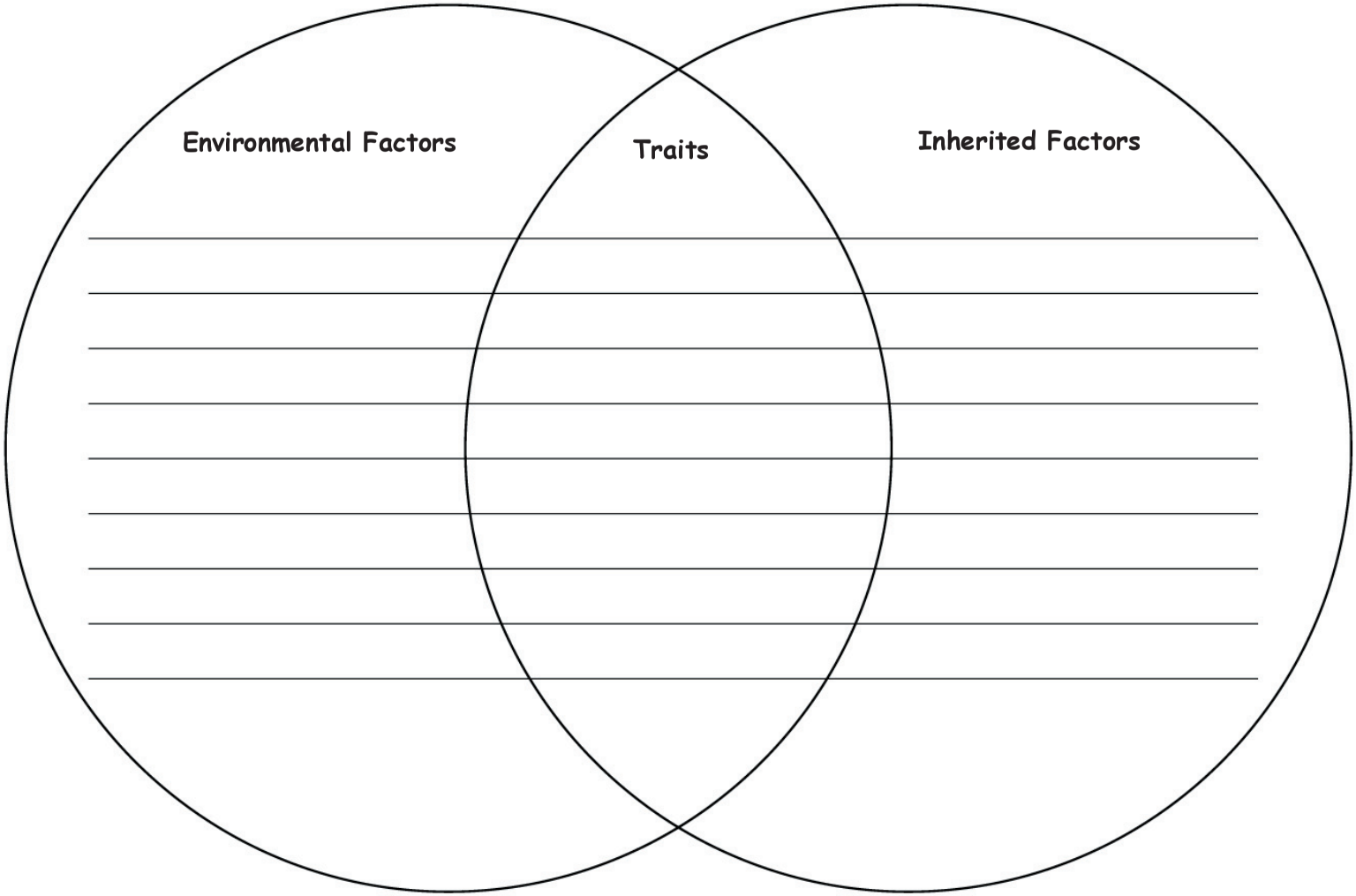
NOTE: After Step 3, when students learn about flowers and pollination, only these experimental plants and the controls will continue to be grown. The others will be discarded to make room for the students' investigations.

- Taking measurements and recording observations (every other day for a few minutes from this point forward)
- Pollinating the plants
- Taking the plants off water to let the seed pods dry
- Harvesting the seeds
- Planting the next generation (one quad with seeds from the experimental parent plants and one from the control parent plants)
- Taking measurements and recording observations of the next generation (the investigation ends in Step 5, Lesson 1, when the class develops an explanation for the results)

8. Use the REAPS questions throughout the lesson where appropriate.

Student Page 2.2A: Venn Diagram of Traits

Some Traits are Inherited and Others Result From Interactions With the Environment



Student Page 2.2B: Experimental Sequence

Planning an Experiment to Answer a Question

Question we hope to answer with evidence from this experiment:

First Step: What key decisions need to be made to plan the experiment?

What do you think the explanation for what will happen is? Why do you think that?

Second Step: What careful steps need to be taken to set up the experiment?

What are the next key steps that will take place?

What are results are we looking for?

Teacher Page 2.2c: Unit Level Graphic Organizer

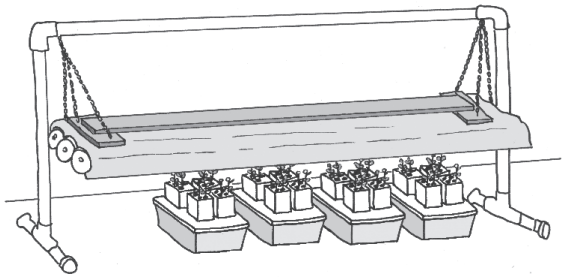
What we did	What we know	How we know it

Teacher Page 2.2d: Fast Plants Pollination Protocol

Wisconsin Fast Plant Pollination Protocol

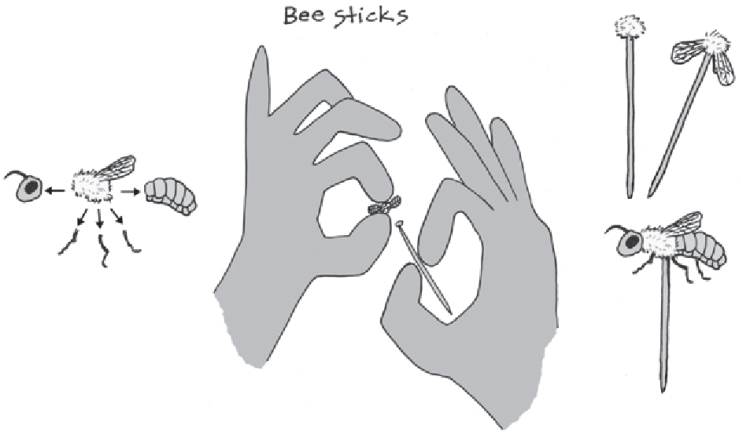
On Days 5–12, Tend the plants

- Refill water reservoirs.
- Adjust the lights every other day so the top of the plants is about 10 cm from the light.



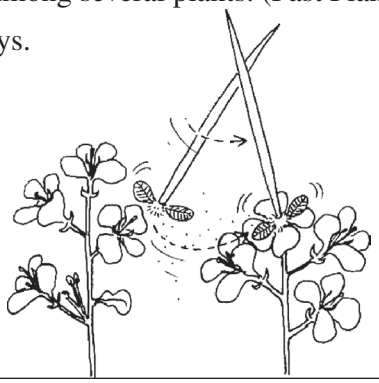
On Day 13, Make beesticks

- Insert the end of the toothpick with the glue into the spot on the thorax were the head was located.



On Days 15–17, Pollinate flowers

- Roll the beesticks over the flowers (anthers) to pick up and deliver the pollen to the stigma. Transfer pollen back and forth among several plants. (Fast Plants do not self-pollinate.)
- Pollinate the flowers for 2–3 days.



Teacher Page 2.2e: Leafless Experiment Calendar

Fast Plants: Will leafless parents produce leafless offspring?

Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*
	1 Step 1, Lesson 1 Teacher Plant [Plant]	2 Step 1, Lesson 2	3 Step 1, Lesson 3 Science Notebooks [Observations]	4 Step 1, Lesson 4 [Observations]	5 Step 1, Lesson 5 [Observations]	
	8 Step 2, Lesson 1a [Observations]	9 Step 2, Lesson 1b [Observations]	10 Step 2, Lesson 1c	11 **Step 2, Lesson 2** **[Cut leaves]**	12 Step 2, Lesson 3	**PREP** **Prepare for pollination**
	15 Step 2, Lesson 4a(1)	16 Step 2, Lesson 4a(2) [Step 2, Lesson 4b is continued after Step 3 in order to have students plant on a Monday]	17 Step 3, Lesson 1a **Step 2, Lesson 2 – Pollinate**	18 Step 3, Lesson 1b	19	**PREP** Remind students to bring supplies for their own experiments
	22 Step 2, Lesson 4b [Students' Experiments]	23 [Observations]	24 [Observations]	25 [Observations]	26 [Observations]	
	29 [Observations]	30 [Observations]	31 [Observations]	32 [Observations]	33 [Observations]	
	36 Step 4, Lesson 1a **Step 2, Lesson 2 – take plants off water** [Observations]	37 Step 4, Lesson 2a [Observations]	38 Step 4, Lesson 2b [Observations]	39 Step 4, Lesson 2c	40 ***Step 2, Lesson 2 – Harvest and plant seeds** [Last Observations]	*(40) Teacher could replant and harvest on side
	43	44 Step 5, Lesson 1	45 Step 5, Lesson 2a	46 Step 5, Lesson 2b	47 Step 5, Lesson 2c	
	50 Step 6, Lesson 1	51 Step 6, Lesson 2				

Key Concepts

- Individuals can be described by their characteristics, or traits.
- Populations can be described by numerical data describing the traits that exist in the population.
- Scientific observations include both things that can be measured and things that cannot.

Evidence of Student Understanding

The student will be able to:

- explain the differences and similarities between effectively describing a single plant and a population of plants.

Time Needed

50 minutes

Materials

For each student

- copy of Paul's Experimental Data from Step 2, Lesson 1
- copy of Student Page 2.3A *Individual Plant and Plant Population Observations*

For each group of 2–3 students

- copy of Student Page 2.3B *Frayer Model on Population (can be on chart paper)*

For each group of 4 students

- quad of Fast Plants

Describing Populations

1. Ask the whole class to think of examples over the last two weeks in which the observations focused on individual plants. Collect examples.

2. Next, ask the class for examples in which the observations focused on a group of plants. Collect examples.

3. Use a Think-Pair-Share strategy to have students explain to the best of their knowledge when a group of plants would be called a population.

- After gathering their ideas, acknowledge similarities with the scientific definition for a population in ecology and provide that definition. **Population: a group of individuals of the same species living in together in the same habitat**

(continued on following page)

REAPS Questions

R **What is a population?** A population is a group of individuals of the same species that are able to interact in a particular area.

E **How is observing and describing a population different from observing and describing an individual?** Individuals are typically described by their specific traits. Populations, on the other hand, are typically described by the mean occurrence of specific traits.

A **Which of the two Fast Plant populations showed the most differences among individuals?** Based on the Paul Williams data, the population grown with fertilizer showed the most variation among individuals.

P **Would you predict that there would be more or less difference among individuals in a population if all environmental conditions were good than if one condition was poor?** Explain your reasoning. Answers will vary, and the important part of this response is the explanation—push students to use logic and sound reasoning to support their prediction.

- Continue the discussion to help students think of characteristics for a population.

4. Have students work individually or in pairs to complete the Student Page 2.3A *Individual Plant and Plant Population Observations*.

5. Direct students to share their responses with at least one other pair of students to look for patterns in how individual plants were described and plant populations were described.

6. Hold a whole-class discussion about patterns in the descriptions. Emphasize the usefulness of describing populations with means, particularly when there are many individuals in the population.

7. Remind students that at the beginning of the lesson you defined what a population is and how during the rest of this unit most of the focus will be on how populations change over generations. For that reason, it is important for all students to help each other be clear what is meant by population.

- Group students in pairs or threes, and have each group complete a population Frayer Model.

8. Discuss as a class, group responses to each of the quadrants and chart one Frayer Model for the whole class. Post and refer to class Frayer Model throughout the rest of the unit.

9. Turn students' attention to the Unit Level Graphic Organizer, and use a Think-Pair-Share strategy to complete a row, summarizing what was learned in this lesson.

10. Use the REAPS questions throughout the lesson where appropriate.

Teacher Background Information

In this lesson, students will be working to define what a population is. One tool they will be using is a graphic organizer known as a Frayer Model. This graphic organizer is divided into four quadrants and assists students in building a working definition for a term, in this case "population" that they are beginning to become familiar with. (See Student Page 2.3B). For more information on the use of Frayer Models, see the Immersion Unit Toolbox.

Advance Preparation

Make copies of:

- Student Page 2.3A *Individual Plant and Plant Population Observations* (one per student or one for every two students depending on the class)
- Student Page 2.3B *Population Frayer Model* (one for every three students)

Implementation Guide

1. Stimulate students to think about whether scientific investigations focus on the traits of individuals or populations by having students compare the two.

- Ask the whole class to think of examples over the past two weeks when their observations were focused on **individual** plants. Make a list of responses on the board.
- Ask the class to list times when their observations were focused on a **group** of plants. Collect examples in a second column on the board.
- Ask students what they can learn about how fast Fast Plants grow by observing an individual plant as **compared** to a group of Fast Plants.

3. Use a Think-Pair-Share strategy to have students explain when a group of plants would be called a population. Circulate around the room during the Think-Pair-Share and listen for misconceptions that need to be addressed for the entire class.

- After gathering the students' ideas, acknowledge similarities with the scientific definition for a population in ecology and provide that definition. **Population: a group of individuals of the same species living in together in the same habitat.**
- Continue the discussion as a class to help students think of the characteristics of a population. See the Frayer Model in #7 for sample characteristics that may be discussed.

4. Have students work individually or in pairs to complete the Student Page 2.3A *Individual Plant and Plant Population Observations.*

5. Direct students to share their responses with at least one other pair of students to look for patterns in how individual plants were described and plant populations were described.

6. Hold a whole-class discussion about patterns in the descriptions. Emphasize the usefulness of describing populations with means, particularly when there are many individuals in the population.

7. Remind students that at the beginning of the lesson you defined what a population is and how during the rest of this unit most of the focus will be on how populations change over generations. For that reason, it is important for all students to help each other be clear what is meant by population.

- Group students in pairs or groups of three
- Pass out one population Frayer Model sheet to each group and explain to the students the meaning of each of the four quadrants. With the whole class, facilitate filling in one response. For example: Simply defined—**a group of individuals of the same species living in together in the same habitat.**
- Instruct each group to complete a population Frayer Model

The following Frayer Model is an example of potential student responses.

Simply defined . . .

A group of organisms of the same species living in the same area

Examples . . .

the people living in Los Angeles
deer living in the same woods
people of a town
orchids on a hillside
people living in the United States

Population

Non–examples. . .

One person
a Fast Plant, a cactus and a tree
all kinds of plants around a pond
eagles and bluebirds in same woods

Characteristics . . .

one species living in the same location
a group that lives in same area or habitat

Adapted from the Frayer Model of Concept Learning
Dr. Dorothy A. Frayer

As student pairs fill in their Frayer models, circulate around the room to determine if students understand what a population is and identify where students may need more guidance to clarify their ideas.

8. Discuss as a class group responses to each of the quadrants and chart one Frayer Model for the whole class. Post and refer to the class Frayer Model throughout the rest of the unit.

9. Turn students' attention to the Unit Level Graphic Organizer, and use a Think-Pair-Share strategy to complete a row, summarizing what was learned in this lesson.

10. Use the REAPS questions throughout the lesson where appropriate

What we did	What we know	How we know it
We described individual plants and populations of plants	All individual plants are different, and populations of plants have traits that can be measured and observed. Scientists use different kinds of descriptions for individuals than they use for populations. Individuals can be described by specifics about their traits. Populations are best described by the means for their traits.	• We have observations for both individual plants and a population of plants that are in the same quad or on the same water reservoir. • We can calculate the mean for how many plants in our class have a particular trait. • Paul's data that we looked at earlier described both individual plants and populations.

Student Page 2.3A: Individual Plant and Plant Population Observations

1. Use the observations that you made when you raised Fast Plants and the observations from Paul's Fast Plant experiments to complete the following table.

Trait	Data for One Plant				Data for One Population			
# of Leaves on Stem								
Hairs on 1st Leaf								
Flowers Pollinated								
Seeds Produced								

2. Describe what is similar and what is different about how you described one plant compared to how you described a population of plants.

Student Page 2.3B: Frayer Model on Population

Simply defined . . .

Examples . . .

Population

Non–examples. . .

Characteristics . . .

Adapted from the Frayer Model of Concept Learning
Dr. Dorothy A. Frayer

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Key Concepts

- Environmental factors influence the traits observed in individuals and populations.
- Scientific progress is made by asking meaningful questions and conducting careful investigations.

Evidence of Student Understanding

The student will be able to:

- develop a testable question about how an environmental stress that could be found in nature may influence variation in the production of seeds in Fast Plants.
- design a scientific experiment that aligns appropriately with the student has chosen testable question.

Time Needed

50 minutes to develop question and develop experiment

50 minutes to design and set up experiment

Materials

For each student

- copy of Student Page 1.1A *Fast Plant Growing Protocol (same as from Step 1, Lesson 1)*
- copy of Student Page 2.4A *Experimenting with the Effects of an Environmental Factor*
- copy of Student Page 2.4B *Planning an Experiment to Answer a Question*
- copy of Student Page 2.4C *Investigation Rubric*

(continued on following page)

Investigating Environmental Stress and Variation

1. Facilitate a class discussion to review the key ideas learned so far in this unit by reviewing the *Unit Level Graphic Organizer*.

2. Remind students about how Paul Williams changed environmental conditions to develop Wisconsin Fast Plants, and play the video segment where he describes more specifically what he did to develop these special plants.

3. Have students compare what they learned from Paul Williams with what students recorded on the *Unit Level Graphic Organizer* about how environmental factors influence variation among individuals in a population.

   - Emphasize the connection between an environmental factor and seed production (successful reproduction that results in the next generation).

4. Have students in groups of three or four develop a testable question about how an environmental stress that could occur in nature might affect individual Fast Plants and a population's ability to reproduce successfully (develop flowers and healthy seed).

   - Hand out copies of Student Page 2.4A *Experimenting with the Effects of an Environmental Factor* to guide groups' planning.

5. Facilitate a class discussion about developing testable questions. Work with students to develop a list of criteria for deciding which questions are scientifically testable.

6. After checking each group's question to be sure it fits your criteria for being feasible and sound as the basis for an investigation, direct students to write individual predictions for the results of an investigation into that question.

7. Have student groups use the Fast Plants Planting Protocol that was used in Step 1 to design their own investigation to answer their question.

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For each group of 4 students

- 2 growing quads
- 16 Fast Plant seeds
- planting materials
- lighting space
- watering system
- fertilizer pellets
- various other materials as needed for experiments

For the class

- video of Paul Williams describing how he changed the environment and selected for plants with the traits he desired to develop Wisconsin Fast Plants

- Hand out copies of Student Page 2.4B *Planning an Experiment to Answer a Question* to help student groups plan controlled experiments.
- Pass out one copy of Student Page 2.4C *Investigation Rubric* for each student, and facilitate a discussion about the expectations for exemplary work.

8. Conduct a peer review for the groups' experimental designs and procedures. During this time, review each group's plan and approve it or direct groups to make revisions.

9. During the next class period, set out materials that students need to set up their investigations. Direct students to set up their investigations.

10. Use the REAPS questions throughout the lesson where appropriate

REAPS Questions

R **What was the environmental stress in Paul's investigation that caused one population to be more successful at producing offspring?** The stress was lack of fertilizer.

E **Explain three characteristics of a testable question.** Look for responses that align with the class criteria.

A **What other environmental stresses might influence how successful the parent plants are at producing offspring?** Answers will vary and should include factors such as temperature, hours of light, color of light, intensity of light, amount of water, and amount of carbon dioxide.

P **What observable traits would be useful to record in an investigation of how an environmental stress affects variation in a population? How would you best record these observations?** Answers will vary and should include traits such as plant height, number of flowers, age at flowering, and number of seeds produced. (Note: From the data provided, the number of leaves did not vary significantly, so, unless your class data for some reason showed variation in that trait, it would be good to ask any student suggesting this trait to give evidence why. This could begin a rich discussion about experimental design and planning for data collection. Look for discussion about how to record the suggested data in ways that support both collection and analysis, such as in data tables.)

S **What is different about scientifically oriented questions and most everyday questions we ask?** Look for responses that identify key feature of scientific questions like testability, ability to secure materials, and limiting variables.

Teacher Background Information

See the *Immersion Unit Toolbox*—Engaging in Scientifically-Oriented Questions for more background on developing scientific questions.

Advance Preparation

Gather planting materials needed for the groups of four students to begin their own investigations. Provide the basic growing materials, a variety of materials that will allow students to change (and measure) the environment, and other miscellaneous lab equipment. Some suggested materials for altering the environment include:

- ability to grow plants in warmer or cooler environments (insulated box with heating pad or heat lamp / refrigerator with a light hung in it)
- colored gels to change the light color
- different soil types
- vinegar, salt, baking soda to change the pH or composition of the water or planting mix
- different sized planting containers to change planting mix volume
- extra seeds for planting different densities

Students may develop questions and investigations that require additional materials. If these are appropriate for testing an environmental stress that could occur in nature, with your approval, students could bring these materials in during the second-class period of this lesson, when the experiments are initiated.

