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Driven to Discover

CITIZEN SCIENCE CURRICULUM GUIDE

Dragonflies and Odonata Central

Acknowledgements

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PROJECT TEAM

Implementation of the Driven to Discover grant project drew on the skills of a diverse team from the University of Minnesota, Department of Fisheries, Wildlife & Conservation Biology; the University of Minnesota Extension; University of Minnesota STEM Education Center; Gustavus Adolphus College; and Odonata Central.

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PDF versions of this curriculum and the corresponding videos may be downloaded for free at www.extension.umn.edu/citizenscience.

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Table of Contents

Welcome to Driven to Discover!

This curriculum series supports student engagement in ecology-based citizen science and science practices: asking questions and defining problems, planning and carrying out investigations, and communicating findings. The citizen science projects provide a natural springboard to these practices and also connect students to real-world research.

The Driven to Discover approach includes a three step process—a recipe that carefully guides students from building science skills into contributing to citizen science, and ultimately, to conducting independent investigations. Each of those three steps serves an essential purpose in fostering the science learning and motivation for which Driven to Discover is known.

BUILDING SCIENCE SKILLS

First, students develop and practice essential science skills and build a foundation of knowledge about the subject they are studying. They develop skills such as recognizing their study organisms and using science tools. Most importantly, students begin to develop habits of mind such as posing questions based on observations and constructing scientific explanations which prepare them for conducting their own investigations.

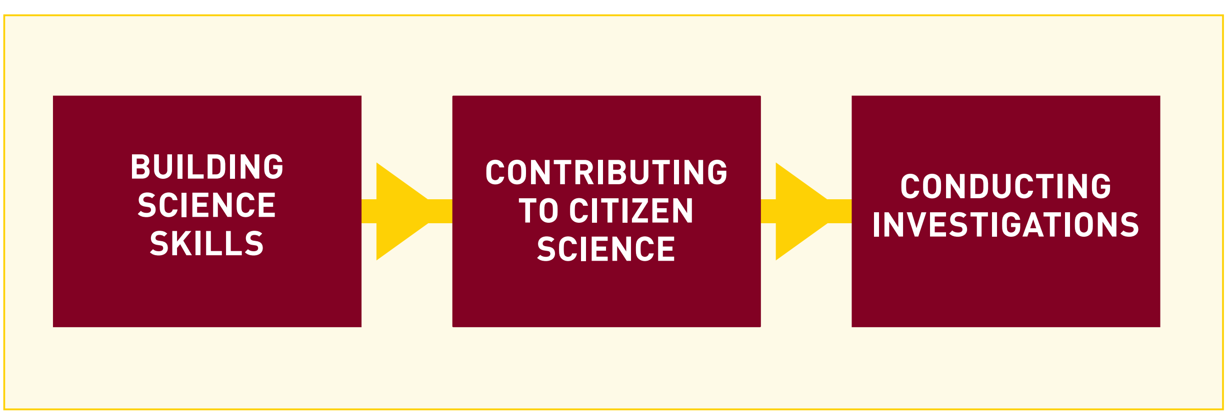
CONTRIBUTING TO CITIZEN SCIENCE

Next, students put their skills to work as they learn to implement the specific protocols of a citizen science project. They learn the essential role they may play in generating new knowledge about the environment through citizen science and gain competence with science tools while learning to record data accurately and enter their data into an online database. These experiences of closely observing nature naturally trigger the curiosity to ask questions, which in turn, provides the inspiration and motivation to pursue the third step in the Driven to Discover process.

CONDUCTING INDEPENDENT INVESTIGATIONS

After building science skills and contributing to citizen science, students are equipped to pursue a project of their own. They learn how to convert

THE DRIVEN TO DISCOVER PROCESS



an "I Wonder" question into a testable question and have the opportunity to graduate from citizen science technician to principal investigator, leading an investigation that answers their own question. Students are encouraged to reflect and rethink to ensure that their investigation makes sense and communicate their progress and findings with their peers.