Make copies of

- Student Page 2.4A *Experimenting with the Effects of an Environmental Factor*
- Student Page 2.4B *Planning an Experiment to Answer a Question* to help student groups plan controlled experiments
- Student Page 2.4C *Investigation Rubric* for each student

Implementation Guide

1. Begin lesson by engaging students in a discussion to review the key ideas learned so far in this unit by reviewing the Unit Level Graphic Organizer.

- Explain to students that in Lesson 4 they will develop their own scientific questions investigating how environmental factors influence the traits observed in individuals and populations.

2. Remind students about how Paul Williams changed environmental conditions to develop Wisconsin Fast Plants (refer to the chart paper from Step 1, Lesson 1), and play the video segment where he describes more specifically what he did to develop these special plants.

3. Engage students in a discussion about what they can add to the Unit Level Graphic Organizer after watching Paul Williams' video. Have students focus on how environmental factors influence variation among individuals in a population.

- Encourage students to think of environmental factors that may influence seed production.
- Point out that seed production (producing seeds) is an important trait in plants because it results in a next generation of plants. Emphasize that without producing seeds, a plant's genes are not passed on to future generations.

4. Point out to students that they are at a very important stage in the investigation process—where they will develop their own scientific questions. Note that scientists such as Paul Williams are extremely careful about how they develop questions, because a scientific question affects:

- what is investigated
- how it is investigated
- how the evidence is analyzed
- how the evidence is explained

Organize students in groups of three or four. Have groups develop a testable question about how an environmental stress that could occur in nature might affect individual Fast Plants and a population's ability to reproduce successfully (develop flowers and healthy seed).

- Hand out copies of Student Page 2.4A *Experimenting with the Effects of an Environmental Factor* to guide groups' planning.

Note: see the *Immersion Unit Toolbox*—Engaging in Scientifically Oriented Questions for additional teacher resources on developing testable questions.

5. Facilitate a class discussion about developing testable questions. Work with students to develop a list of criteria for deciding which questions are scientifically testable.

- Have students volunteer ideas for criteria. Record responses on the board. Then, with the whole class, do a quick evaluation of which responses to include in a rubric. Refine the list and add into a student rubric. Be sure that criteria include:

  a. The question is testable. The question can be tested using scientific observations and/or experimentation. Point out that some questions are not testable, such as questions about belief or opinion.

  b. The question is directed toward gathering evidence that can be described, explained or predicted by scientific investigation.

  c. The question is scientifically oriented. (clarify)

  d. The question is stated clearly.

- Explain that for their student investigation, they will have one more criterion:
  - The question needs to focus on the idea they have been covering in

the unit so far: the influence that an environmental factor may have on a trait that can be passed to the next generation. In this case, how an environmental stress that could occur in nature might the ability of individual and populations of Fast Plants to reproduce successfully (develop flowers and healthy seed).

6. Check each group's question to be sure it fits the criteria for a testable question, which is feasible for the students to investigate. Then direct students to write their individual predictions for the results of their investigations.

7. Have student groups use the Fast Plants Planting Protocol that was used in Step 1 to design their own investigation to answer their question.

- Hand out copies of Student Page 2.4B *Planning an Experiment to Answer a Question* to help student groups plan controlled experiments.
- Provide one copy of Student Page 2.4C *Investigation Rubric* for each student.
- Use Think-Pair-Share for students to read and understand any expectations for their investigation design. The student rubric includes only the "Exemplary" column to encourage students and to avoid confusing students with a broader grading rubric.

8. Have students conduct a peer review for the groups' experimental designs and procedures. During this time, review each group's plan and approve it or direct groups to make revisions.

- If students want to design experiments that require materials they can bring from home, check for appropriateness and tell students they must remember to bring in any needed materials the next day so that planting is not delayed.

9. Directs students to set up their experiments according to their description in their science notebooks.

10. Use the REAPS questions throughout the lesson where appropriate.

Experimenting with the Effects of an Environmental Factor

Question we hope to answer with evidence from this experiment:

Environmental Factors we are planning to keep the same

1 experimental Environmental Factor we will change

Why we think this Environmental Factor might affect the variation in one or more traits in the population.

How we think this Environmental Factor might affect the reproductive success of individuals in the population.

Student Page 2.4B: Planning an Experiment to Answer a Question

Planning an Experiment to Answer a Question

Question we hope to answer with evidence from this experiment:

First Step: What key decisions need to be made to plan the experiment?

What do you think the explanation for what will happen is? Why do you think that?

Second Step: What careful steps need to be taken to set up the experiment?

What are the next key steps that will take place?

What are results are we looking for?

Student Page 2.4C: Investigation Rubric

Criteria	Exemplary
Scientific Question: Is testable through scientific investigation	The question is stated clearly. The question is scientifically testable. • There is a way someone can test the question by using scientific observations and/or experimentation. • The question is not about belief or opinion which cannot be tested. • The question does not start with "why." The question is scientifically-oriented. • The question centers on objects, organisms, and events in the natural world. (Same as 1st testable definition.) • The question indicates that it can and will be answered by gathering data that will be used to develop an explanation. For this lesson: Question about the impact that an environmental stress might have on seed production (reproductive success) in a population of Fast Plants.
Prediction or Hypothesis	Prediction and/or hypothesis are clearly stated Prediction and/or hypothesis include explanations.
Experimental Design/ plan/ procedure?	The experimental plan is appropriate for the question being asked. • The plan indicates how information that is clearly related to the chosen scientifically oriented question will be collected. Investigation design includes: • Procedures (and protocols) for how to make observations, and accurate measurements. • Explanation for how to identify and control variables. • The tools and techniques described are appropriate for the question being asked.
Explanation: Is based on evidence	The explanation is stated clearly. The explanation is focused on answering the question. The explanation addresses the hypothesis or prediction. The explanation is based on evidence: • Explanation is based on both experimental evidence and scientific information from reliable sources. • The explanation and the evidence are linked logically. For this lesson: The explanation uses evidence to explain the relationship observed between environmental influences and the variation of the trait (seed production).

STEP 3

Overview

Step 3 focuses on reproduction in flowering plants. In this step, students observe their flowering Fast Plants closely and learn about flower structures and their functions and pollination. After dissecting one Fast Plant flower, students make and use bee sticks to pollinate their flowers. Understanding how reproduction must occur for parents to influence the next generation with their genetic code is foundational for students to later be able to explain if their experimental environmental stress could impact future generations.

Key Concepts

- The flowering plant life cycle includes pollination, which leads to seed production.
- Reproductive success in flowering plants is when a plant produces flowers that are successfully pollinated and produce seeds that grow into new plants.
- Experimental data and observations need to be systematically collected and carefully organized so that they can provide evidence to support claims that can answer the question being investigated.

Evidence of Student Understanding

The student will be able to:

- successfully cross-pollinate the class's Fast Plants.
- accurately explain how flowers and pollination are integral to reproductive success in flowering plants

Time Needed

100 minutes

Materials

For each student

- 1 copy of Student Pages 3.1A *Understanding Flowers*
- 1 copy of Student Page 3.1B *Pollination Worksheet*
- 1 copy of Student Page 3.1C *Fast Plants Pollination Protocol*
- 1 bee stick (from the Fast Plants growing kit or assembled from a dead, dried bee glued to a toothpick)

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Investigation: Flowers and Pollination

1. Introduce students to Step 3 by providing perspective on the importance of what the students do next. Explain that they will influence whether or not their plant's genes are passed on to the next generation of plants. Explain that in Step 3, they will pollinate their plants by using the same method that bees use.

- Briefly revisit the Unit Level Graphic Organizer to show how flowers and reproduction have not yet been studied before this lesson.
- Explain how understanding reproduction is an important part of understanding variation in a population because much of the variation comes from the genetic code that is passed down from parents to offspring.

2. Review the parts of a flower with students by conducting the flower dissection outlined in Student Page 3.1A *Understanding Flowers*.

- Distribute Student Pages 3.1A *Understanding Flowers* to guide students through the dissection steps.
- Because Fast Plant flowers are small, have students work individually so that they can clearly see the reproductive structures in the flower.
  - Provide hand lenses to help students see the structures.

3. Provide students with a copy of Student Page 3.1b *Pollination Worksheet* and have them work in pairs to complete the activity. After students complete the Pollination Worksheet, hold a discussion that focuses on key points, including how:

- pollination is an important example of the interdependence between plants and animals
- flowers and pollination are essential for reproductive success in flowering plants

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- 1 Fast Plant flower for *Understanding Flowers* dissection exercise
- hand lens, scissors, tweezers, and tape

For each group of 4 students

- flowering Fast Plants from the investigations

For the teacher

- 1 copy of Teacher Page 3.1a *Understanding Flowers*
- 1 copy of Teacher Page 3.1b *Pollination Worksheet Key*

- pollination can be a variable in an experiment if one outcome that is being measured is the number of seeds produced

4. Group students in pairs within their experimental groups. Provide each pair of students with a copy of Student Page 3.1C *Fast Plants Pollination Protocol*.

- Direct students to read the instructions for making and using a bee stick before constructing their own bee sticks.

5. If they are flowering, have students pollinate their Fast Plants according to the procedures in the Fast Plants Pollination Protocol.

- Plan for all students to pollinate their Fast Plants at least once when the flowers have first opened.

6. Direct students' attention to the Unit Level Graphic Organizer, and have them complete another row.

7. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **Where do you find the genetic code that is passed on to offspring by flowering plants?** It is in the pollen and eggs.

E **What is reproductive success in Flowering Plants?** Reproductive success in Flowering Plants is when a plant produces flowers that are successfully pollinated and produce seeds that grow into new plants.

A **What would be the measure of reproductive success for a male frog?** The number of eggs produced by all females whose eggs were fertilized with the male's sperm would be the measure of his reproductive success.

P **With the observations and data you have collected so far, do you think the environmental stress in your experiment will affect your Fast Plants' reproductive success? Explain your prediction.** Answers will vary, depending on whether students can see differences between their experimental and control populations that might affect flower production.

S **What do you know now about reproduction in flowering plants that you did not know before?** Answers will depend on students' prior knowledge.

Teacher Background Information

What is a Flower?

What is a flower? In human eyes, it is something to enjoy, with colorful petals and fragrance. However, for many plants, the critical part of the flower is not the dramatic blossom. Within that blossom are the organs of reproduction that allow the plant to reproduce sexually and create offspring slightly different from itself.

Many plants can arise directly from an existing plant through asexual reproduction. However, when a leaf cutting sprouts new roots or an iris plant is divided, this asexual reproduction gives rise to offspring that are genetically identical to the parent plant. Hence, asexual reproduction will not generate the variation necessary to allow the species to slowly adapt to the environmental changes that will inevitably occur.

Sexual reproduction requires the union of two gametes, a male sperm and female egg, to form a zygote (fertilized egg). Uniting eggs and sperm from different plants provides a challenge. Plants, which are largely immobile, have evolved strategies to move their male gametes long distances to fertilize the female gametes. One common strategy involves employing animals, often insects, to carry pollen (male gametes) to the pistil (female reproductive organ).

In order to attract the insects into such service, the plants provide food, in the form of nectar or pollen. However, the plant must first attract the insects. This attraction must happen when the reproductive organs within a flower are ready to provide and receive pollen. Plants have evolved a constellation of intriguing features by which they can "advertise" the availability of pollen and nectar to the pollinators. These "advertisements" include familiar flower characteristics such as dramatic colors and color patterns, distinctive fragrances, and large or complex shapes. The flower advertises the availability of nectar, which lures the pollinators into service.

Therefore, the answer to the question "What is a flower?" is a matter of the perspective of the viewer. For an insect, the flower is an essential source of sugar-rich nectar and protein-rich pollen. To humans, it is a delightful gift of beauty. However, for plants, the flower is the means by which they are able to generate, through sexual reproduction, the variation necessary for evolution and survival of their species.

Inside the Flower

Flowers are the reproductive organs for flowering plants, containing both the male and female gametes. Most flowers have the same basic parts, though they are often arranged in different ways. Each of the four main parts of a flower, the sepals, petals, stamens, and pistil serve particular functions in flowering and sexual reproduction. The sepals are the green leaf like structures that enclose and protect the developing flower. The petals are the colored leaf like structures that lie within the ring of sepals and frequently serve to attract pollinators.

The stamen consists of the filament, a slender stalk upon which is borne the anther. Within the anther are the pollen grains, which contain the male gametes or sperm cells.

The pistil usually has three parts, the stigma (which traps the pollen), the carpel (ovary), and the style (the neck between the two). Basic (Fast Plants) flowers have two carpels fused together and separated by a thin membrane. The carpels house the ovules, each of which contains the female gametes.

In *Brassicas* and many other species that need to attract specific pollinators, nectaries are also present. These nectaries, strategically located in the flower, secrete sugar-rich nectar. Their location ensures that nectar-gathering insects and other animals will receive pollen from anthers and transmit it to its stigmas as they forage.

For bees and other nectar-gathering insects, flowers are a source of food. As a bee drives its

head deep into the Fast Plant flower to reach the sweet nectar, it brushes against the anthers and stigma. Pollen is trapped in the bee's body hairs. As the bee moves from plant to plant, cross-pollination occurs and genetic information is widely transferred.

In the classroom or laboratory, the action of bees is mimicked using a ***bee stick*** constructed from the body of a bee. When pollinating Fast Plants, collect pollen on the bee stick by rolling the bee thorax over anthers of open flowers, and check for yellow pollen collecting on hair. Deposit pollen collected on the bee stick to the stigmas of other flowers on other plants by touching or rolling the bee stick over stigmas. It is important to repeat this process while moving from plant to plant because Fast Plants are normally "self-incompatible." That is, each stigma prevents germination of its own pollen, but not the pollen of another plant.

Throughout this lesson, emphasize the concept that **reproductive success** in Fast Plants occurs when a plant produces flowers that are successfully pollinated, produce seeds, and the seeds are viable (able to germinate and grow into plants that can also reproduce).

Implementation Guide

1. Introduce students to Step 3 by providing perspective on the importance of what the students do next. Explain that they will influence whether or not their plant's genes are passed on to the next generation of plants. Explain that in Step 3, they will pollinate their plants by using the same method that bees use.

- Briefly revisit the Unit Level Graphic Organizer to show how flowers and reproduction have not yet been studied before this lesson.

Review what students have covered in their Unit Level Graphic Organizers by asking them to highlight ideas related to reproduction from the lists under "What we know" and "How we know it."

- Ask what is known about how Fast Plants reproduce.
- Ask how the number of flowers on Fast Plants may or may not influence the number of offspring from each plant (its reproductive success). Use the student's response to assess the students' prior knowledge about flowers, reproduction and the meaning of reproductive success.
- Explain to students that if their experimental Fast Plants are beginning to flower, they need to be pollinated.

Throughout this lesson, help students make a connection between a doing a good job of pollinating (successful pollination) and the number of seeds a plant produces (seed production), as well as how seed production is a measure of reproductive success. As the unit progresses, students need to understand how reproductive success results in parents successfully passing their genetic code to the next generation so that they can explain natural selection.

2. Review the parts of a flower with students by conducting the flower dissection outlined in Student Page 3.1A *Understanding Flowers*.

- Distribute Student Pages 3.1A *Understanding Flowers* to guide students through the dissection steps.
- Because Fast Plant flowers are small, have students work individually so that they can clearly see the reproductive structures in the flower.
  - You may wish to make an overhead transparency of the page showing flower structures to use to clarify what structures students see during their dissection and emphasize their functions.
  - Provide hand lenses to help students see the structures.

3. Engage students in thinking about why and how they will pollinate their plants by having them work in pairs to complete the Student Page 3.1b *Pollination Worksheet*. The Pollination Worksheet is used in this step to guide students to understand the flower structures associated with seed production and the pollination process.

You may want to have students write a short story from the perspective of a bee that visits a flowering Fast Plant and describe what flower parts the bee encounters. Ask the students to explain what happens when the bee moves from one flower to another. These stories can provide a formative assessment opportunity which you can use to determine if students understand that seeds develop from pollinated flowers. You can also look for evidence in the stories that students understand that the offspring that grow from seeds have inherited half their genetic information from each parent plant.

After students complete the Pollination Worksheet, use a class discussion to continue focusing students' attention on such key points as:

- how pollination is an important example of the interdependence between plants and animals (animals depend on plants for food/energy and plants depend on animals to assist in pollination)

- how flowers and pollination are essential for reproductive success in flowering plants. Without successful flower pollination, seeds are not produced and a plant's genes are not passed on to the next generation of plants.
- how pollination can be a variable in an experiment if one outcome that is being measured is the number of seeds produced. (Seed production depends on careful pollination; no pollination means no seeds produced.)
- how reproductive success depends on flowers, successful pollination, seed production, seed germination and growth and development of the new plant

4. Group students in pairs within their experimental groups. Provide each pair of students with a copy of Student Page 3.1C *Fast Plants Pollination Protocol*.

- Direct students to read the instructions for making and using a bee stick before constructing their own bee sticks.

5. Before students pollinate their flowers, you may want to demonstrate how to pollinate flowers so you can emphasize how to take care of the plants during the process. Remind students that the reproductive success of their plants depends on how well they pollinate the plants. The number of flowers can indicate reproductive success, only if the flowers are successfully pollinated and seeds are produced. In fact, seed production is a more meaningful indicator of reproductive success.

- Direct students to pollinate their plants. For fun and to encourage students to engage more in the process, you can play the music "Flight of the Bumblebee" or suggest that everyone buzz during pollination.
- Plan for all students to pollinate their Fast Plants at least once when the flowers have first opened to have the experience, even if the last data being collected is the number of flowers produced (and not amount of seed produced).

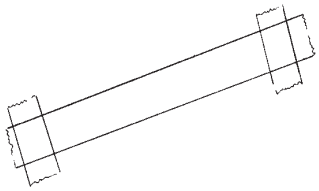
6. Direct students' attention to the Unit Level Graphic Organizer, and have them complete at least one additional row. For example, see the chart below.

7. Use the REAPS questions throughout the lesson where appropriate. You may wish to check yourself and/or use a peer review again to check students' science notebooks at this point for the quality of data collection that students are recording to be certain they have accurate evidence to use when developing explanations later.

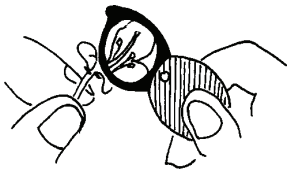
What we did	**What we know**	**How we know it**
Looked really closely at Fast Plant Flowers Pollinated our Fast Plants	Fast Plants produce seeds that grow into the next generation of plants. Flowers that are pollinated develop into seedpods that contain seeds. Reproductive success in Fast Plants means that a plant produced flowers that produced seeds and grew into offspring.	• We see our Fast Plants are flowering, and their flowers contain pollen. • We dissected flowers and compared the structures we saw to pictures that named them, and we talked about how flowers develop into seeds. • Our Fast Plants grew from seeds.

Flower Dissection Strip

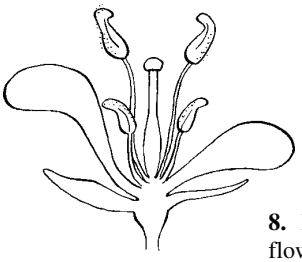
1. Make a flower dissection strip as a permanent record of the flower. Tear off a 15 cm strip of clear tape and place it on your work surface sticky side up. Secure it at each end with a small strip of tape.



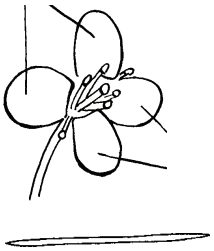
3. Using a hand lens, carefully examine the brassica (Fast Plants) flower. Compare your flower to the work-sheet of the brassica flower.



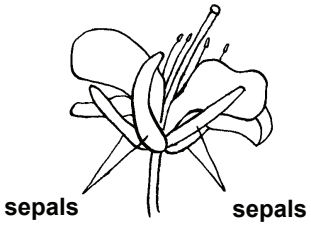
4. Identify the primary parts *(sepals, stamens, petals, and pistil)* of your flower.



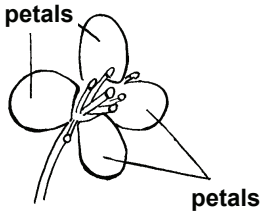
5. A toothpick or tweezers will help to separate the flower parts.



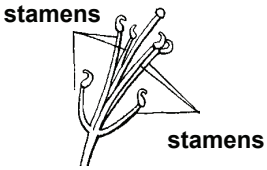
6. *Sepals* are usually green, looking like modified leaves. Sepals protect the flower in the bud stage.



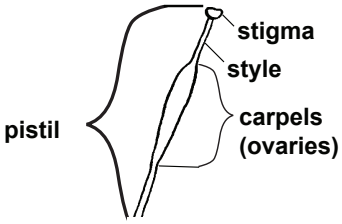
7. Notice the arrangement of the *petals*. The petals attract insects with their bright colors.



8. Inside the flower are the male flower parts, *stamens* — thread-like stalks *(filaments)* with pollen-carrying knobs called *anthers* on top. Count the number of stamens and notice how they are arranged around the pistil.

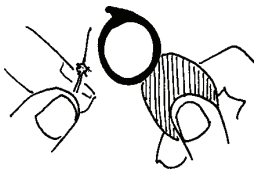


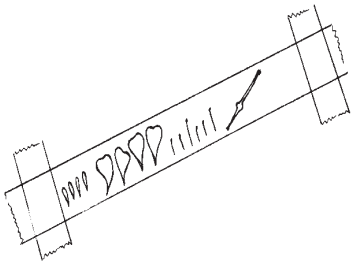
9. The *pistil* is the female part of the flower, and it collects pollen on its sticky top, the *stigma.* The *carpel* inside the base of the pistil contains the eggs *(ovules).*



10. Working with a tweezers, remove the flower parts and lay them in order on the sticky tape. Remove the flower parts in order: the four sepals, the four petals, the six stamens (see illustration below).

11. Finally, you are left with just the pistil attached to the stem at the receptacle. With a hand lens, observe the *nectaries* around the bottom of the ovary. Touch a nectary with a toothpick and then touch the toothpick to your tongue. Can you taste the sugar? Then, stick the pistil at the end of your flower strip.

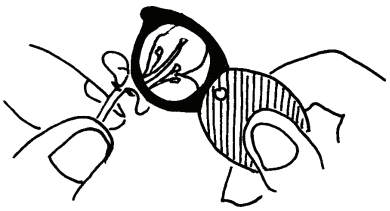




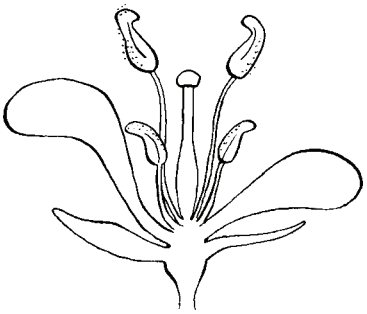
12. Take the complete flower strip off of your work surface and place it, sticky side down, onto a clean piece of paper. Now you have a "record" of your flower. Label the parts.

Flower Observational Exercise

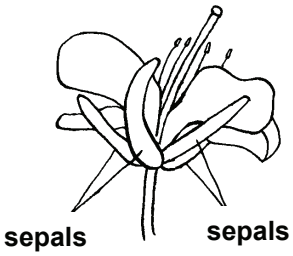
1. Using a hand lens, carefully examine the brassica (Fast Plants) flower. Compare your flower to the worksheet of the brassica flower.



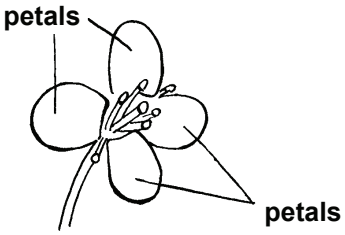
2. Identify the primary parts (sepals, stamens, petals, pistil) of your flower.



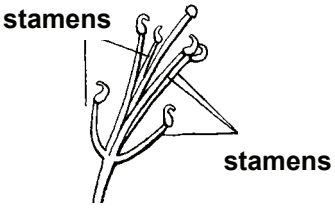
3. *Sepals* are usually green, looking like modified leaves. Sepals protect the flower before it opens.



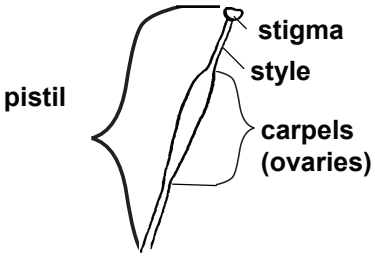
4. The *petals* attract insects with their bright colors.



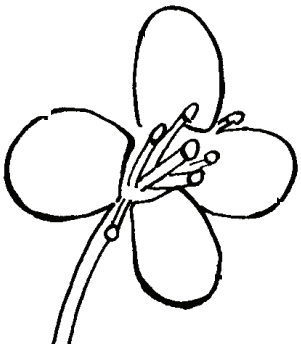
5. Inside the flower are the tall male flower parts, *stamens* — with knobs called *anthers* on top. Pollen is carried on the anthers. Count the number of stamens.



6. The *pistil* is the female part of the flower, and it collects pollen on its sticky top, the *stigma*. The *carpels* inside the pistil contain the eggs or ovules.



7. Make your own drawing of what you see. Label all the parts.

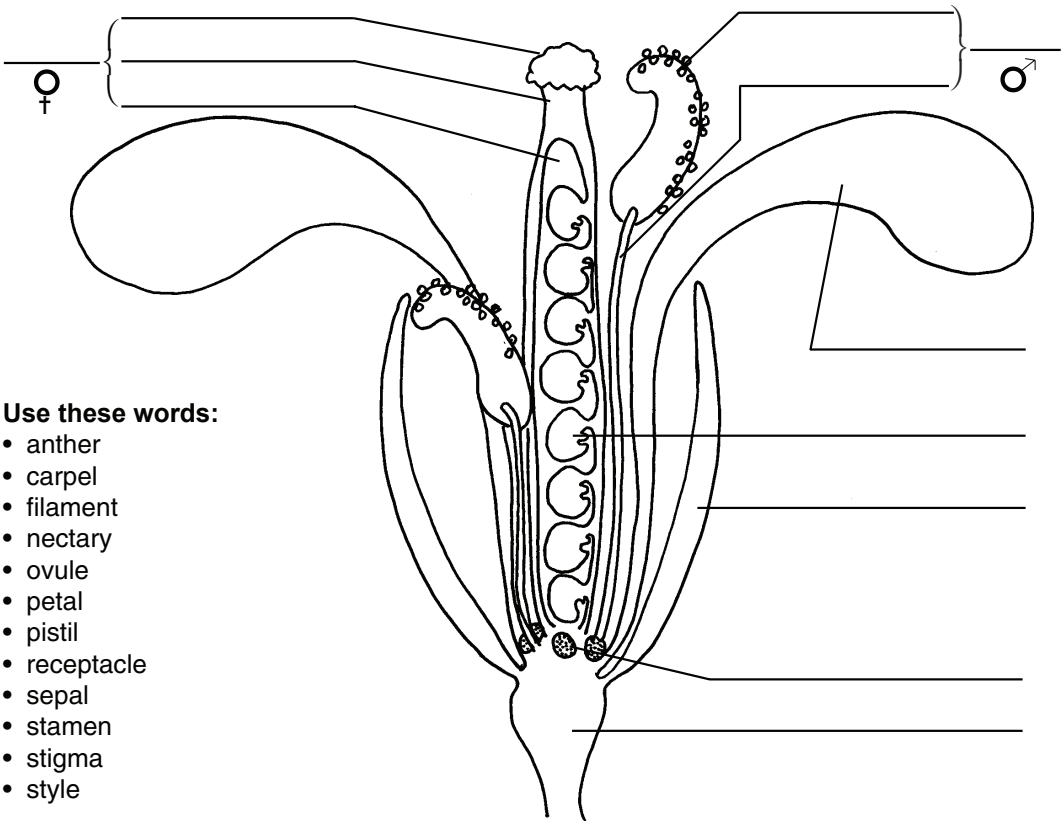


Flower Worksheet

Name _____

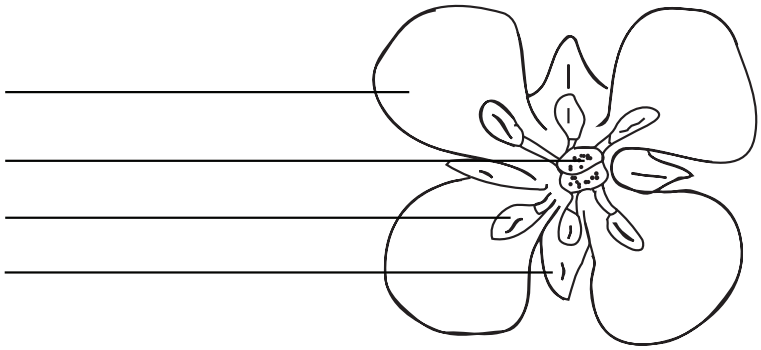
Date _____

The Brassica Flower



Use these words:

- anther
- carpel
- filament
- nectary
- ovule
- petal
- pistil
- receptacle
- sepal
- stamen
- stigma
- style



Pollination Worksheet

Name _____

Date _____

Pollination

Number the sentences from 1-7 to show what happens when pollination takes place.

_____ The pollen on the stigma grows a tube to an ovule and fertilization takes place.

_____ A bee seeks nectar from a flower.

_____ The fertilized ovule develops into a seed.

_____ The bee moves to another flower on another plant.

_____ While gathering nectar from the nectaries the bee brushes against the anthers.

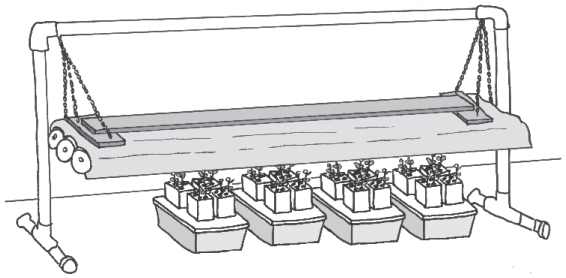
_____ Pollen from the anthers stick to the bee's hairy body.

_____ While the bee gathers nectar some pollen from the first plant is rubbed onto the stigma of the new plant.

Student Page 3.1C: Fast Plants Pollination Protocol

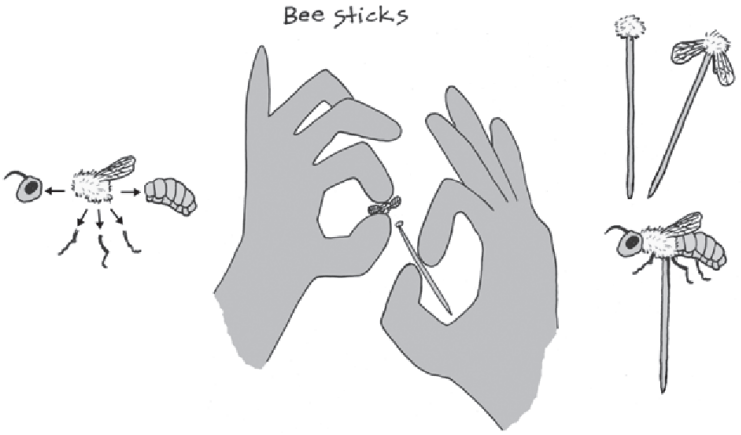
On Days 5–12, Tend the plants

- Refill water reservoirs.
- Adjust the lights every other day so the top of the plants is about 10 cm from the light.



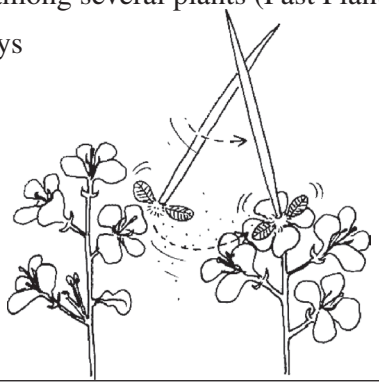
On Day 13, Make beesticks

- Insert the end of the toothpick with the glue into the spot on the thorax were the head was located.



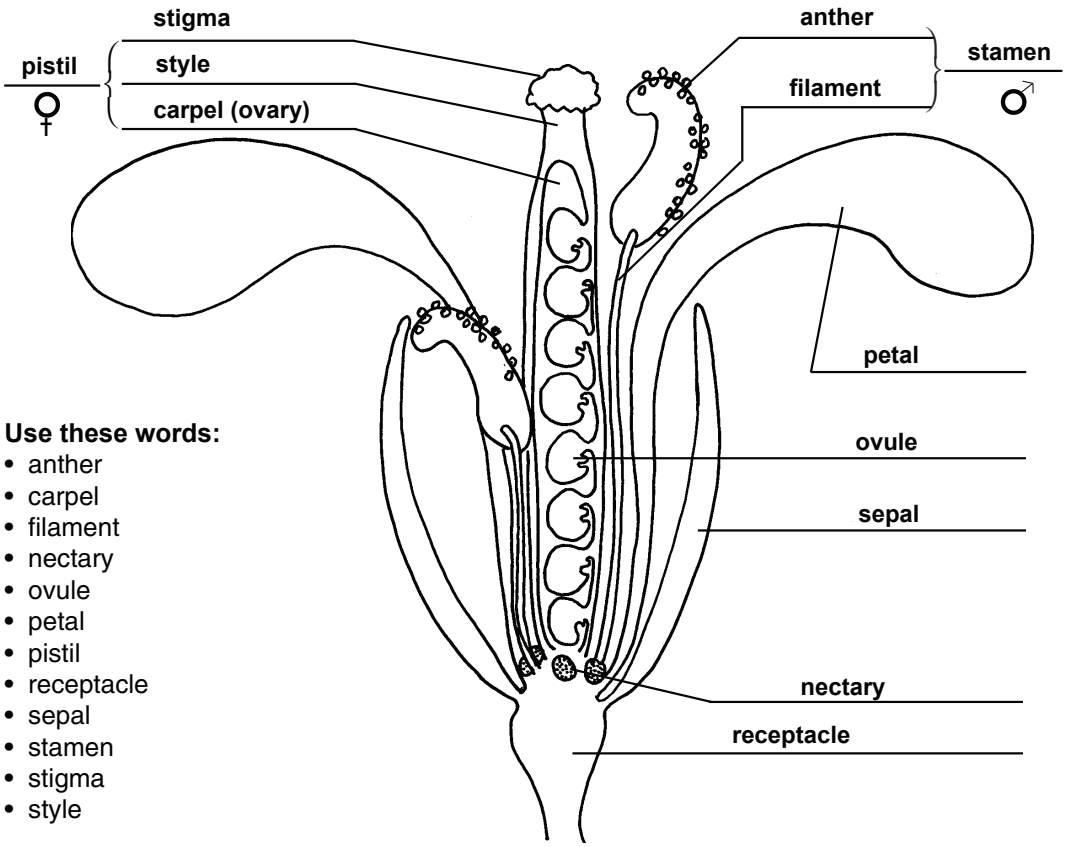
On Days 15–17, Pollinate flowers

- Roll the beesticks over the flowers (anthers) to pick up and deliver the pollen to the stigma. Transfer pollen back and forth among several plants (Fast Plants do not self–pollinate)
- Pollinate the flowers for 2–3 days



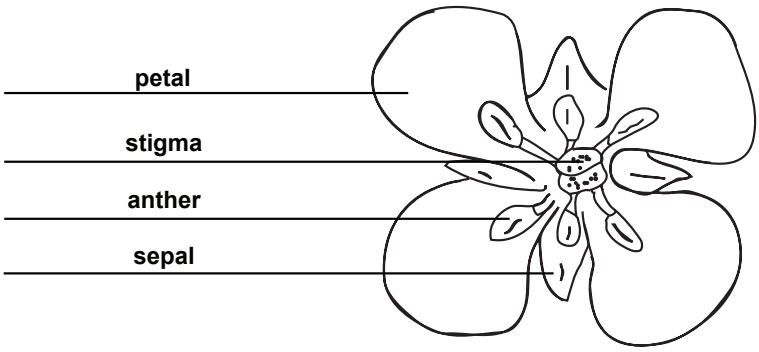
Flower Worksheet

The Brassica Flower (Key)



Use these words:

- anther
- carpel
- filament
- nectary
- ovule
- petal
- pistil
- receptacle
- sepal
- stamen
- stigma
- style



Pollination Worksheet

Pollination (Key)

Number the sentences from 1-7 to show what happens when pollination takes place.

6 The pollen on the stigma grows a tube to an ovule and fertilization takes place.

1 A bee seeks nectar from a flower.

7 The fertilized ovule develops into a seed.

4 The bee moves to another flower on another plant.

2 While gathering nectar from the nectaries the bee brushes against the anthers.

3 Pollen from the anthers stick to the bee's hairy body.

5 While the bee gathers nectar some pollen from the first plant is rubbed onto the stigma of the new plant.

STEP 4

Overview

The three lessons in this step, together, provide an opportunity for students to build an understanding of artificial selection as a mechanism for rapid change and natural selection as a mechanism for gradual change in a population over time.

In the first lesson, students engage in a natural selection simulation that models how disease affects a population of plants with an equal number of disease resistant and disease susceptible plants. In the second lesson, students analyze and explain the data, noting that after three generations of disease, an environmental stress (disease) has influenced the variation of a trait (disease resistance or susceptibility) within the plant population. The simulation shows by example how selective pressure affects the variation that occurs in successive generations.

The third lesson provides students with the opportunity to apply what they have learned about natural selection to develop logical explanations for two fictional scenarios, after reading about more examples of both artificial and natural selection.

Key Concepts

- Individual organisms with certain traits are more likely than others to survive and have offspring.
- Simulations can be used in science to simplify a natural phenomenon to make it possible to test and understand.

Evidence of Student Understanding

The student will be able to:

- explain how the simulation is like a situation that could be found in nature in which some individuals are more likely than others to survive an environmental stress and have offspring.
- explain why a simulation is a useful tool for studying a situation that would take many generations to occur in nature.

Time Needed

50 minutes

Materials

For each student

- copy of Student Page 4.1A *Simulation—The Disease Strikes*
- copy of Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*

For each group of 4 students

- 50 1/4" non-locking washers to represent susceptible plants (each with a painted dot on one side)
- 100 1/4" non-locking washers (without a painted dot) to represent resistant plants

Selection Simulation

1. Explain to the class that the first lesson in this Step is a simulation that is in some ways like playing a game with specific rules.

- Introduce how a simulation is a tool in science like how an experiment is a tool for learning more about something that occurs in nature.
- Make it clear that the entire simulation needs to be completed during a single science period because it would be difficult to set it back up again part way through the simulation.

2. Read the following question as a class, then have students record their thoughts or answers in their science notebooks.

- **If a disease is present in a population of plants for three generations, what will happen to the average number of plants that are resistant to the disease?**

3. Read the following overview with the class to explain how this simulation will work. **Have students explain the roles and key terms in their own words to check for understanding**.

- In this simulation, washers will represent plants living in a particular environment. The environment is your lab table.
- Some of the washers have a red dot painted on one side. The red dot on some of the washers represents an inherited trait that makes the plant **susceptible** to disease.
- Washers without a dot represent plants that are **resistant**. Resistant plants DO NOT BECOME infected by disease.
- In this simulation, three team members in each group of four students will play the role of Disease Vectors. They will infect and kill susceptible plants during periods of infection that

(continued on following page)

are controlled by the Plant Pathologist. The fourth person in each group will play the role of Plant Pathologist, a scientist who studies plants and their responses to diseases.

- **Disease Vectors:** Stand with your backs to the plant population until the Plant Pathologist tells you to start "infecting plants."
- **Plant Pathologists:** You control the time when the disease vectors can infect the plant population. You must also spread and mix the plant population in the environment (your lab table) while the disease vectors have their backs turned.

4. Divide the class into groups of four. Give each student a copy of Student Page 4.1A *Simulation: The Disease Strikes*, and review the key points of the procedure one more time as a class.

5. Have student groups conduct the simulation and record what happened in their science notebooks. Circulate among groups to check for accuracy in data collection.

6. After the simulation materials are cleaned up, give each student a copy of Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*, and either assign students to complete as homework or in class the first half of the page (through the RESULTS section) Have students explain in their own words what happened in the simulation.

7. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **What was the environmental stress in the simulation?** The stress was the disease.

E **Was there variation among individual plants in the simulation population?** Yes, there was variation in the trait that determined resistance or susceptibility to the disease.

A **What other environmental stresses might influence how successful the parent plants are at producing offspring?** Answers will vary and ought to include factors such as temperature, availability of water, soil quality.

P **What do you think would have happened to the number? How would you best record these observations?** Answers will vary and ought to include traits such as plant height, number of flowers, age at flowering, and number of seeds produced. (Note: From the data provided, the number of leaves did not vary significantly, so, unless your class data for some reason showed variation in that trait, it would be good to ask any student suggesting this trait to give evidence why. This could begin a rich discussion about experimental design and planning for data collection. Look for discussion about how to record the suggested data in ways that support both collection and analysis, such as in data tables.)

S **What about the simulation helped your learning most?**

Advance Preparation

Decide how you will organize students into groups and assign their roles. Place dots on 50 washers in each set of 150 washers then place washers in zip lock bags to hand out to student groups. Make copies of Student Pages.

Implementation Guide

Note: Allow 5–10 minutes every day or other day for students to make observations and notebook entries. You may want to schedule these observations for the beginning of each class to ensure that records are kept.

1. Explain to the class that in this lesson the students will participate in a simulation used to represent something that happens in real life. Some simulations are like playing games with specific rules.

- Explain that scientists use simulations as tools to model how something occurs in nature, just as experiments. Simulations can be used to simplify something that occurs in nature to understand and test it.
- Explain to the class that the first lesson in this Step is a simulation that is in some ways like playing a game with specific rules.
- Make it clear that the entire simulation must be completed during a single science period.

2. Ask student: If **a disease is present in a population of plants for three generations, what will happen to the average number of plants that are resistant to the disease?** Then have students record their thoughts or answers in their science notebooks.

Explain to students that in this simulation they will imagine that a population of plants is infected with a disease for three generations. Point out that before the students start the simulation, half of the plants are resistant to the disease and half are susceptible. Have students predict how the average number of plants resistant to disease will change after three generations.

Encourage students to discuss the question and why they chose the predictions they did, then have students record their ideas in their science notebooks.

3. Read the following overview with the class to explain how this simulation will work. Have students explain the roles and key terms in their own words to check for understanding.

Divide the class into groups of four. Give each student a copy of Student Page 4.1A *Simulation: The Disease Strikes*, and review it with the class. In this simulation, washers will represent plants living in a particular environment. The environment is your lab table.

- Some of the washers have a red dot painted on one side. The red dot on some of the washers represents an inherited trait that makes the plant **susceptible** to disease. A plant that is susceptible WILL BECOME **infected** by disease in this simulation. A **disease vector** will carry the disease. A disease vector is an organism that carries disease-causing agents to other organisms.
- Washers without a dot represent plants that are **resistant**. Resistant plants DO NOT BECOME infected by disease.