This curriculum is organized into sections that align with these three phases of the project. Exercises are provided throughout the three phases to encourage students to develop and to apply the habits of mind related to asking questions based on observations as well as constructing scientific explanations. Student pages are provided to support student learning and to document their thinking.

The Driven to Discover project is the result of many years of teacher professional development, curriculum development, and field testing with a variety of audiences. The continuing theme across multiple iterations is the core three-step process of building science skills, contributing to citizen science, and conducting investigations. There are many ways to implement these three steps, and resources are provided to support you in constructing an experience for your students that both aligns with the three steps and works for your classroom.

A parallel project was developed to serve non-formal audiences such as nature centers, scouts/4-H, and afterschool programs. You are welcome to explore the resources from that project by downloading the free curriculum and corresponding youth workbook at www.extension.umn.edu/citizenscience.

INTEGRATING DRIVEN TO DISCOVER INTO YOUR SCHOOL YEAR

Teachers implement Driven to Discover in a variety of ways. Do what works best for you. Remember, your citizen science project may require involvement at specific times of year. For example, don't plan to observe pollinators in January in the Upper Midwestern United States—you won't have much luck. The following pages provide two implementation strategies for how you may integrate the pieces of the Driven to Discover curriculum into your classroom.

FULL IMPLEMENTATION SEQUENCE

(Note: this plan distributes all of the curriculum lessons across the whole school year. You may also wish to conduct the lessons on consecutive days. This plan reflects approximately 15-21 class periods.)

PHASE	DATE	TASK
PREPARATION	Before you begin	• Establish your citizen science data collection site. - Does it have sufficient target study subjects (enough pollinators/birds/dragonflies/etc.) to study? - Are there any safety considerations? How will you handle these? • Secure permission to access the study location if needed. • Complete any administrative requirements for taking students outdoors. • Confirm citizen science data entry procedures, and practice entering data (see chapter 3). - Decide how you will manage class/student accounts. • Gather necessary materials for projects. - "Building Science Skills" lesson plans (see chapter 2). - Citizen science data collection (see chapter 3). • Prepare a central place to gather "I Wonder" questions (see chapter 1 lesson 2).
BUILD SCIENCE SKILLS	September	• Introduce the citizen science project (watch the video available at https://monarchlab.org/). • Complete chapter 2 lessons 1, 2, & 3. • Collect "I Wonder" questions (see chapter 1, lesson 2). • Introduce the Evidence/Claims/Reasoning process, and practice constructing scientific explanations (see chapter 1, lesson 1).
CONTRIBUTE TO CITIZEN SCIENCE	October	• Collect Citizen Science Data once or several times (see chapter 3). • Collect and discuss "I Wonder" questions. • Enter citizen science data to database.
	November	• Conduct Science Behind the Scenes lesson (chapter 2). • Collect and continue discussing "I Wonder" questions.
	December	• Introduce data analysis lesson (chapter 3).
CONDUCT INVESTIGATIONS	April	• Conduct mini-investigation as a class (see chapter 4). • Design independent investigations (see chapter 4).
	May	• Collect data for independent investigations (student homework or in class). • Prepare final reports/displays (student homework or in class).
	June	• Present reports at local science fair or similar event.

CONDENSED IMPLEMENTATION SEQUENCE

(Note: This plan reflects approximately 4-8 class periods, utilizing only some of the lessons. It may be implemented in fall or spring.)

PHASE	DATE	TASK

PREPARATION	Before you begin	• Establish your citizen science data collection site.
		  - Does it have sufficient target study subjects (enough pollinators/birds/dragonflies/etc.) to study?
		  - Are there any safety considerations? How will you handle these?
		• Secure permission to access the study location if needed.
		• Complete any administrative requirements for taking students outdoors.
		• Confirm citizen science data entry procedures, and practice entering data (see chapter 3).
		  - Decide how you will manage class/student accounts.
		• Gather necessary materials for projects.
		  - "Building Science Skills" lesson plans (see chapter 2).
		  - Citizen science data collection (see chapter 3).
		• Prepare a central place to gather "I Wonder" questions (see chapter 1, lesson 1).