4. Explain that three students in each group will play the role of Disease Vectors. They will infect and kill susceptible plants during periods of infection that are controlled by the Plant Pathologist. The fourth student in each group will play the role of Plant Pathologist, a scientist who studies plants and their responses to diseases.

Explain vectors and how pathologists will infect plants:

- **Disease Vectors:** will listen carefully to the Plant Pathologist for directions. You must stand with your backs to the plant population until the Plant Pathologist tells you to start "infecting plants."
- **Plant Pathologists:** controls the time when the disease vectors can infect the plant population. You must also spread

and mix the plant population in the environment (your lab table) while the disease vectors have their backs turned.

5. Have student groups conduct the simulation. Circulate among groups to determine if students understand the simulation and to check for accuracy in data collection.

6. After the simulation, have students put materials away. Then give each student a copy of Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*. Decide ahead of time whether students will fill in part of the student page in class and all or part of the assignment as homework. Have students use their own words to explain what happened in the simulation.

7. Use the REAPS questions throughout the lesson where appropriate.

Simulation—The Disease Strikes

In this simulation, washers will represent plants living in a particular environment. The environment is your lab table. Some of the washers have a red dot painted on one side.

The red dot on some of the washers represents an inherited trait that makes the plant susceptible to disease. A plant that is **susceptible** WILL BECOME infected by disease in this simulation. A disease vector will carry the disease. A **disease vector** is an organism that carries disease-causing agents to other organisms

Washers without a dot represent plants that are resistant. **Resistant** plants DO NOT BECOME infected by disease.

In this simulation, three team members will play the role of Disease Vectors. They will infect and kill susceptible plants during periods of infection that are controlled by the team member playing the role of **Plant Pathologist,** a scientist who studies plants and their responses to diseases.

Disease Vectors*: Listen carefully to the Plant Pathologist for directions. You must stand with your backs to the plant population until the Plant Pathologist tells you to start "infecting plants."*

Plant Pathologists*: You control the time when the disease vectors can infect the plant population. You must also spread and mix the plant population in the environment (your lab table) while the disease vectors have their backs turned.*

Infection 1

Plant Pathologist: Tell the Disease Vectors to turn their backs.

Spread and mix the starting plant population in the environment.

The starting population is made up of 25 susceptible and 25 resistant plants. Be sure that no red dots are showing.

- When you are ready, say "start" for the Disease Vectors to turn around and begin.

  Disease Vectors should pick up one washer at a time, using only one hand, for 20 seconds.

  If a Disease Vector picks up a washer with a dot, it becomes infected and dies. Remove it from the environment to a separate pile

  If a Disease Vector picks up a washer with no dot, the washer remains in the environment.
- **Say "stop" after 20 seconds**, and make sure all vectors quit infecting plants at that time.

  At the end of Infection 1, work as a team to carefully count and record the number of surviving plants. Note separately how many surviving plants are resistant plants and how many are susceptible plants.
- Record this information on your data sheet.

(continued on following page)

Simulation—The Disease Strikes

Infection 1 *(continued from following page)*

Add the Second Generation

Work as a team to prepare the next generation of plants as follows.

- Simulate reproduction in the plant population by adding the following offspring:
  - For every surviving resistant plant, add one more resistant plant (plain washer with no red dot).
  - For every surviving susceptible plant, add one more susceptible plant (washer with a dot).

On your team data sheet, record the numbers of resistant and susceptible plants in this new starting population.

Infection 2

Repeat the procedure used in the first infection.

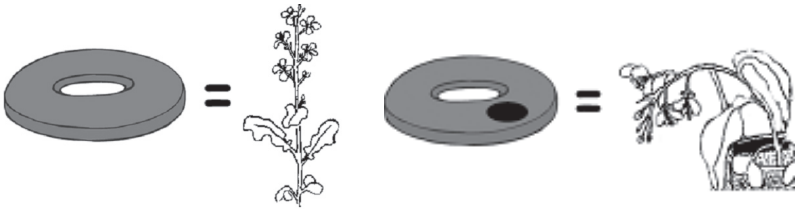
At the end of Infection 2, work as a team to carefully count and record the number of surviving plants. Note separately how many are resistant plants and how many are susceptible.

Record this information on your data sheet.

Calculate the Third Generation

- You will calculate and record the size of the next starting population, but you will not need the washers.
- Simulate reproduction in the plant population by calculating the following numbers of offspring to add to the number of survivors to determine what the third-generation starting population would be:
  - For every surviving resistant plant, add one more resistant plant.
  - For every surviving susceptible plant, add one more susceptible plant.
- On your team data sheet, record the total numbers of resistant and susceptible plants that would be in the third-generation starting population.
- There will not be a third infection.

Student Page 4.1A: Simulation—The Disease Strikes (continued)



GENERATION 1	Disease Resistant Plants	Disease Susceptible Plants
Number of Plants in the Population to Start this Generation		
Number of Plants Killed by Disease in this Generation		
Number of Plants Living at the End of this Generation		
Number of Offspring to Add before the Next Generation		
Number of Plants to Start the Next Generation		

GENERATION 2	Disease Resistant Plants	Disease Susceptible Plants
Number of Plants in the Population to Start this Generation		
Number of Plants Killed by Disease in this Generation		
Number of Plants Living at the End of this Generation		
Number of Offspring to Add before the Next Generation		
Number of Plants to Start the Next Generation		

GENERATION 3	Disease Resistant Plants	Disease Susceptible Plants
Number of Plants in the Population to Start this Generation		

Using a Simulation to Develop a Scientific Explanation

Describe a situation in nature something like the simulation and how it could happen:

What parts of the simulation are **MOST** like the natural world?

What parts of the simulation are **LEAST** like the natural world?

RESULTS: Describe in your own words what happened to the population in the simulation.

Explain 2 reasons why the simulation is a useful tool for studying how an environmental factor could effect a population.

EXPLANATION: Explain why your group got the results that you did.

COMPARE: How do other groups' results and explanations compare to your group's?

Key Concepts

- Individual organisms with certain heritable traits are more likely than others to survive and have offspring, and they influence the traits in future generations more than those that do not survive or produce many offspring.
- Scientists use appropriate tools and techniques to gather, analyze, and interpret data.

Evidence of Student Understanding

The student will be able to:

- construct and analyze a graph showing how the percentage of individuals who are resistant and susceptible in the population changes over generations when the disease is present in the environment.
- explain how graphing data is useful for seeking patterns in evidence that can lead to scientific explanations.

Time Needed

90 minutes

Materials

For each student

- 1 sheet of graph paper
- 1 set of colored pencils with at least two colors (same two colors for the class)
- 1 copy of Student Page 4.1B U*sing a Simulation to Develop a Scientific Explanation* (from the previous lesson)
- 1 copy of Student Page 4.2A *What, No Fries?*

Selection Simulation Analysis

1. Review with the whole class what took place in the simulation and their responses to the first few prompts on the Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*.

2. Explain to students that representing results as graphs provides another way to look for patterns in the data collected during the simulation. Show students a histogram (bar graph).

- Explain to students that each group will put its simulation results on a histogram (bar graph), and that it will be important for all of the graphs to be on a similar scale and use the same format so the class can look for patterns among all groups' results.

3. Discuss and decide on the graphing format all students will use (see Implementation Guide).

- Point out the data that will be included in students' histograms:
  - Generation 1's starting populations of both susceptible and resistant plants.
  - Generation 2's starting populations of both susceptible and resistant plants.
  - Generation 3's starting populations of both susceptible and resistant plants.

4. In their science notebooks, direct all students to apply the class formatting and make histograms (bar graph) from their group's simulation data.

- Also have each group make one large graph (poster-sized) so that it will be visible for the whole class.
- Have groups post their large graphs so they are visible to the whole class.

5. Using their histograms, hold a discussion, and have students identify patterns in the data and propose

(continued on following page)

explanations. Discuss why and how the population changed from the first to the third generation.

6. Have students review their copies of Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*, and either assign students to complete the remaining sections as homework or work in class.

- Use this Student Page as a way to assess students' understandings of the simulation key points.

7. Assign as homework or provide time in class for students to read Student Page 4.2A *What, No Fries?*

- Choose an appropriate reading strategy to break up the reading if completed in class.
- Use a Think-Pair-Share strategy for students to consider prompts like:
- How does the story of the Lumper potato compare and contrast to what happened in the simulation?
- What might a plant pathologist (like Paul Williams) who works on potatoes have done to help Irish farmers in the 1840's?

8. Direct the class's attention to review the key ideas learned so far in this unit by reviewing the Unit Level Graphic Organizer.

9. In their science notebooks, assign students to write a two-paragraph explanation for the overall class results observed in the plant-disease simulation. (See Implementation Guide for suggested terms to include.)

10. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **Which role in the simulation had the greatest variation in how it affected the results among the groups in your class?** If the Plant Pathologists follow the instructions correctly, the vectors play the role that shows the most variation in how quickly they "infect" the population.

E **What was the largest difference among results that student groups reported from the simulation? What explains that difference?** Responses will depend on the class results. Look for students to explain logically whether the difference in results was because of differences in how the simulation was conducted or because of chance in vectors' success at eliminating susceptible plants.

A **How would your results have been different if the simulation rules were changed so that each surviving plant had two offspring instead of one?** The starting population for the second would have been twice what it was, and that would have changed what the vectors had to choose from, making the starting population of the third generation different (and still larger because there would still have been more plants to begin with).

P **Where would you look for plant populations in real-life situations today that have traits that make some individuals susceptible to disease while others are resistant?** Answers will vary and could include any natural environment where plants grow.

S **What did you do in this lesson that was like what a scientist does?** Responses may include such things as developing and analyzing graphs, looking for patterns in data, developing evidence-based explanations, using a simulation to study a natural phenomenon.

Advance Preparation

Decide in advance how you will have students generate their graphs. This lesson is written so every student makes a graph of the simulation results in their science notebook, and then each group produces a poster-sized graph of their group's and their class's data analyses. Even though fewer graphs could make the point, having each student draw her or his own graph ensures that all students understand the process.

Implementation Guide

Note: Allow 5–10 minutes for students to make observations and notebook entries.

1. Have students describe how they simulated what happens when a disease affects a plant population for three generations.

- Have students share their responses to the first few prompts on the Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*. Use their response to assess whether students understand the key concept: "Individual organisms with certain heritable traits are more likely than others to survive and have offspring, and they influence the traits in future generations more than those that do not survive or produce many offspring."

2. Explain to students that representing results as graphs provides another way to look for patterns in the data collected during the simulation. Show students a histogram (bar graph).

- Explain to students that each group will put its simulation results on a histogram (bar graph), and that it will be important for all of the graphs to be on a similar scale and use the same format so the class can look for patterns among all groups' results.

Prompt students to think about how they will compare their simulation results, by reminding students how they compared their investigation results with Paul Williams' results by using graphs back in Step 1. Again, reinforce the idea that graphs are another way to visualize results. Encourage student to imagine how they can put their results from the simulation on a graph.

3. Discuss and decide on the graphing format all students will use.

- Point out the data that will be included in students' histograms:
  - Generation 1's starting populations of both susceptible and resistant plants.
  - Generation 2's starting populations of both susceptible and resistant plants.
  - Generation 3's starting populations of both susceptible and resistant plants

Show students a histogram (bar graph).

- Explain that in the histograms that they will draw, separate bars represent the resistant and susceptible plants.
- Facilitate a class discussion to determine a set of standards for how the graphs will be formatted and the scale that will be used. Explain that using the same standards makes it is easier to compare results from the different groups. Have class decide on:
  - Which color bar will represent susceptible plants
  - Which color bar will represent resistant plants
  - What scale (on the Y axis) will be used to show the number of plants

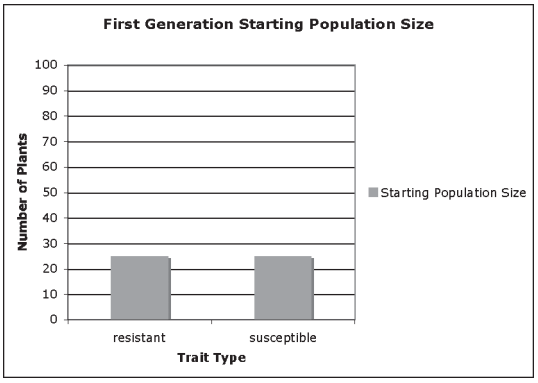
4. In their science notebooks, direct all students to apply the class formatting and make histograms (bar graph) from their group's simulation data (In this way, all students will work with the data and make graphs, though only one graph from each group will be shared with the whole class).

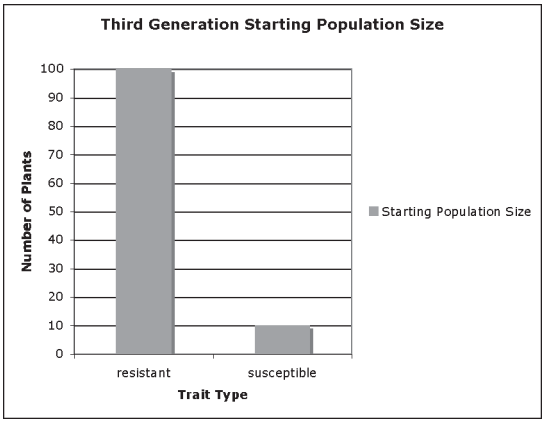
- Also, have each group make one large graph (poster-sized) so that it will be visible for the whole class. Be sure these larger graphs are also the same scale so they can be compared and analyzed for patterns.
- Have groups post their large graphs so they are visible to the whole class.

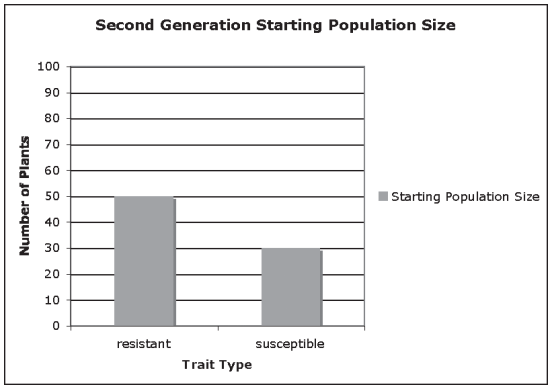
5. Using their histograms, hold a discussion, and have students identify patterns in the data and propose explanations. Discuss why and how the population changed from the first to the third generation.

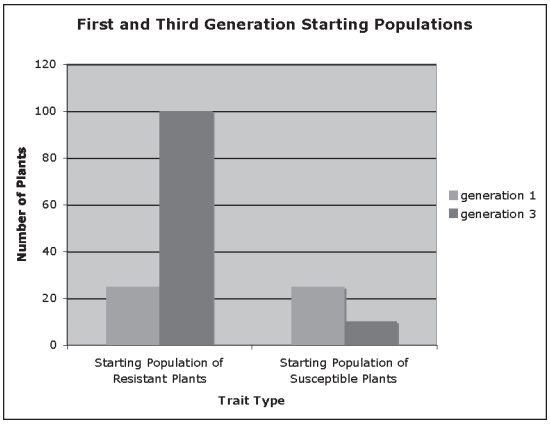
The key concept supported by the simulation data is that when there is an environmental stress (such as disease) that is ongoing, it can change the percentage of individuals in a population who have traits that make them better able to survive and reproduce under those conditions. The graphs show this shift towards fewer individuals who are susceptible, though, in most cases, the variation remains—a few individuals remain in the disease-stressed environment.

The following graphs are similar to what your class is likely to develop:









Ask if the simulation helps students picture how disease might change the makeup of a population of plants (such as the percentage of susceptible plants in a population). Reinforce the idea that one benefit of simulations, models, and graphs is that they can make it easier for investigators to imagine and represent what is happening in the real world.

6. Have students review their copies of Student Page 4.1B *Using a Simulation to Develop a Scientific Explanation*, and either assign students to complete the remaining sections in class or to do as homework. Use this Student Page as a way to assess students' understandings of the simulation key points.

7. Assign as homework or provide time in class for students to read Student Page 4.2A ***What, No Fries?***

It is recommended that a reading strategy and class time be used to help students comprehend the important points in this reading.

When students complete the reading, use a Think-Pair-Share strategy for students to consider:

- How does the story of the Lumper potato compare and contrast to what happened in the simulation you did when you pretended to infect a plant population with disease?
- If a plant pathologist, like Paul Williams, were around in the 1840's, what could he or she have done to help Irish farmers?

8. Direct the class' attention to review the key ideas learned so far in this unit by reviewing the Unit Level Graphic Organizer. In their science notebooks, assign students to write a two-paragraph explanation for the overall class results observed in the plant-disease simulation.

9. Assign students to write in their science notebooks a two-paragraph explanation for the overall class results observed in the plant-disease simulation. Students can use the following terms in the paragraphs:

natural selection

population

trait

resistance

variation

inherited

stress

susceptible

generation

environment

This is practice for a similar question that students will be asked to answer in the summative assessment.

10. Use the REAPS questions throughout the lesson where appropriate.

Student Page 4.2A: What, No Fries?

Imagine riding to your favorite fast-food restaurant. Your stomach is growling for a sandwich and fries. You rush in the door, and get in line to order. Finally, you place your order—one chicken sandwich and a large order of French fries. The worker replies, "Sorry, no fries." And everywhere you go, it is the same answer: No more fries. How could that ever happen?

What would you think if you were told that there were no fries because all of the potato crops died from disease? Would your life be different without potatoes? For some people, life without potatoes means life without enough food. For example, in the 1800s, people in Ireland ate potatoes for nearly every meal. These families cooked potatoes in many different ways. Irish farmers grew potatoes both to feed their families and to sell. They depended on potatoes for food and money. Then, suddenly the potato crops began to die from disease. Imagine how scared the Irish farmers and their families were when their potatoes began dying in the field.

Why Potatoes?

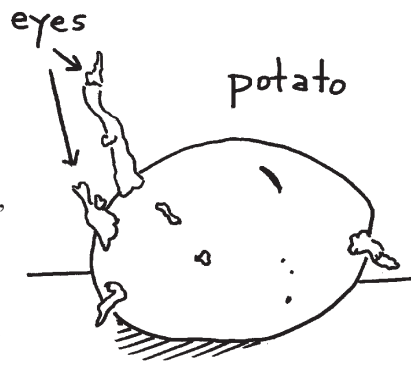
Why are potatoes so popular? Potatoes are grown all over the world. Potatoes are a valuable food because they taste good and are nutritious. They are an important source of nutrients, including vitamins and minerals. Potatoes can also be stored for a long time without refrigeration. Being able to store potatoes easily through the winter is important.

Potatoes were originally grown in South America, probably in Bolivia, Chile, and Peru. More than 400 years ago, the Inca Indians in those countries grew potatoes in their mountain valleys. They made a light flour-like mixture from potatoes, which they used to bake bread. The word "potato" comes from the Haitian name, *batata*, for sweet potato.

Potatoes Travel to Europe

Spanish explorers ate potatoes for the first time when they traveled to South America. Both Spanish and English explorers brought potatoes from South America back to Europe and England in the 1500s. Then, potatoes became popular in Europe. They grew well in the cold climate of Ireland where most other crops would not.

Irish farmers grew potatoes and stored them in pits dug into the ground. All winter, potatoes stored in these pits could be dug up and cooked to feed families. When Ireland grew and there were more people to feed, they grew more potatoes. New potato plants were started each year by cutting out potatoes' "eyes" and planting the chunks in the ground.



Growing new plants from "eyes" is another way that plants can produce offspring.

It is different from producing offspring from seed. The new potato plants that grew from "eyes" were identical to the previous generation. That is different from new generations grown from seed because offspring grown from seed have a mix of inherited traits from their parents.

Irish farmers growing potatoes noticed that their plants were not exactly alike. There was variation in the way that the plants grew and the way the potatoes developed. One kind of potato plant grew particularly well in the cool Irish environment. The farmers planted more of that kind. They named it the "Lumper" potato. Each year, the Irish potato farmers planted a new crop of Lumper potatoes. After many years, Lumper potatoes became nearly the only variety of potato grown in Ireland.

Disease and Starvation

Can you think of a reason why it might be a bad thing for all farmers to grow the same potato variety? It did not seem like a problem at the time it was happening in Ireland. However, it turned out to be a serious problem. Lumper potato plants grow in very similar ways, and that is good. They also get diseases in very similar ways, and that is bad.

In 1845, a fungus that attacks some potato plants arrived in Ireland from South America. This fungus was able to easily live and reproduce in the Irish environment. The fungus was a new environmental stress introduced to Irish farms from South America.

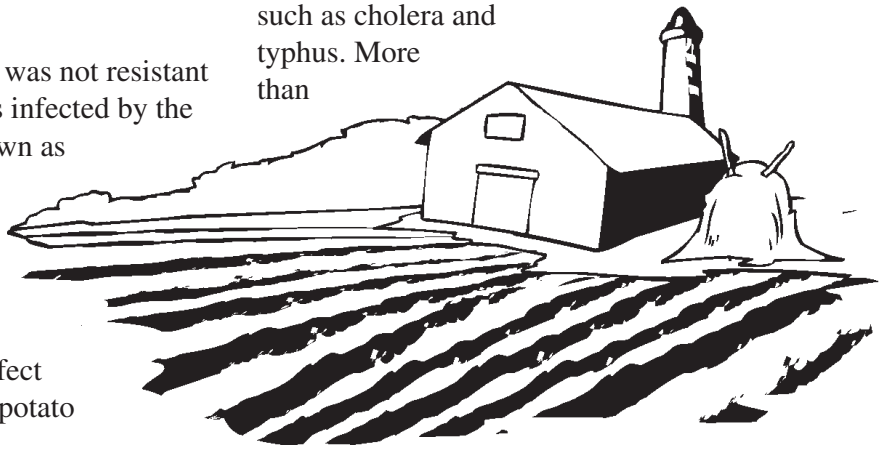
Unfortunately, the Lumper potato was not resistant to this new fungus. Lumper plants infected by the fungus developed the disease known as potato late blight. The Lumper potato was susceptible to, or likely to get, the disease caused by the fungus. Because this fungus lived easily in the Lumper potato's environment, it had a perfect opportunity to attack the Lumper potato plants. Because most of the potato plants in Ireland were these susceptible ones, the fungus quickly spread across the whole country.