BUILD SCIENCE SKILLS	Week 1	• Introduce the citizen science project (watch the video available at https://monarchlab.org/). • Conduct a lesson from chapter 2. • Collect citizen science data (see chapter 3). • Enter citizen science data to database. • Collect "I Wonder" questions.
CONTRIBUTE TO CITIZEN SCIENCE	Week 2	• Conduct mini-investigation as a class.
CONDUCT INVESTIGATIONS	Week 3	• Science Behind the Scenes lesson (see chapter 2). - Simplify instruction time for lesson to one class period. • Collect "I Wonder" questions.

THE PROCESS AND PRACTICE OF SCIENCE

From the beginning of human history, people have asked questions about natural phenomena. Science is a process for answering these questions through investigation. It is not a rigid set of procedures but rather a broad approach to investigation that begins with questions like Why? What's going on? How is this explained? This approach leads an investigator to reasoned, evidence-based answers to those questions.

The process and practice of science are often called "The Scientific Method" or "Scientific Inquiry." But, whatever they're called, science investigations use logical and rational steps to reach conclusions about the world around us. Through observations, questions, hypotheses, data collection, and logical reasoning, the process of science serves as a helpful framework that ensures that a scientist may be confident in the answers they find.

Science Investigations Involve Both Knowledge and Skills

When conducting an investigation, scientists weave together an understanding of basic science concepts such as how ecosystems function, the behavior and habitat needs of individual species, and how nature changes over time. To do this, they use skills such as asking questions, interpreting data, and supporting arguments with evidence.

Anyone Who Practices the Process of Science is a Scientist

Scientific investigations begin with observations of the world which lead to questions. Scientists think of possible explanations, or hypotheses, for their questions and gather evidence that might lead them to favor one hypothesis over another. Ideally, they design experiments or conduct other kinds of studies to answer their questions and share their findings with their peers. Investigations are often cyclical, with reflections on the experience sparking new questions for study. That's what being a scientist is all about.

When students take on the role of scientist, they come to understand the very nature of science (Koomen et al. 2014). In addition to *learning about* science, they are *learning by doing* science. They begin to acquire the thinking skills important in everyday life and may even set on a course toward pursuing careers in science (National Research Council 2000).

USDA Natural Resources Conservation Service scientists collecting data.

A STEPWISE PROCESS

Science investigations may be both quite simple (e.g., ask questions and methodically pursue answers) and overwhelmingly complex (e.g., a ten-step process with piles of data). Either way, doing science boils down to the process of asking questions based on observations and methodically pursuing answers (see figure 1). Across all these steps, scientists draw on creative thinking to challenge assumptions, to draw connections, to generate ideas, to realize new insights, and to create new procedures.