This fungus caused the potatoes to get the disease, potato late blight. Those potatoes that survived with the disease would not keep through the winter. They rotted during storage. Even worse, the fungus lived through the winter to infect the next potatoes that farmers planted.

Potato late blight can strip all the leaves from every plant in a whole field of potatoes in just days. Eventually, it also rots the potatoes. In Ireland in 1845 to 1848, the environmental stress caused by the fungus seriously endangered families' food supplies. Acres and acres of potatoes were destroyed by the disease. Irish farmers found their winter food rotting in their cellars.

The blight did not completely destroy Irish potato crops the first year. The next spring, farmers planted "eyes" from whatever potatoes they had left that were not rotten. The potatoes seemed all right, but the fungus was still on them. When spring rains began, the fungus became active, and the blight began again. Within weeks all the farmers' potato plants died. In just three years, the Lumpers were nearly extinct.

All those Irish families who relied on potatoes for food had to find something else to eat. Hungry people who ate the rotten potatoes got sick. Villages suffered with diseases such as cholera and typhus. More than



a million Irish people—about one of every nine—died in the Great Potato Famine of the 1840s. About 1.25 million left Ireland to find new environments that did not have the stress of the fungus. The starvation caused by the fungus and the disease it carried was terrible.

Threats Today

Potato crops worldwide are still threatened by the same fungus that caused the Great Potato Famine. In 2001, Russia was close to a large-scale potato crisis. Each year, Russia loses 4 million tons of potatoes because of potato late blight. Summer rains and humidity make some Russian environments ideal for the fungus to grow. This threat of blight affects millions of people still today.

More recently, science and technology are helping to control the fungus that causes potato late blight. In addition, in research labs around the world and at meetings such as the Collaborative Research on Potato Late Blight workshop, scientists are working together to fight against future outbreaks that could again cause widespread destruction of potato crops. Scientists are also working to develop and select new potato varieties that are resistant to infection from the fungus.

Summary

When the number of people living in Ireland kept growing, farmers needed to produce more food to feed them. Potatoes were a good food to grow more of because they could be stored through the winter without refrigeration. To increase potato production, Irish farmers selected and produced the one variety of potatoes that did best, the Lumper. They did not know that it could be dangerous to eliminate the variation in their potato fields. When a new fungus moved into Ireland, it turned out to be an environmental stress that the Lumper potato could not survive. All of the Lumper potato plants were susceptible, and a disease caused by the fungus killed farmers' crops. More than a million people starved to death because they depended on potatoes to feed their families.

Now we know that variation in traits that are coded for by genetic information is very important. Variation among individuals makes it possible for a population to survive when a new environmental stress occurs. Now that we understand how important variation is, we can make better decisions about keeping variation in our crops and appreciate its strength in any population.

Key Concepts

- Genetic variation provides a population with the potential to reproduce under changing environmental conditions.
- Changes in environmental conditions can affect the survival of individual organisms and entire species.
- Without variation in a population, changes in environmental conditions can lead to extinction.

Evidence of Student Understanding

The student will be able to:

- choose and justify a logical explanation for why one trait in a fictional population of organisms could have increased in the percentage of individuals who display the trait after thousands of generations.
- explain a logical explanation for how a fictional population of organisms could become extinct.

Time Needed

50 minutes

Materials

For each student

- 1 copy of Student Page 4.3A ***What history could explain this mystery?***
- 1 copy of Student Page 4.3B ***Artificial and Natural Selection***

Artificial and Natural Selection

1. Hold a whole-class discussion to review the key ideas learned so far in this unit by reviewing the Unit Level Graphic Organizer.

- Have volunteers review big ideas learned from the simulation, emphasizing how it modeled an explanation for how the percentage of individuals with a particular version of a trait could change in future generations.

2. Give every student a copy of Student Page 4.3A ***What history could explain this mystery?***

- Explain that students will work as you direct (individually or in pairs) to study the images and invent a logical explanation that is like how scientists might explain similar evidence about real populations of organisms.
- Explain that students will use evidence from their experiences in the unit (refer to the Unit Level Graphic Organizer) and evidence from a reading they are about to receive to create their explanation for what happened to the populations shown in the Student Page.

3. Use an appropriate reading strategy for your class, and assign the reading on Student Page 4.3B ***Artificial and Natural Selection***.

4. After students complete the reading, work as a class to add evidence to the Unit Level Graphic Orgnizer in preparation for writing their explanations about the fictional populations.

5. Assign students to complete 1 copy of Student Page 4.3A ***What history could explain this mystery?***

- Review students' explanations and provide feedback.

6. Use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **Recall what the change was in the population of plants that was simulated by washers in the previous lesson.** The population of plants in the simulation changed over three generations to have a higher percentage of individuals with the disease resistant trait.

E **Classify the following as either a possible environmental stress or a possible adaptation. Be prepared to explain the criteria you used to make your decisions.**

cold winters	**poisonous bite**
disease	**predators with a poisonous bite**
extra eyelid that blocks sand	**ability to walk upright on two legs**
frequent cloudy days	**drought (lack of rain)**

Look for responses such as:

Possible Environmental Stresses:

– cold winters
– disease
– predators with a poisonous bite
– frequent cloudy days
– drought (lack of rain)

Possible Adaptations:

– poisonous bite
– extra eyelid that blocks sand
– ability to walk upright on two legs

A **Use natural selection as the process, and suggest an explanation like a scientist could propose for why Earth's dinosaurs no longer exist.** Look for answers to include application of the last lessons' key ideas that if an environmental stress was introduced to the dinosaurs' habitat, and if the dinosaur populations did not have sufficient variation among their traits to have any survivors, then their populations would go extinct.

P **How has your prediction changed about the effect of the environmental stress you are testing in your group's experiment?** Answers will vary, depending on whether students can use evidence from the last several lessons to broaden or revise their initial experimental predictions.

S **What have you done in this unit that helped you the most to understand why variation is important in a population for it to survive environmental changes?**

Implementation Guide

1. Hold a whole-class discussion to review the key ideas learned so far in this unit by reviewing the Unit Level Graphic Organizer.

- Have volunteers review big ideas learned from the simulation, emphasizing how it modeled an explanation for how the percentage of individuals with a particular version of a trait could change in future generations.
- Ask: What change in the plant population was simulated by washers in the previous lesson? *The percentage of plants with the disease resistant strain increased.*

2. Give every student a copy of Student Page 4.3A ***What history could explain this mystery?***

- Explain that students will work as you direct (individually or in pairs) to study the images and invent a logical explanation that is like how scientists might explain similar evidence about real populations of organisms.
- Explain that students will use evidence from their experiences in the unit (refer to the Unit Level Graphic Organizer) and evidence from a reading they are about to receive to create their explanation for what happened to the populations shown in the Student Page.

3. Use an appropriate reading strategy for your class, and assign the reading on Student Page 4.3B ***Artificial and Natural Selection***. You may want to organize students into groups of 2–3 students and use collaborative annotation for this reading. Circulate around the class while reading and listening to the student's comments to assess their understanding of the material. Have a whole class discussion about artificial and natural selection and ask:

- Can you think of any reason why changing the cabbage population by selecting only for red cabbage might be a problem? *Because there is less variation in the traits (genetic make up) in a population of red cabbages, there is a greater risk that the entire population of red cabbage could be destroyed by an environmental factor, such as a disease that red cabbage are not resistant against. If the students don't mention similarity between the red cabbage story and what happened to the Lumper potatoes in the previous story, you may want to bring it up.*
- Can you explain why natural selection is a slower process than artificial selection? Why does natural selection generally take many generations while artificial selection can occur within a few generations? *Because in artificial selection, the breeder breeds only those individuals with the selected trait, eliminating all individuals without the selected trait. However, in natural selection, environmental stresses usually do not eliminate all individuals without the select trait at once. Some individuals with variations of the trait are more likely to survive with natural selection.*

4. After students complete the reading, work as a class to add evidence to the Unit Level Graphic Organizer in preparation for writing their explanations about the fictional populations. You may want to use a think-pair-share strategy to help students prepare to write.

5. Assign students to complete 1 copy of Student Pages 4.3A *What history could explain this mystery?*

- Use peer review or presentations to review students' explanations and provide feedback.

Look for responses to the questions on Student Pages 4.3A *What history could explain this mystery?* similar to those that follow:

Population Y

1. When Generation c lived here, it was dry like a desert. The only plants were cacti and it was very dry. When Generation t lived here, it was very different. It looks more like a wetland now than a desert, because there is a river and two ponds. The plants are also different. There are flowers, water plants, and leafy trees that Generation t has.

In the desert not much water, the heat, and the lack of shade could all possibly be environmental stresses. In the wetland, too much water, cooler temperatures, and the wrong kinds of plants could possibly be environmental stresses.

2. One trait is the shape of the critters' feet. Most of them have feet with toes, but three of them have webs for feet.

The variation among the individuals in Generation c was influenced by their genetics. Each critter has its own set of genes that determine what it looks like. The variation is also influenced by the environment. Environments can influence variation because some variations don't survive as well. For example, maybe critters with webbed feet can't run as fast, so their feet get burned on the hot sand and they get infections and die. Then, only the critters with toes are able to live and reproduce. The environment helped determine which critters ended up living. So, it also determined which variation of the feet trait we would see.

3. There are both kinds of feet in both Generations. In Generation c, 3 critters have webs and 13 have toes. In Generation t, it is just the opposite. 15 have webs, and only 3 have toes.

4. Reproductive success and natural selection explain the difference in the variation between Generation c and Generation t, because they have to do with who lives and gets to reproduce.

In the desert, webbed feet were a variation. There weren't many critters with webbed feet, but there were some. When the environment got wetter, the critters without the webbed feet didn't have as good of a foot adaptation. Their toes didn't work as well as the webbed feet in the water. The webbed feet ended up being an adaptation for the new habitat.

Then, maybe the webbed foot critters got more food, and then could have more babies. They had more reproductive success than the critters with the toes.

In 20,000 generations, there would end up being a lot more critters with webbed feet, because they had lots more babies along the way. Natural selection is what you call it when one adaptation has more reproductive success than another, so the critters with that trait live and make babies with that trait and the other ones don't.

Population Z

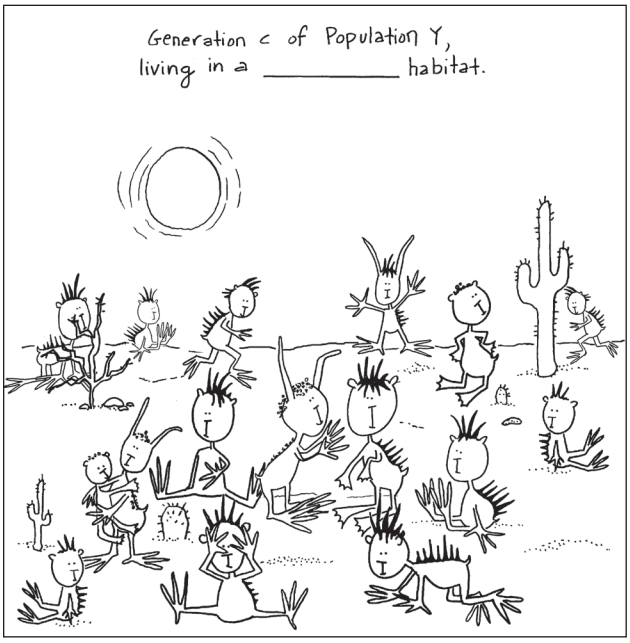
1. When the habitat got wetter, Population z disappeared. They might have all died or they might have had to move away.

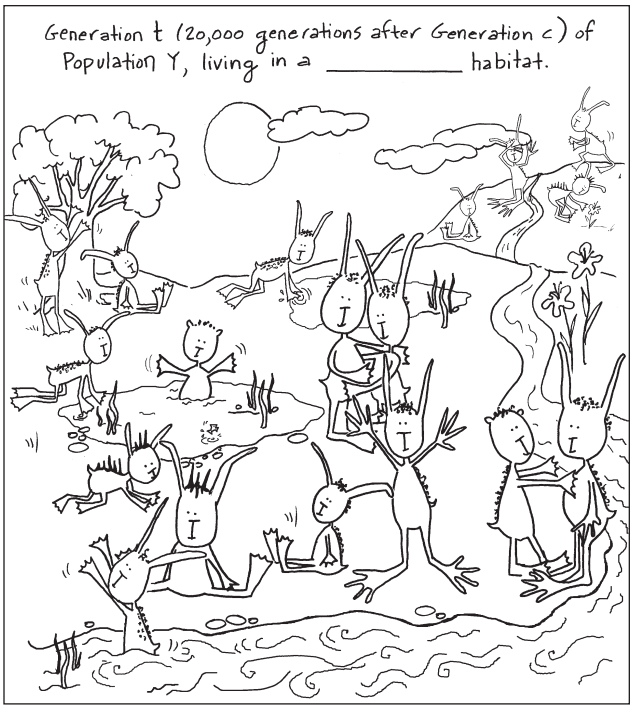
The explanation for my answer is that there is less variation in Population Z than there was in Population Y. There aren't any critters with long ears, spiky hair, or webs for feet. Those individuals with some of the variations in Population Y had more reproductive success in the new wetland habitat. The extra water was an environmental stress and none of the critters in Population Z had the variations that were adaptations for it.

Since population Z didn't have those variations they would have all died and become extinct unless they all just moved away to some place where it was still dry.

6. Use the REAPS questions throughout the lesson where appropriate.

Student Page 4.3A: What History Could Explain This Mystery?





1. Describe how the environment that **Generation *t*** lives in has changed since **Generation *c*** lived there. List at least one possible environmental stress in each of the two environments.

2. Choose one trait in **Generation *c***. What influences the variation in that trait among the individuals?

3. For the same trait that you selected in #2, describe the differences in the variation of that trait between **Generation *c*** and **Generation *t***.

4. How could **reproductive success** and **natural selection** explain the differences in variation between **Generation *c*** and **Generation *t*** that you described in #3.

Student Page 4.3A: What History Could Explain This Mystery?

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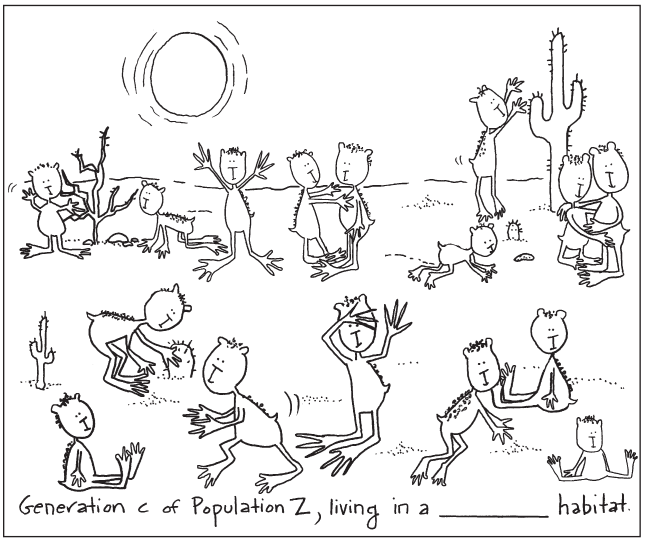
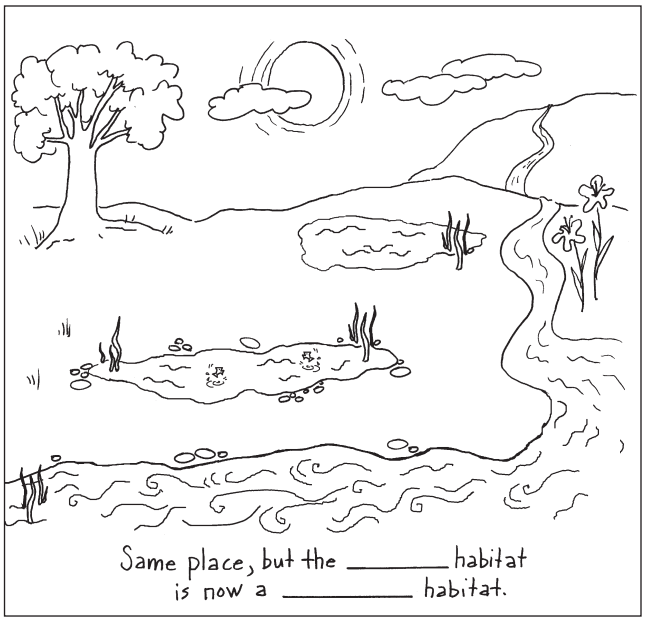




1. **Generation *c*** of Population Z lived at the same time **Generation *c*** of Population Y. Once the habitat changed, Population Z met a very different fate. What happened to Population Z?

- Explain your answer using the following terms: environmental stress, reproductive success, adaptation, and variation.

Student Page 4.3B: Artificial and Natural Selection

Have you ever heard the expression, "Variety is the spice of life?" In other words, wouldn't life be dull without variety? Imagine a world where all humans looked and acted identically. Wouldn't that quickly become boring? Not only might it be boring, it also could be dangerous. Consider this: if everyone were identical, everyone would be at the same risk any time an infectious disease was introduced. For example, if one person from your identical class became ill with a stomach flu virus, everyone in your class (and your neighborhood, and your community) likely would get ill because their immune systems would be identical. However, because we are all unique individuals, our bodies respond differently to diseases and other environmental factors.

When individuals in a population express a trait or characteristic in different ways, we call that variation. For example, having fingerprints is a human trait. Fingerprints are different for every human. There are many fingerprint variations. Other traits have variations, too, such as hair color, length of toes, and how fast you grow. The question is where does this variation come from?

Variation begins when reproduction involves the joining of genetic information from two individuals. One example is when a human mother and father have a baby. Genetic information is carried in reproductive cells. In humans, sperm and eggs carry this information in a "code" called DNA. In flowering plants, the DNA is carried in pollen and eggs. The code determines what traits can develop in an individual. Because half of the code comes from each parent, the offspring's code is unique.

Genetic information determines what traits are possible to develop, but the environment in which you live also influences what you see in the mirror. Your physical traits are the result of the interactions between the genetic information you inherited from your parents and the environment in which you live. Consider, for example, a child born with genetic information that could make it possible for her to grow six feet tall. If that child doesn't get enough nutritious food, she may only grow to be five feet tall. Can you think of other examples where the environment interacts with genetic information to determine how traits are expressed? The Fast Plants that didn't get enough fertilizer are another example. The plants had the genetic code to grow tall, but they were short because their environment lacked nutrients.

Natural Selection

Look around your class or any group of humans and you will see certain traits that are much more common than others. For example, look at your classmates' hands. Nearly everyone is born with the genetic code to develop four fingers and a thumb. Why is there so little variation in the number of fingers? Did the ancient human ancestors also have four fingers and a thumb? That is one type of question that humans are often curious to answer.

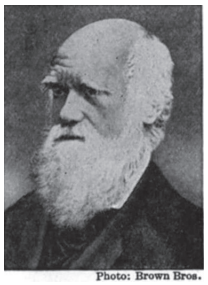


Photo: Brown Bros.

Scientists develop explanations for questions by gathering as much evidence as they can and using that evidence to draw logical conclusions. In the1800s, two scientists named Charles Darwin and Alfred Wallace became very curious about how to explain variations they observed. Darwin was a naturalist sailing to islands across the oceans. His job was to record observations and learn about as many organisms as he could at every place the ship stopped. He began to notice patterns in the traits and variations he observed, and it made him wonder why. After many years studying his and other scientists' observations and ideas, he presented a logical explanation for why some populations have different kinds of variation than others. Wallace reached the same conclusion and published his explanation at about the same time as Darwin.

Charles Darwin and Alfred Wallace concluded that some variation in traits improve survival, depending on the environment. They reasoned that if a trait increased the chance that an individual would survive long enough to reproduce, the trait could be passed on to offspring (through the parent's genetic information). If many individuals passed on this trait then future generations of the population would have a greater percentage of individuals with that trait. It took a long time for Darwin and Wallace to figure out this explanation for the patterns they saw in their observations.

Think through this example. Imagine a large rabbit population living in the snowy Alaskan countryside. Rabbits have fur—that is a trait they all share. Consider how there would be variations in fur color shown by rabbits in that large (imaginary) population. Imagine that most of the rabbits have all white fur. Now imagine that a small percent have light brown fur. We might ask the question, "Why don't half the rabbits have brown fur?"

Darwin would likely ask us to think about whether the white fur trait gives those white-furred individuals a survival advantage. Would white rabbits in Alaska be better able to survive? Think about whether it would be easier to escape from a wolf or other predator if you were a rabbit with white fur running on snowy ground. If you were harder to see, it would be easier to escape. If the white rabbits are not eaten as much, they are more likely to live long enough to reproduce and raise a litter of offspring. What color would you expect their offspring to be? If the parents are white-furred, and if fur color is a trait that is passed through genetic information to the offspring, the bunnies will likely be white.