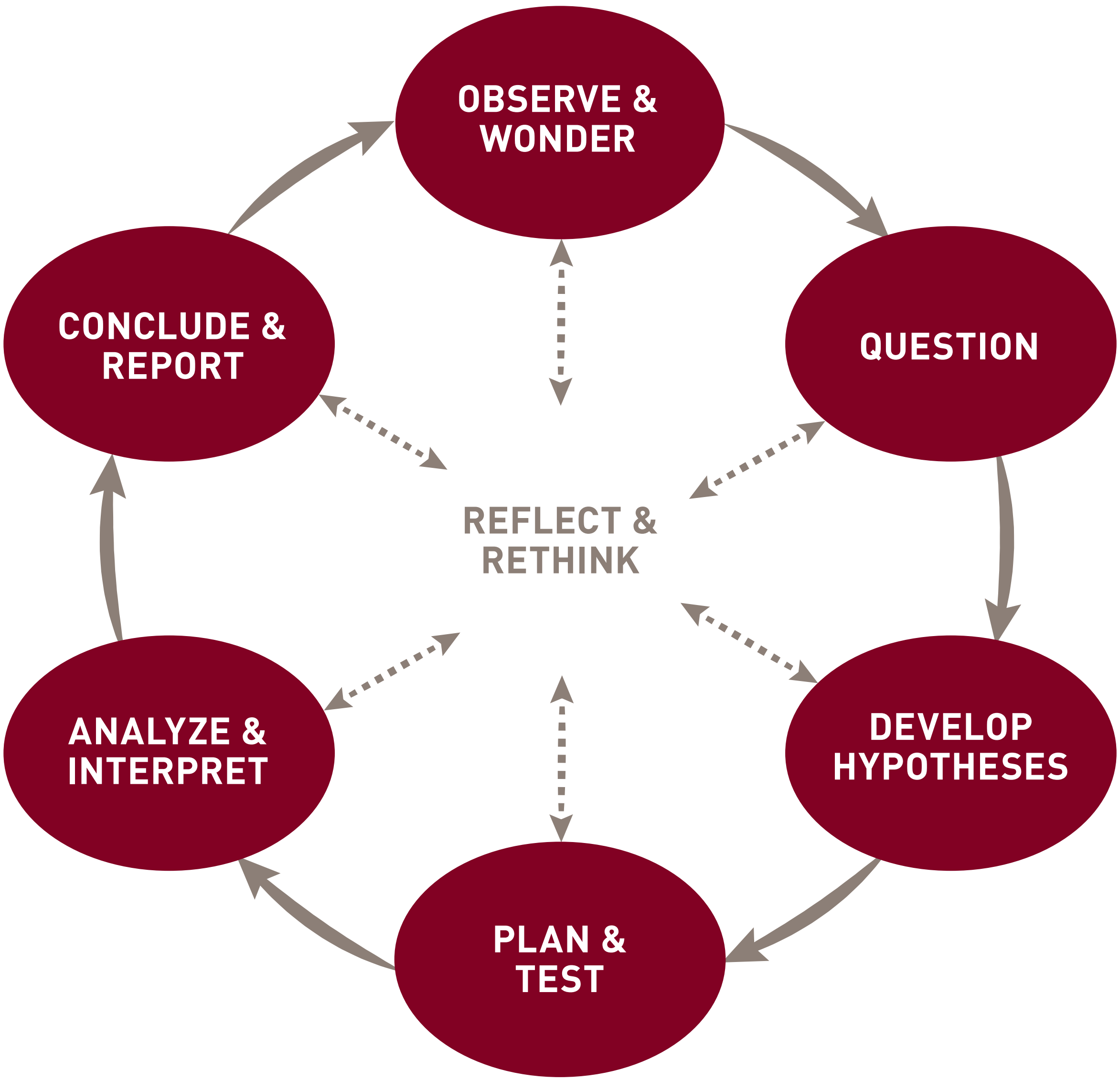


FIGURE 1. Scientific discoveries are made through the process of investigation, though scientists often use the term "research" or "the scientific method" to describe what they do. Investigations involve detailed examination of phenomena with the goal of discovering and interpreting new knowledge, whether the knowledge is new to humankind, to a small group of people, or even just to the person doing the research.

OBSERVE & WONDER A scientific investigation begins when someone focuses attention on the world around them and uses their senses to experience what's there. They may compare what they see to what they already know or to other things they see. They may record notes or illustrations about their observations in a journal.

QUESTION Observations naturally trigger curiosity. At this stage, observers become scientists. When they pose questions, they may challenge assumptions, synthesize observations, or infer that what they see involves more than meets the eye. Though scientists may ask thousands of questions, they must narrow down their specific query to pursue answers.

DEVELOP HYPOTHESES Scientists use logical reasoning to theorize about the possible answers to their questions and to evaluate why some answers may be more likely than others. Often, scientists identify factors they think will make one answer more likely than others.