What about the rabbits with brown fur? If more brown-furred rabbits are caught by predators and eaten because they are easier to see, they will not survive to become parents. If they cannot pass down their genetic information for brown fur to the next generation, then fewer rabbits in the future population will have brown fur. Even though some brown-furred rabbits will likely survive and become parents, there likely will be fewer and fewer in future generations.

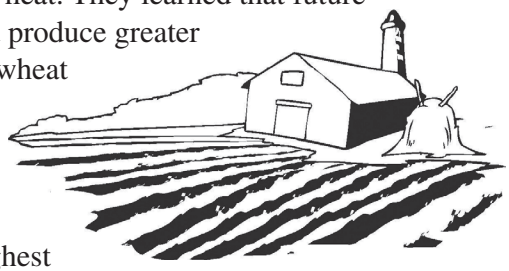
However, what would happen to a population of these rabbits living in a California desert? Perhaps the white-furred rabbits would be easiest for the coyotes and owls to see and capture. How might that influence the percentage of rabbits with white fur in future generations? In the California deserts, future generations would probably have few white-furred rabbits and many brown-furred rabbits.

Where a population lives—in Alaska, California, or wherever on Earth—the environment and environmental stresses essentially "select" certain characteristics of plants and animals for survival and reproduction. Those characteristics or traits that are passed down to future generations through inherited genetic information may become more or less common in a population, depending on whether they are beneficial or not. If an inherited trait gives an individual a better chance to survive and reproduce in a particular environment, biologists call that trait an adaptation. Which traits are adaptations depends on the environment and the population. It takes many, many generations for a population to gradually change to have a greater percentage of individuals showing a particular adaptation. The process by which this happens is called natural selection. Darwin developed the term natural selection for the explanation he reasoned and supported with observations and evidence.

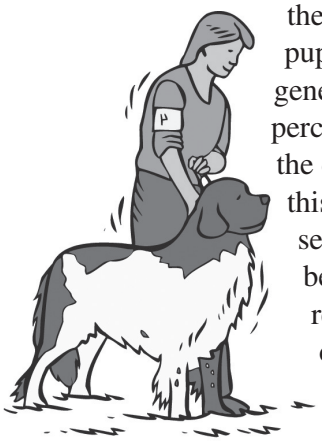
Artificial Selection

One of the pieces of evidence that Darwin used in developing his explanation came from farms. He could clearly see that farmers selected plants

with certain traits that were beneficial and planted only those seeds. Experience showed that by doing this, farmers could generate crops of plants in which the beneficial trait became more common in future generations. For example, wheat farmers selected seeds to plant the next year from the plants that produced the greatest amount of wheat. They learned that future crops would produce greater and greater wheat harvests if they chose to plant seeds from the highest production plants. This process is called artificial selection because the farmer chooses which plant will have the greatest reproductive success and influence the next generation.



Another example of artificial selection can be seen in dog-breeding programs. Think of the many different dog breeds, all with distinct variations that are characteristic to the breed. For example, Border collies have been selectively bred to have behavioral and physical traits that are well suited for herding sheep. In each generation, breeders selected the dogs with the best trait for successful sheepherding. Those were the dogs they chose to breed to produce puppies. Then the following generations had higher percentages of puppies with the desired herding traits. In this way, breeders artificially selected which dogs would be most successful at reproducing and passing down their traits.



Farmers and ranchers during Darwin's time had been using artificial selection to increase the quality of their crops, also. However, they did not know what scientists now know about genetics, so they lacked key understanding about inheritance. Still, Darwin observed patterns and used evidence from artificial selection to support his ideas about how natural factors could play a role in selecting which traits would become more common in a population over time.

Artificial selection is used to refine a population to better suit human needs. Plant and animal breeders often see changes in only a few generations. Natural selection is generally a much slower process. Think about what is different between artificial and natural selection that might cause natural selection to be a slower process. Imagine that you are a farmer, and you raise cabbage. Suppose that red cabbage sells for a lot more money than green cabbage. So, the more red cabbage you raise, the more money you make. Would you save seeds from any green cabbage to plant next year? You might select exclusively for red cabbage. The shift towards more red color in future cabbage generations could happen relatively quickly if ONLY seed from red cabbage was kept. Can you think of any reason why changing the cabbage population by selecting only for red cabbage might be a problem?

Today, artificial selection has influenced nearly everything you eat. Strawberries are larger than ever, chickens lay more eggs than before, and dairy cattle produce far more milk than their wild ancestors did. Examples of artificial selection's influence are easy to find. Examples of natural selection can be found, too, but they take many more generations to unfold. Can you explain why natural selection is a slower process than artificial selection?

- Individual organisms with certain heritable traits are more likely than others to survive and have offspring, and they influence the traits in future generations more than those that do not survive or produce many offspring.
- Scientists use appropriate tools and techniques to gather, analyze, and interpret data.

STEP 5

Overview

In this two-part step, students first explain that the acquired trait of leaflessness is not passed on to offspring based on evidence from the leafless plant investigation conducted by the class. In the second lesson, students describe how environmental factors can influence the variation of traits and reproductive success in a population based on evidence from their own investigations.

Previously, in Step 2, Lesson 2, the whole class was guided to design one investigation to test if leaflessness—a trait created by cutting leaves off of Fast Plants—would be passed on to offspring. Here in Step 5, Lesson 1, the teacher models for the students how to analyze experimental results and develop a scientific explanation. Students will use this analysis model to analyze their own results and develop scientific explanations for their variation investigations in the next Step 5, Lesson 2.

Key Concepts

- Acquired traits, like the leafless condition acquired by the plant in Step 2, Lesson 2, are not inherited.
- Experimental evidence and credible scientific information can be used to support claims that can be logically linked to form scientific explanations.
- When fact and opinion are intermingled in a claim, or an explanation does not follow logically from the given evidence, the explanation and/or conclusion is not considered scientific.

Evidence of Student Understanding

The student will be able to:

- explain if the class's experiment with leafless plants supported or did not support their original prediction about the question: If we made a new trait—leaflessness—by clipping the leaves from a Fast Plant, would the plant's offspring inherit that trait?
- develop an evidence-based explanation for the leafless plant experimental results and recognize the key components of that explanation.
- species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations.

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Building Evidence-based Explanations

1. Remind the class that in Step 2.2, you worked together to develop an investigation to answer the question, **Will the trait of being leafless, which was brought about by cutting the leaves off of two parent plants, be inherited by the parents' offspring?** Explain that in this step, you will use evidence to support an explanation which answers this question.

2. Make it clear to students that they will be going through this same process to develop an explanation on their own for their variation investigation in the next step, so it is important to pay close attention.

3. Have students take out and read their Student Page 2.2B *Experimental Sequence* to review their initial predictions and expectations for how the experiment would unfold.

4. Hold a whole-class discussion about one or two results from the experiment to clarify what is meant by results and evidence before students use the Student Page 5.1A to summarize and analyze the experimental results.

5. Assign students to work in pairs to complete the first two pages of Student Page 5.1A *Building Scientific Explanations*. Travel around the class to clarify directions and determine what students find most challenging.

6. Call together a whole-class discussion to complete a set of example entries, including the explanation on page 3 of Student Page 5.1A *Building Scientific Explanations*.

- Display a copy of the student pages on an overhead, chart paper, or white/black board while giving examples.
- Use a Think Aloud strategy to model how to develop a logical explanation for the results, using evidence to support the reasoning.
- As you model the explanation development, demonstrate how the process is underpinned

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Time Needed

50 minutes

Materials

For each student:

- 1 copy of Student Page 5.1A *Building Scientific Explanations*
- written record of observations from the Leafless Fast Plant experiment (Started in Step 2, Lesson 2)

For the class:

- 1 overhead transparency of Student 5.1a *Building Scientific Explanations*

by the question: **How should we organize the evidence to present the strongest explanation?** (NRC, 1996)

- Complete the Think Aloud by modeling how to reflect on the initial prediction and compare it to the resulting explanation by using the Venn diagram on page 4 of Student Page 5.1A *Building Scientific Explanations*.

7. After the class discussion in which you model how to develop a scientific explanation, have students apply what they learned by completing the last two pages of Student Page 5.1A *Building Scientific Explanations*.

8. Conclude with a whole class discussion about adaptations and how inherited versus acquired traits influence reproductive success and so the next generation.

9. Record key ideas learned from the experiment and explanation development on the Unit Level Graphic Organizer, and use the REAPS questions throughout the lesson where appropriate.

REAPS Questions

R **What is a heritable trait?** A heritable trait is a characteristic that is passed from parent to offspring through the genetic code. **What is the difference between inherited and acquired traits?** Inherited traits can be passed from parent to offspring, but acquired traits are not coded for in the genetic code and so cannot be passed to the next generation through reproduction.

E **What are the key things to remember to include in an evidence-based explanation? Why are those things important for a scientific explanation?** Strong scientifically oriented explanations include claims or reasons that are linked with evidence using good logic.

A **Explain how acquired traits affect the next generation of a population of plants.** Acquired traits cannot affect the next generation of plants. Note: In humans and some other organisms, an acquired trait such as something learned can affect the next generation through teaching; however, the genetic code cannot be affected by an acquired trait. Explain why an acquired trait can be an adaptation or not. Because an adaptation is an inherited trait (so that it influences future generations) that makes an organism better able to survive in its environment and reproduce successfully to pass along that trait, an acquired trait cannot be an adaptation.

P **What similarities and differences do you think there will be between writing the explanation for this experiment and writing the explanation for your own experiment?** This Predict question sets the stage for students to transfer their experience in this lesson (and others) to their own experimental results.

S **What new questions do you have now about inherited and acquired traits?** Use this question to check for students' understanding of these key concepts.

Teacher Background Information

This lesson is a culminating experience for the investigation into how leaflessness caused by clipping two Fast Plants' leaves off before flowering will be passed to the next generation. When students analyze the results, informally assess their understandings of acquired versus inherited traits as well as the term adaptation.

Project 2061 notes the following research points to keep in mind about students' common misconceptions regarding adaptation:

Middle-school and high-school students may have difficulties with the various uses of the word "adaptation" (*Clough & Wood-Robinson, 1985a*; *Lucas, 1971*; *Brumby, 1979*). In everyday usage, individuals adapt deliberately. But in the theory of natural selection, populations change or "adapt" over generations, inadvertently. Students of all ages often believe that adaptations result from some overall purpose or design, or they describe adaptation as a conscious process to fulfill some need or want. Elementary- and middle-school students also tend to confuse non-inherited adaptations acquired during an individual's lifetime with adaptive features that are inherited in a population (*Kargbo et al., 1980*).

This lesson is also intended to provide an opportunity to support students' learning about and preparing to develop scientific explanations. The *Immersion Unit Toolbox* is an additional source for information about developing evidence-based explanations.

Advance Preparation

Seeds from the experimentally treated parent plants must be allowed to mature, be planted, and grow to a size where leaves are clearly visible (approximately 4–5 days) before beginning this lesson. In addition, students need one or two opportunities to make observations during the experiment.

Implementation Guide

Allow 5–10 minutes for students to make observations and notebook entries before or after lesson.

1. Explain to students that in Step 5 they will:

- revisit the investigation question and experimental results from Step 2 Lesson 2: "Will the trait of being leafless, caused by cutting the leaves off of two parent plants, be inherited by their offspring?"
- review and analyze the results
- use evidence to support an explanation, which answers the question from Step 2 Lesson 2.

2. Prompt students to pay close attention to how the class uses evidence to develop an explanation by explaining that they will go through this same process on their own in the next step. (See ***Immersion Unit Toolbox***—Formulating Evidence from Explanations) Direct students to pay attention to:

- What observations they made and why
- What results or evidence they need to build an explanation
- How the evidence relates to the question

3. Organize students in the same groups they were in when they worked on Step 2 Lesson 2. Have students in each group take out and read their Student Page 2.2B *Experimental Sequence* to review their initial predictions and expectations for how the experiment would unfold.

4. Engage students in a discussion about what is meant by results and evidence by holding a whole-class discussion about results from the experiment. While discussing the experiment, have students describe the difference between the terms:

- Result – something that is the outcome of testing
- Evidence – data that can be used to explain something

Then ask students how they would describe the information collected in the leafless plant investigation.

5. Assign students to work in pairs to complete the first two pages of Student Page 5.1A *Building Scientific Explanations*. Travel around the class to clarify directions and determine what students find most challenging.

6. Call together a whole-class discussion to complete a set of example entries, including the explanation on page 3 of Student Page 5.1A *Building Scientific Explanations*. Display copies of the student pages on an overhead, chart paper, or white/black board while giving examples.

Use a Think Aloud strategy to model how to develop a logical explanation for the results, using evidence to support the reasoning. As you model the explanation development, demonstrate how the process is underpinned by the question: ***How should we organize the evidence to present the strongest explanation?*** (NRC, 1996)

- **Review Question** Before I start looking at evidence, I want to look at the question again, to make sure that the explanation answers the question. One of the challenges of doing experiments is making sure that the evidence we're collecting addresses the exact question that is being asked. Answering something other than the question may seem odd, but it's a common mistake.
- **Decide on What Kind of Result You are Looking For to Explain the Question.** The question: "If we made a new trait—leaflessness—by clipping the leaves off of a Fast Plant, would the leafless plant's offspring inherit the leafless trait?" The question tells us that the result we want to see is if the offspring do or do not have leaves.
- **Compare Your Prediction with What Actually Happened**. I see from the

Investigation Sheet 2.2 that I predicted that the offspring from the leafless plants would have leaves. I'm glad that I wrote down why I predicted this, because I can compare what I was thinking then with what I know now. I wrote down why I made this prediction. I based my prediction on my personal experiences observing the offspring of plants, animals and humans. I can think of many examples of environmental factors changing a trait, such as people cutting or dying their hair. But, from experience, I know that even if both parents dyed their hair purple or cut their hair off these environmental factors would not change the color or length children's hair. These environmental factors would not directly change the inherited traits.

- **Review Evidence to See if it Matches or Refutes Your Prediction**. I can see from the investigation notebook records and by looking at the plants, that all of the offspring of the leafless plants—have leaves. It looks like my prediction was right.
- **Look for other Forms of Evidence that will Support or Refute Your Explanation**. It's tempting to go ahead and create an explanation now, but since we are acting as scientists, we need to do one more thing that scientists do. As scientists, we would look for any other evidence connected to the question. It is always important to include all evidence, even if it suggests a different answer or explanation from your own results. Where would we look for more evidence? From our own data and from investigations done by other scientists. When we do the next investigation, students will be able to compare their evidence between themselves just as scientists do.

Continue the Think Aloud by modeling how to reflect on the initial prediction and compare it to the resulting explanation by using Student Page 5.1A *Building Scientific Explanations*.

- Once we have all of the evidence together, we need to summarize the information. Our investigation was designed to look for two possible outcomes; the offspring plants would either have or not have leaves. All of the offspring from the investigation had leaves
- **Use Evidence to Develop an Explanation**. My next step is to use the evidence from the investigation to build an explanation of what happened. I need to determine the best order and way to present this evidence and the reasoning to make the strongest explanation. Having leaves is an inherited trait, just as having brown hair, being tall, or having long fingers are inherited traits. But in this case, being leafless is not an inherited trait; it was caused it by an environmental factor—people cutting off leaves. So far, our evidence supports the idea that this environmental factor, cutting off the leaves, does not change inherited traits.

7. After the class discussion in which you model how to develop a scientific explanation, have students apply what they learned by completing the last two pages of Student Page 5.1A *Building Scientific Explanations*.

8. Conclude with a whole class discussion to introduce adaptations and how inherited versus acquired traits can influence both reproductive success and which genetic material is passed on to the next generation.

- Provide a definition for ***adaptation***: an inherited trait that makes an organism better able to survive and reproduce in a particular environment.

9. Record key ideas learned from the experiment and explanation development on the Unit Level Graphic Organizer, and use the REAPS questions throughout the lesson where appropriate.

What we did	What we know	How we know it
Clipped leaves from two Fast Plants that we grew from seed and recorded observations to determine if they would pass that trait to their offspring. Analyzed our observations and measurements from the leafless investigation.	Leaflessness is an acquired trait, and acquired physical traits cannot be passed to the next generation.	• We have data from the class experiment. • We learned from a discussion our teacher led about adaptations.

Student Page 5.1A: Building Scientific Explanations

Question we hope to answer with evidence from this experiment and research:

What did you predict would happen? Why did you think that?

Describe all of the results that you observed while doing this experiment:

What other information have you learned from your studies that relates to this experiment? List the sources for this evidence, too.

Student Page 5.1A: Building Scientific Explanations (continued)

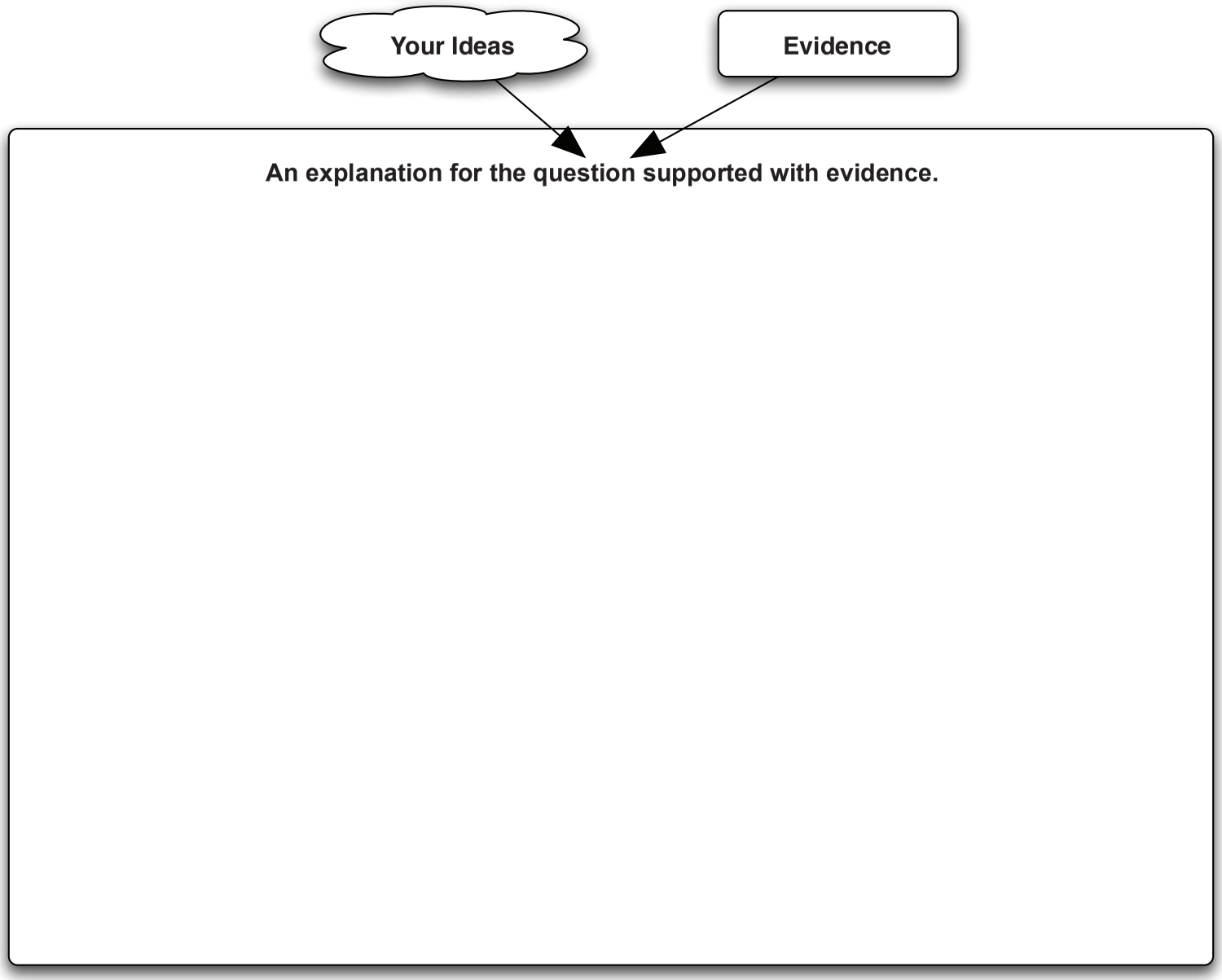
Results that you observed while doing this experiment

Other information you learned from your studies that relates to this experiment

List your ideas about how you could explain the results from the experiment and answer the question you were investigating:

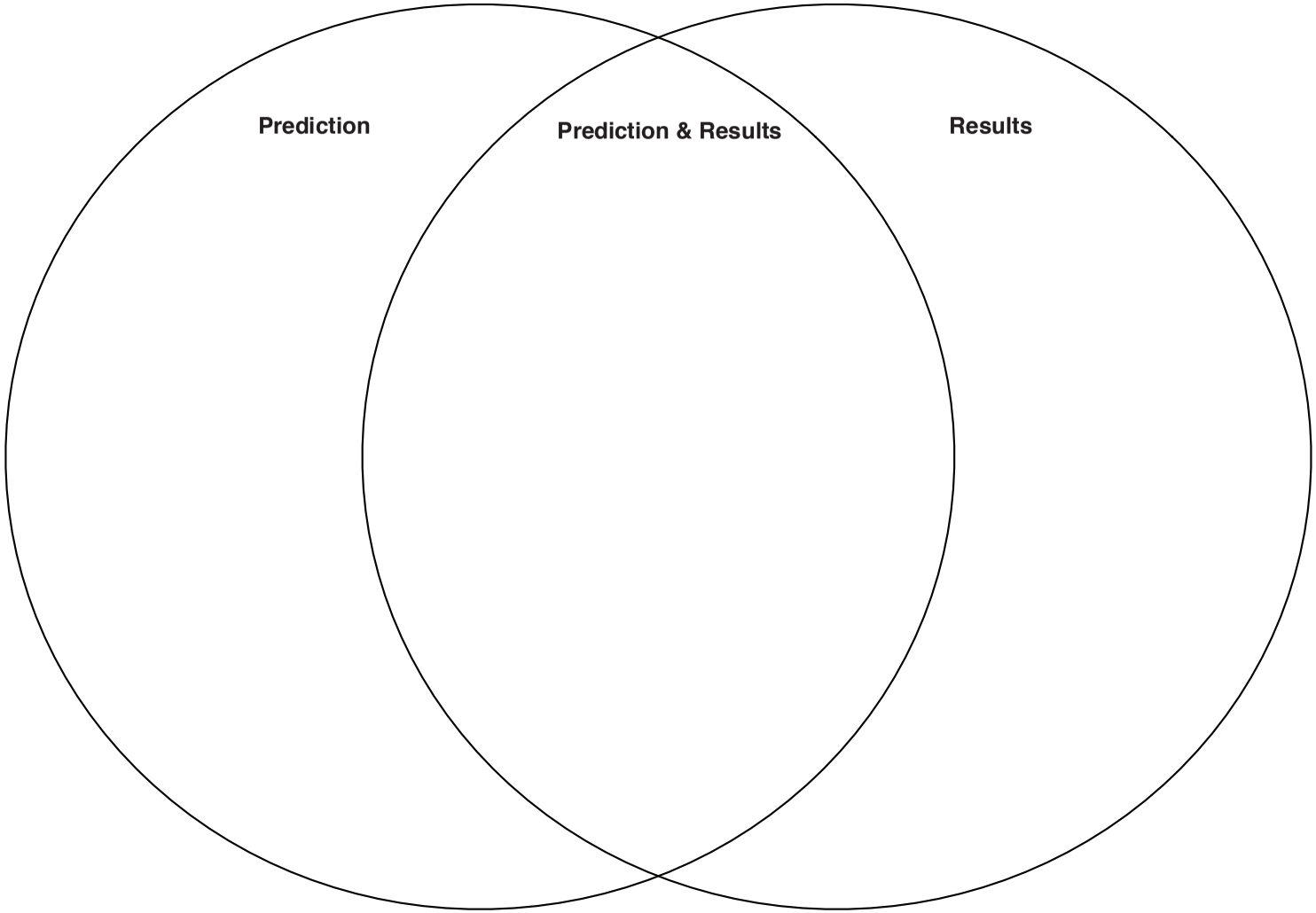
List the evidence that is linked to each of your ideas about the results:

Student Page 5.1A: Building Scientific Explanations (continued)



Student Page 5.1A: Building Scientific Explanations (continued)

Compare and contrast your prediction from Lesson 2.2 with the results and your explanation:



Key Concepts

- Naturally occurring variations of traits in a population are influenced by genetic and environmental factors and evolve over generations by selective processes.
- Experimental evidence and credible scientific information can be used to support claims that can be logically linked to form scientific explanations.
- When fact and opinion are intermingled in a claim, or an explanation does not follow logically from the given evidence, the explanation and/or conclusion is not considered scientific.

Evidence of Student Understanding

The student will be able to:

- explain if their group's experiment with Fast Plants supported or did not support their original prediction about their question regarding the influence of an environmental factor on variation in reproductive success within the population.
- explain how their work developing explanations is like what scientists do as they seek to answer questions about the natural world.

Time Needed

100 minutes

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Investigation Explanation

1. Start the lesson by focusing student attention on the Unit Level Graphic Organizer to discuss what students know now about how the traits of populations can change over time.

- From evidence that the class has accumulated, highlight evidence that could be used to explain change of traits in individuals and populations over time.

2. Explain that in this lesson, students will pull together all they have learned in this unit plus the data collected from their investigations to explain their experimental results and answer their original question, *How might an environmental stress affect variation and reproductive success in Fast Plants*?

- Remind students that the data they collected in the investigation is not their only evidence. Other investigations, readings (such as *The Development of Fast Plants*, and the Fast Plants Growing Protocol) and other observations they have looked at in this unit provide additional evidence.

3. Hand out to each student a copy of Student Page 5.1A *Building Scientific Explanations*, and have them complete it individually while talking with their investigation group members.

- Revisit with students the Investigation Rubric that was given out when they began this investigation in Lesson 2.4, and explain your expectations for developing scientific explanations to conclude the environmental stress and variation investigations.

- Remind students that this will be completed as the one used in the last lesson to develop an explanation for their experiments.

4. Explain to the class how you will have students present their explanations. Give guidelines for the way their presentations will be evaluated:

- the criteria for an exemplary presentation

- the amount of time each group will be allotted

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Materials

For each student:

- 1 copy of Student Page 5.2A *Building Scientific Explanations*
- 1 copy of Student Page 5.2B *Investigation Rubric (same as used in Step 2, Lesson* 4*)*
- 1 copy of Teacher Page 5.2b *Investigation Rubric*
- science notebooks with data and observations from the environmental stress and variation experiment

For each group of 4 students

- presentation materials as needed (overhead transparencies, etc.)

- the expectation of individual participation among the group members during the presentation
- the essential presentation components:
  - question asked
  - prediction
  - procedure
  - experimental results
  - explanation for results and response to the question asked
  - additional questions raised

5. Before students complete their explanations, conduct the REAPS discussion to check for understanding.

6. Have students present their explanations as directed. During and after the presentations, summarize the key points in the investigations that were evidence for the following:

- how variation within a population is influenced by environmental factors
- how environmental factors can influence reproductive success in a population

REAPS Questions

R **What traits did you observe in this investigation?** Answers will vary, depending on what students observed in their experiments.

E **What claims can be supported by the experimental evidence collected by you or your classmates?** Answers will vary, depending on students' experimental results.

A **What claims can be supported by readings and other scientific information that relate to the question asked in your investigation?** Answers will vary, depending on students' claims. Evidence that is linked to claims with explicit logic and sound reasoning is key to whatever scientific explanation students develop for their investigation.

P **How do you predict the environmental factor that you investigated will affect seed production? Why is that an important question when studying natural selection?** Seed production is a strong indicator for reproductive success. It is reasonable to infer that those plants that produce more seeds in a population are also more likely to have adaptations that will influence future generations.

S **How is what you did in this lesson like what a scientist does? Scientists use logic and reasoning to link evidence to claims when they develop explanations and seek to answer questions about the natural world.**

Implementation Guide

1. In Step 5 Lesson 2, students will build explanations for the question, **How might an environmental stress affect the variation of traits and reproductive success in Fast Plants?** using evidence from the investigation, reading and other sources, as well as from what they have learned in this unit.

2. To remind students about the importance of how changes occur in populations, start the lesson by using the Unit Level Graphic Organizer. Use the graphic organizer to guide a student discussion about what the students know about how populations can change over time.

- From the evidence the students have collected, highlight any evidence that can be used to describe or explain changes in traits of individuals or populations over time.
- Explain to students that in this lesson they will gather and analyze all they have learned in this unit, including the evidence to develop an explanation for the question asked at the beginning of the unit.
- Remind students that the data they collected in the investigation is not their only evidence. Other investigations, readings (such as *The Development of Fast Plants*, and the Fast Plants Growing Protocol) and other observations they have looked at in this unit provide additional evidence.

3. Hand out to each student a copy of Student Page 5.2A *Building Scientific Explanations*, and have students complete it individually while discussing it with group members.

- Explain to students that they will use the same method they used in Student Page 5.2A *Building Scientific Explanations* when they develop explanations for the environmental stress and variation investigation question.
- Revisit with students the Investigation Rubric that was given out when they began this investigation in Lesson 2.4.
- Remind students that this will be completed as the one used in the last lesson to develop an explanation for their experiments.

4. Explain to the class how you will have students present their explanations. Give guidelines for the way their presentations will be evaluated.

- the amount of time each group will be allotted
- the expectation of individual participation among the group members during the presentation
- the essential presentation components:
  - question asked
  - prediction
  - procedure
  - experimental results
  - explanation for results and response to the question asked
  - additional questions raised

5. Before students complete their explanations, conduct the REAPS discussion to assess the students' understanding.

6. Have students present their explanations as directed. Use this opportunity to assess student understanding of the key points. During and after the presentations, summarize the following key points:

- how the variation of traits within a population is influenced by environmental factors
- how environmental factors can influence reproductive success in a population

Student Page 5.2A: Building Scientific Explanations

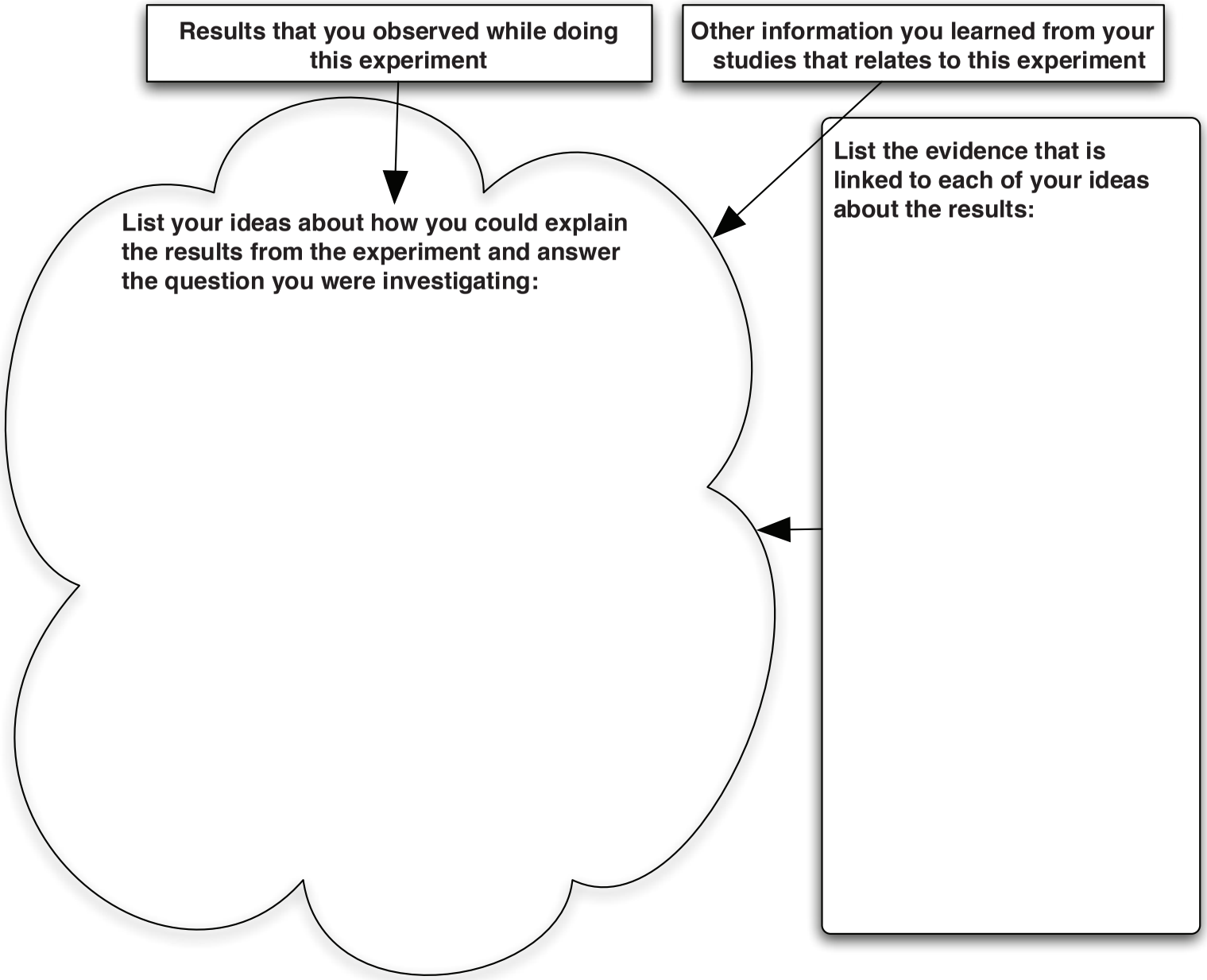
Question we hope to answer with evidence from this experiment and research:

What did you predict would happen? Why did you think that?

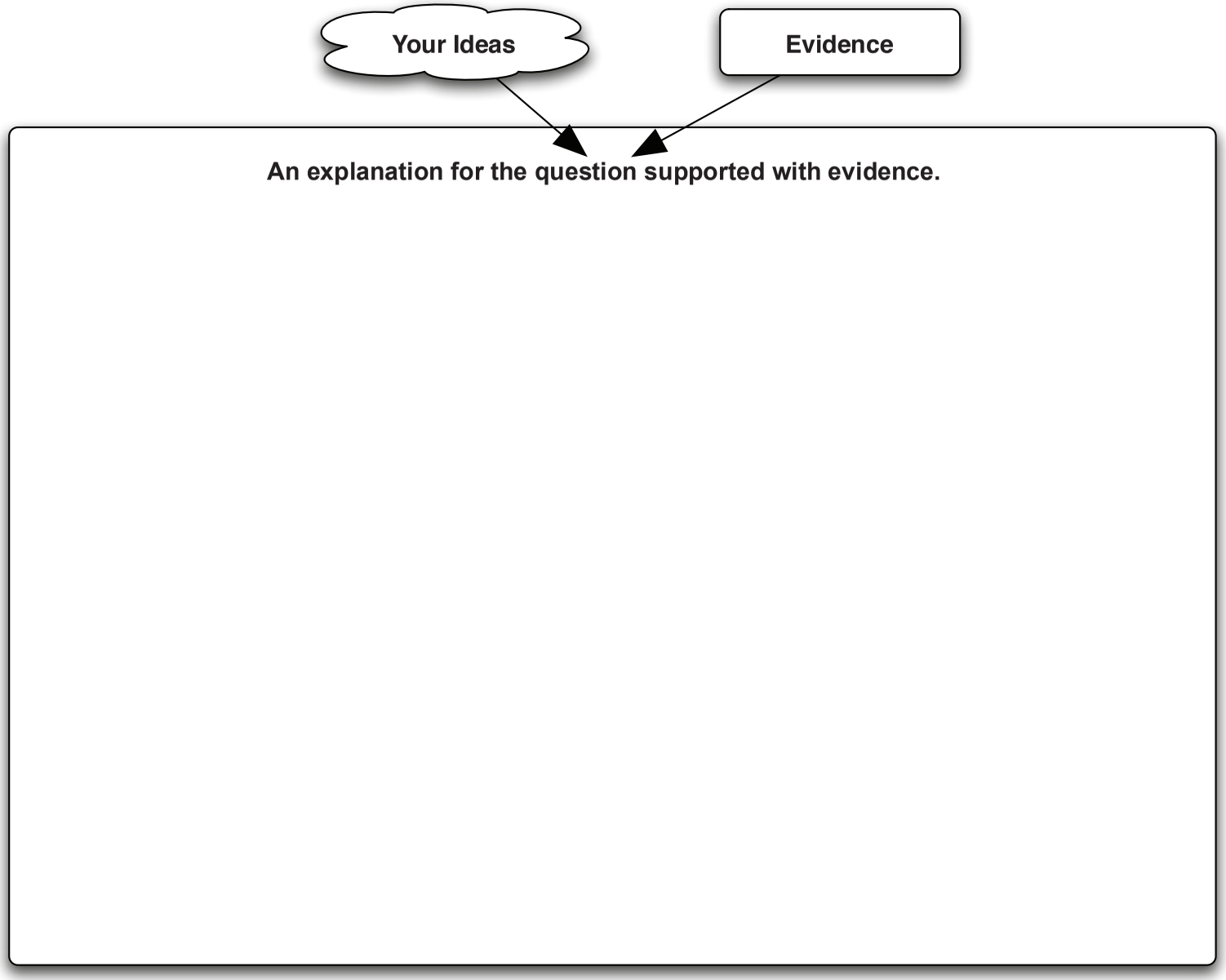
Describe all of the results that you observed while doing this experiment:

What other information have you learned from your studies that relates to this experiment? List the sources for this evidence, too.

Student Page 5.2A: Building Scientific Explanations (continued)

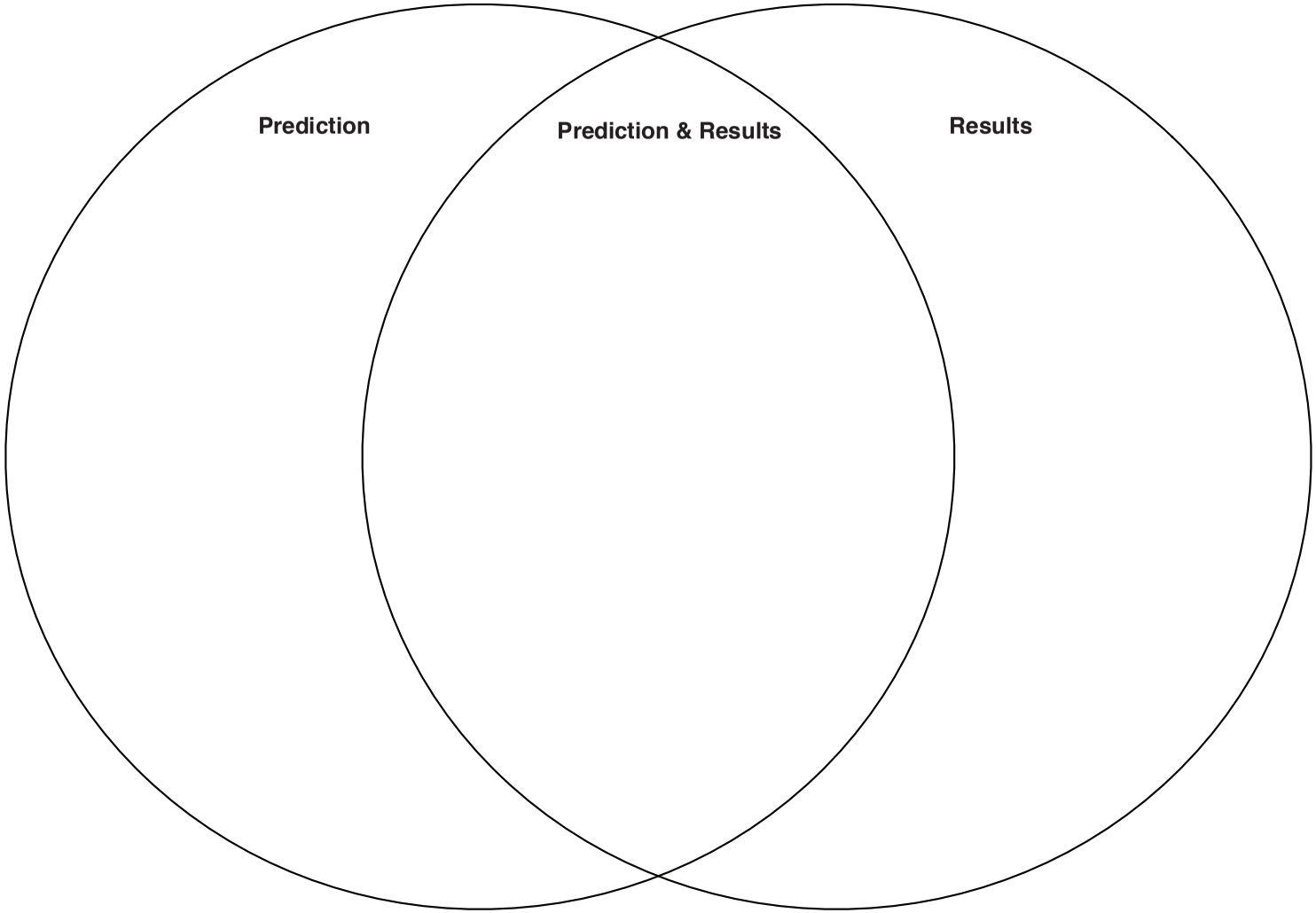


Student Page 5.2A: Building Scientific Explanations (continued)



Student Page 5.2A: Building Scientific Explanations (continued)

Compare and contrast your prediction from Lesson 2.2 with the results and your explanation:



Student Page 5.2B: Investigation Rubric

Criteria	Exemplary
Scientifically Oriented Questioning: Investigating a testable question about how environmental factors affect variation and reproductive success in Fast Plants	Experiment is based on an interesting and scientifically testable question about the impact that an environmental stress might have on seed production (reproductive success) in a population of Fast Plants. Chosen question is directed toward finding out information that can be described, explained, or predicted by scientific investigation. Initial prediction is clearly stated and includes explanations for both why it was predicted and whether or not it was supported by the experimental evidence.
Experimental Design—Variation, reproductive success, and environmental factors: Shows ability to design and conduct a scientific investigation	Experimental procedure sets the stage for gathering information that is clearly related to the chosen scientifically oriented question. Investigation design includes procedures for systematic observation, making accurate measurements, and identifying and controlling variables. Mathematics, tools, and techniques chosen are appropriate to the question asked.
Explanation: Claims are logically linked to evidence to support a strong explanation about how an environmental stress affects variation and reproductive success in Fast Plants	Explanation clearly shows critical thinking about evidence. Explanation is based on claims that are supported by both experimental evidence and scientific information from reliable sources. Explanation is built from claims and evidence that are logically linked. Explanation is stated in terms of the relationship between two or more variables. Explanation clearly refers to the question and to the hypothesis or prediction.

Teacher Page 5.2b: Investigation Rubric

Criteria	Exemplary	Accomplished	Beginning
Scientifically Oriented Questioning Seed Production (Reproductive Success) and Environmental Factors	Experiment is based on an interesting and scientifically testable question about the impact that an environmental stress might have on seed production (reproductive success) in a population of Fast Plants. Chosen question is directed toward finding out information that can be described, explained, or predicted by scientific investigation. Prediction and then hypothesis are clearly stated and include explanations.	Experiment is based on an interesting and scientifically testable question that relates to environmental stress without linking it to seed production (reproductive success). Chosen question needs additional clarification to focus it on information that can be described, explained, or predicted by scientific investigation. Prediction and then hypothesis are stated and include a brief explanation.	Experiment is based on a question that either is not scientifically testable or is unrelated to how environmental stress can affect seed production (reproductive success). Chosen question requires equipment, techniques, or time that is unavailable to this class Or question cannot be described, explained, or predicted by scientific investigation. Either the prediction or hypothesis is missing or lacks explanation.
Experimental Design—Variation and Environmental Factors Shows ability to design and conduct a scientific investigation	Experimental procedure sets the stage for gathering information that is clearly related to the chosen scientifically oriented question. Investigation design includes procedures for systematic observation, making accurate measurements, and identifying and controlling variables. Mathematics, tools, and techniques chosen are appropriate to the question asked.	Experiment is based on a scientifically oriented question that is indirectly related to the chosen scientifically oriented question. Investigation design either lacks procedures for systematic observation or accurate measurements, or else does not identify and control variables. Mathematics, tools, and techniques chosen could be improved in order to appropriately address the question asked.	Experiment is based on a question that is unrelated to the chosen question. Investigation design is poorly planned for making systematic observations, making accurate measurements, and identifying and controlling variables. Mathematics, tools, and techniques chosen are either missing or else inappropriate for the question asked.
Explanation: Uses evidence to explain the relationship observed between environmental influences and seed production (reproductive success)	Explanation clearly shows critical thinking about evidence. Explanation is based on claims that are supported by both experimental evidence and scientific information from reliable sources. Explanation is built from claims and evidence that are logically linked. Explanation is stated in terms of the relationship between two or more variables. Explanation clearly refers to the question and to the hypothesis or prediction.	Explanation generally refers to the evidence. Explanation relies heavily on claims supported by opinion and/or inferences rather than evidence. Explanation is based on unclear connections between claims and evidence. Explanation refers to variables without clearly stating relationships between them. Explanation refers only to the question or else to the hypothesis or prediction.	Explanation does not refer to the evidence. Explanation is based solely on opinion and/or guesses. Explanation either makes no connections or makes inappropriate connections between claims and evidence. Explanation lacks reference to variables. Explanation lacks reference both to the question and to the hypothesis or prediction.

STEP 6

Overview

There are two lessons in the concluding step for this Immersion Unit. The first lesson serves as a review and formative assessment in which students revisit the concept that reproductive success is defined by an individual organism's ability to produce fertile offspring. To understand natural selection, one must understand that reproductive success differs among a population's individuals largely because their traits vary.

The second lesson in Step 6 guides students to analyze data from an imaginary population of Fast Plants grown in conditions with an environmental stress, then to identify a trait that appears to increase individual reproductive success. Finally, students are asked to infer how that trait's frequency might change in future generations if the environmental stress remains constant. In this way, the teacher and students together evaluate each student's understanding of the role that environmental pressures and natural selection play in the variation of traits in a population.

Key Concept

- *Reproductive success* occurs when individual organisms pass their genetic information to fertile offspring, influencing the percentage of individuals with similar traits in the next generation.

Evidence of Student Understanding

The student will be able to:

- define, characterize, and explain *reproductive success*.

Time Needed

50 minutes

Materials

For each group of 2–3 students

- Student Page 6.1A *Reproductive Success Frayer Model* to be copied on to a piece of chart-sized paper or a similar-sized space at a black- or whiteboard *(optional: To expedite the lesson, Frayer model posters can be made in advance for student groups.)*
- 1 marker for the paper or presentation board

For the class

- 1 copy of Teacher Page 6.1a *Reproductive Success Frayer Model* for suggested student responses

Explaining Reproductive Success

1. Individually, have students do a 2-minute Quickwrite using the following prompt:

   - What is *reproductive success*?
   - Do not collect the Quickwrites at this time. However, explain that this lesson will be a review about *reproductive success* because this is such an important idea to know if students are going to be able to explain the process of natural selection.

2. Assign students to groups of two or three. Provide each group with a Frayer Model chart focused on *reproductive success*.

   - Either draw the Frayer Model charts in advance or use one example chart/overhead transparency to show students how to make their own.

3. Circulate among groups as they fill in their charts, to check for understanding.

   - Note which groups have solid entries in the four quadrants so they can be called upon to explain that quadrant to the class after the Frayer Models are completed.

4. Select several groups to report to the whole class.

   - Have each group explain only one quadrant from the Frayer Model chart to help keep students engaged in hearing the presentations.
   - Ask the reporting groups to summarize their definition of reproductive success.

5. Use the REAPS questions throughout the lesson where appropriate.

(continued on following page)

REAPS Questions

R **Give an example of reproductive success in a particular organism.** Ask students to name a particular plant or animal. Whatever the organism is, reproductive success is defined by that organism's ability to produce a relatively large number of healthy offspring who can also reproduce.

E **How can a trait that makes a plant less edible improve reproductive success when the plants are being exposed to an herbivore?** Those plants that are less edible will be more likely to survive and reproduce and therefore to have reproductive success.

A **What is the connection between reproductive success and natural selection?** Natural selection explains why those organisms that have a particular adaptation will likely have the greatest reproductive success and so cause future generations to have more individuals with the adaptation.

P **What would you expect to see happen over many generations to a population that has a few individual members that have an adaptation? Explain.**

S **What do you find most challenging to understand about how reproductive success influences future generations?** Check this question before going on to Lesson 6.2 to be certain students have a solid grasp of the implications that different degrees of reproductive success have on future generations before needing to apply that concept in the unit's summative assessment.

Advance Preparation

To make this lesson move more quickly, the Reproductive Success Frayer Model charts (enlarged charts as shown in Teacher Page 6.1a *Reproductive Success Frayer Model)* can be made on butcher or other chart paper in advance. The lesson calls for one Frayer Model for every 2–3 students so that all students are actively engaged throughout the process of writing responses. Larger-sized groups in field trials tended to have members who became disengaged and disrupted the class.

Implementation Guide

1. Individually, have students do a 2-minute Quickwrite using the following prompt:

- What is reproductive success?
- Do not collect the Quickwrites at this time. However, explain that this lesson will focus on reproductive success because this is such an important idea to know if students are going to be able to explain the process of natural selection. If students are not clear about what reproductive success is and how it influences future generations, they will not be able to apply that notion to interpret the scenarios in the unit's summative assessment that occurs in Lesson 6.1.

2. Assign students to groups of two or three. Provide each group with a Frayer Model chart focused on reproductive success.

- Either draw the Frayer Model charts in advance or use one example chart/ overhead transparency to show students how to make their own.

3. Circulate among groups as they fill in their charts, to check for understanding.

- Note which groups have solid entries in the four quadrants so they can be called upon to explain that quadrant to the class after the Frayer Models are completed.

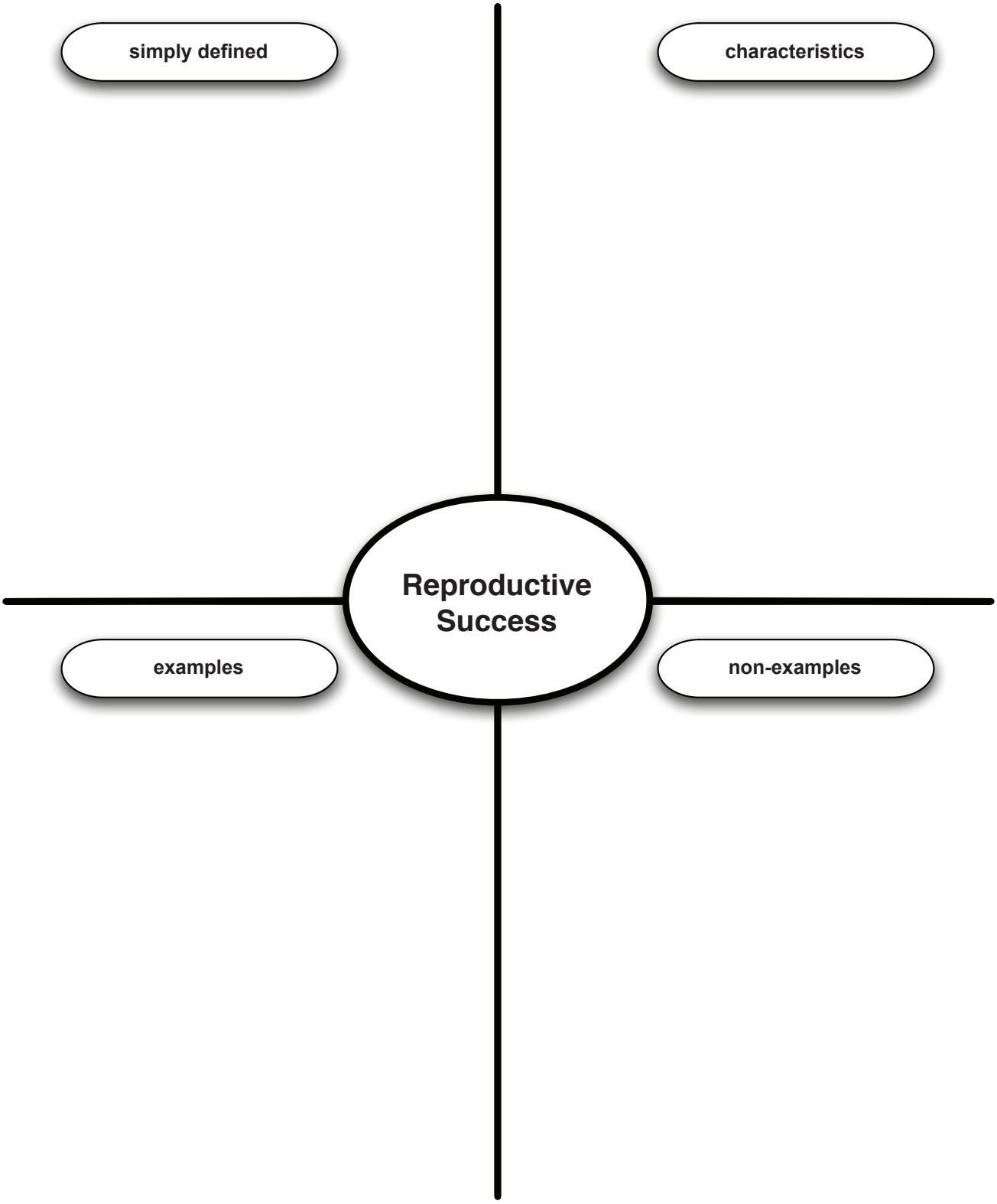
4. Select several groups to report to the whole class. At this stage, students should be able to say that if one plant has more offspring (that are healthy and able to reproduce) than another plant, it has greater reproductive success. Individuals who exhibit a trait that is an adaptation—a trait that allows it to survive under local conditions—typically have greater reproductive success than those individuals who do not exhibit the adaptation.

Remind students that an adaptation is a trait that an organism already has that allows it survive and reproduce successfully under local conditions. It is NOT a change. Organisms that do not have the trait may not survive and pass on their genes to the next generation.

- Have each group explain only one quadrant from the Frayer Model chart to help keep students engaged in hearing the presentations.
- Ask the reporting groups to summarize their definition of reproductive success.

5. Use the REAPS questions throughout the lesson where appropriate.

Student Page 6.1A: Reproductive Success Frayer Model



Teacher Page 6.1a: Reproductive Success Frayer Model

(sample possible student responses)

Reproductive Success

simply defined

Successful organisms live long enough to reproduce, and produce offspring that live.

characteristics

Individual becomes a "parent"

Parents have lots of offspring

Offspring survive and can also reproduce

Because of some trait that is an advantage, the individual who has that trait has more offspring than most others in the population,

examples

In Fast Plants:
- Lots of seeds
- Seedlings that are alive and healthy
- Seedlings that grow well and produce flowers that are pollinated
- Parent plants that produce seeds quickly

In Birds:
- Several eggs
- Parents that can find a lot of food to bring back to the nest
- Baby birds that survive to leave the nest
- Offspring that live long enough to mate, and that lay fertile eggs

non-examples

In Fast Plants:
- Few seeds
- Seeds that do not germinate
- Plants that die before they make seeds
- Seedlings that cannot grow well and reproduce
- Flowers that are not pollinated (or that for other reasons produce no seeds)

In birds:
- Empty nest or broken eggs
- Baby birds that are weak or starving
- Birds that die before ever building a nest

Key Concepts

- Individual organisms that have certain traits are more likely to survive and have offspring.
- Changes in environmental conditions can affect the survival of individual organisms and entire species.
- Small differences between parents and offspring can accumulate in successive generations so that descendants are very different from their ancestors.

Evidence of Student Understanding

The student will be able to:

- analyze data from a population of Fast Plants grown in conditions with an environmental stress and identify a trait that appears to increase individual reproductive success;
- infer how the trait identified as an adaptation might occur with greater frequency in future generations if the environmental stress remains constant.

Time Needed

50 minutes

Materials

For each student:

- 1 copy of Student Page 6.2A *Evaluate—Patterns in Variation*

Explaining Variation and Natural Selection

1. Explain to students that this final lesson in the Immersion Unit is a time for them to show all they understand about variation and natural selection.

2. Hand out Student Page 6.2A *Evaluate—Patterns in Variation*, and review the information that is given.

- The x-axis is the number of hairs on individual plants (on the leaf margins), and the y-axis is the number of plants in the population.

3. Tell students to use the graph (on Student Page 6.2A *Evaluate—Patterns in Variation*) to answer the questions. Remind them to give specific numbers as evidence to support their explanations.

- For example, in Population B the trend is an increasing hairiness, as shown by the shift from a mean of 8 to a mean of 37.

4. Collect and assess students' responses, then discuss as a whole class.

5. Reflect on what the class has learned through this Immersion Unit experience.

REAPS Questions

This summative assessment provides an opportunity for students to demonstrate their understanding of the key concepts for this unit. The assessment questions are embedded in the student page.

Teacher Background Information

In this lesson, students will have an opportunity to apply and show what they understand about the connection between reproductive success and natural selection. In order to do this, students are given data for multiple generations of one population of Fast Plants grown under conditions of environmental stress (exposure to a herbivore, the cabbage white butterfly) and of another, control population with no stress (no butterflies).

Students will follow the progression of a heritable trait (leaf hairs) that confers reproductive advantage in the presence of the environmental stress of an herbivore (butterfly). If plants with lots of leaf hairs have greater reproductive success than variants with few hairs (when around butterflies), then we will see a shift toward plants with lots of leaf hairs in subsequent generations. Students see data for the number of leaf hairs per plant in each generation.

Students will look for a positive correlation between reproductive success and a particular heritable trait, the number of leaf hairs. The control situation is to look at the number of hairs in the absence of the environmental stress (that is, in an absence of butterflies). The number of hairs should be stable from generation to generation in the control population. Students should see an increase in the relative number of plants with lots of hairs in later generations of the test population (exposed to the herbivore).

Advance Preparation

For this lesson, copy enough student pages for each student to have their own. Make one overhead transparency or use another strategy for displaying the graphs to the class just long enough to clarify what is meant by the labels on the axes. The x-axis is the number of hairs on individual plants (on the leaf margins), and the y-axis is the number of plants in the population.

Implementation Guide

1. Explain to students that this final lesson in the Immersion Unit is a time for them to show all they understand about variation and natural selection.

2. Hand out Student Page 6.2A *Evaluate—Patterns in Variation*, and review the information that is given.

- The cabbage white butterfly larvae eat the Fast Plants.
- The x-axis is the number of hairs on individual plants (on the leaf margins), and the y-axis is the number of plants in the population.

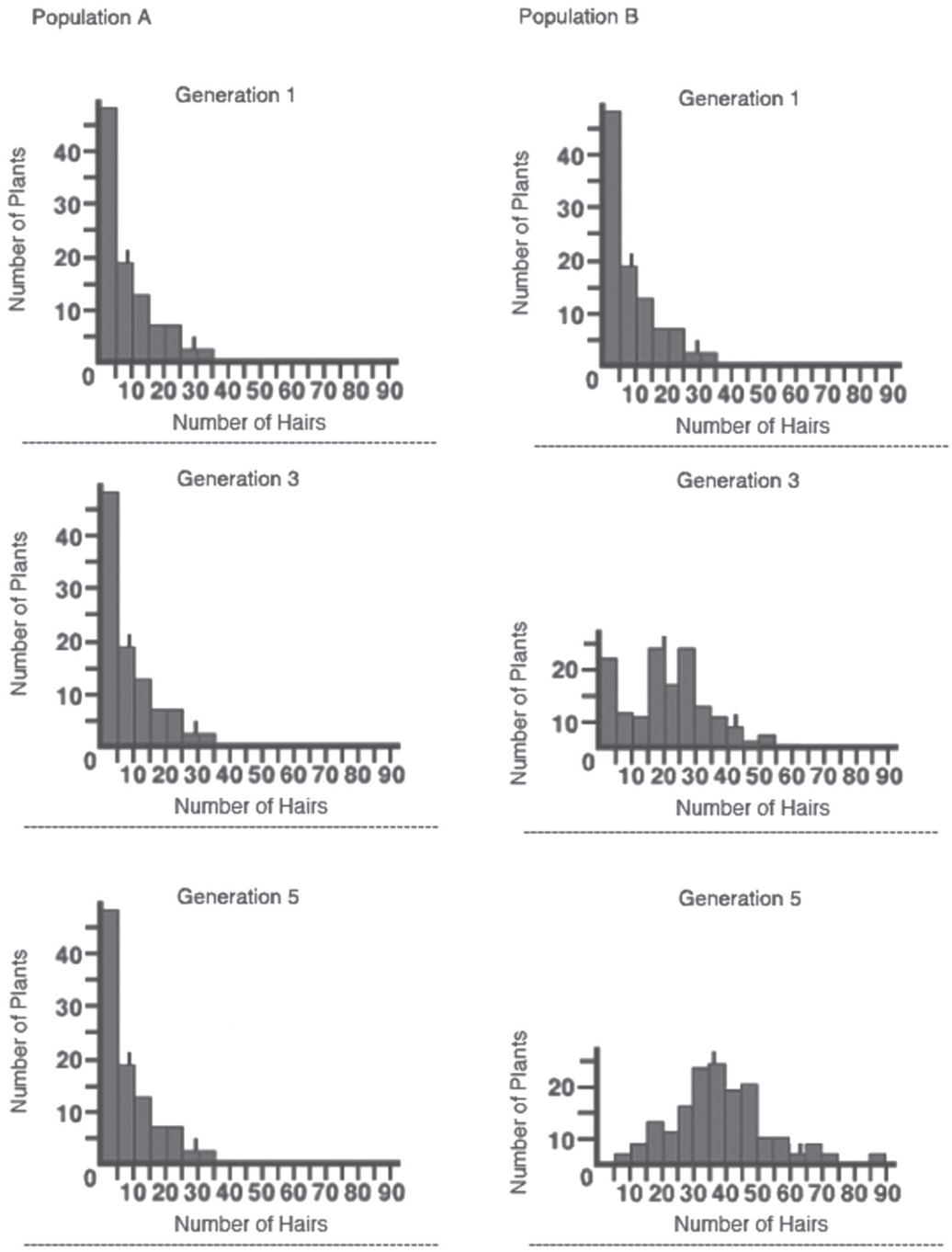
3. Tell students to use the graph (on Student Page 6.2A *Evaluate—Patterns in Variation*) to answer the questions. Remind them to give specific numbers as evidence to support their explanations.

   a. For example, in Population B the trend is an increase in hairiness, as shown by the graph.

4. Collect and assess students' responses, then discuss as a whole class. What you are looking for is evidence that the students understand that if there is a constant environmental stress, traits identified as adaptations might occur in a greater percentage of the population in future generations. To understand this idea, students need to understand reproductive success, natural selection, and adaptation.

5. Reflect on what the class has learned through this Immersion Unit experience.

Student Page 6.2A: Evaluate—Patterns in Variation



Student Page 6.2A: Evaluate—Patterns in Variation (continued)

1. Look at the graphs showing data from a study of two populations of Fast Plants that were observed for five generations.

- Population A was grown without butterflies.
- Population B was grown with an environmental stress: cabbage white butterflies.

Plants within each population vary in the number of hairs on their leaves. This is a heritable trait.

2. Explain these experimental results by answering the following questions about the graphs for Populations A and B.

Be sure to include the following terms in your answers:

- variation
- reproduce
- natural selection
- generation
- environment
- adaptation

3. Explain what happened to the number of hairs in Population A from the first to the fifth generation.

4. How do the data and graph for Population B change from the first to the fifth generation?

5. What can you infer about which plants in Population B had the greatest reproductive success?

- Explain why this is a logical, scientific explanation for the evidence given in the graphs.

6. If Population B continued to live and grow in the environment with the cabbage white butterfly, explain what you expect would happen to the average number of hairs on plants in the population.