PLAN & TEST In this stage, scientists organize a systematic method for collecting data that will confirm or contradict their hypotheses. They may use tools such as thermometers, microscopes, chemical tests, or binoculars; or they may just use their own eyes and ears to collect information. They must remain as objective and consistent as possible through the data collection process to ensure that their evidence is sound and not biased in some way.

ANALYZE & INTERPRET Once the data are gathered, scientists summarize the data, often using statistics to provide evidence to explain what they've found. This kind of analysis may include very simple summaries or complex analyses that document the statistical significance of their data. Then, they apply their best logical reasoning to give the information meaning.

CONCLUDE & REPORT When considering all the data, scientists determine which hypothesis is best supported by the evidence. They often use graphs or tables to make a claim or to explain to others what they found and what they think their findings mean.

REFLECT & RETHINK Scientists must continually re-evaluate their assumptions, consider alternatives, identify problems with their process, seek input, troubleshoot, and ask more questions. At any point, they may rethink their investigation plan and take a new direction with new questions. The dotted arrows in figure 1 illustrate this critical reflection.

Facilitator Skills That Foster Scientific Thinking

The process of science is learner-driven, so the teacher must take a back seat to his or her students' curiosity. The instructor facilitates the learning process, so a lesson plan for an investigation might look more like a facilitation plan in which the instructor plans ahead for the many different ways an activity may turn out (Step-by-step facilitation-plan creation 2004). Such a plan helps retain the focus on the essential learning points and habits of mind the students should take away from the experience while still allowing them to drive the process.

Facilitating scientific inquiry experiences requires flexibility, patience, tolerance of ambiguity, and an emphasis on student skill building. When learner-driven inquiry takes place, the teacher becomes a learner too. And not just in learning the content area but in gaining a deeper understanding of both her or his students' thinking processes and the process of science itself.

CONNECTIONS TO NEXT GENERATION SCIENCE STANDARDS

Though the specific requirements vary from state to state, all students must learn the process of science in one form or another. Both the Next Generation Science Standards (NGSS Lead States 2013) and the Framework for K-12 Science Education (National Research Council 2012) outline foundational concepts and science practices that guide science education. The process of doing science is both a teaching method and a learning goal. Though specific standards increase in complexity from kindergarten through grade 12, the Standards promote asking questions, planning and implementing investigations, and communicating results for all age levels.

While each step in a scientific investigation is crucial for developing a clear grasp of how science is done, any one lesson or activity might not embody all the steps. Depending on the learning setting, it may not be possible or appropriate to carry out the entire learner-driven investigation process. In some cases, it may be useful for the instructor to guide the process by providing a provocative question or a pre-determined set of data in the interests of dedicating more learning time to specific steps in the process.

Summary

The goal of the Driven to Discover process is for investigations to be driven, as much as possible, by the students' questions. At the heart of science, investigations draw on and feed scientists' natural curiosity. Through the experience of doing science investigations, students develop essential skills: those that help them learn how to learn.

Each curriculum in the series focuses on an ecological topic and partners with a citizen science program.

Birds
eBird
Cornell Lab of Ornithology
http://www.ebird.org/

Dragonflies
Odonata Central
The University of Alabama
http://odonatacentral.org/

Phenology
Nature's Notebook
National Phenology Network
https://www.usanpn.org/natures_notebook

Pollinators
The Great Sunflower Project
San Francisco State University
https://www.greatsunflower.org/

Insect life cycle. Illustration by Maria Sibylla Merian, a German and Dutch scientist who lived from 1647 - 1717.

LESSON 1

CONSTRUCTING SCIENTIFIC EXPLANATIONS THROUGH CITIZEN SCIENCE

OBJECTIVE

This activity supports students in developing habits of mind that contribute to scientific reasoning. It may be integrated into any lesson and repeated often.

NEXT GENERATION SCIENCE STANDARD CONNECTION

Science Practice 6: Constructing explanations and designing solutions

TIME REQUIRED

Initial instruction 30–60 minutes, with ongoing practice sessions of 5–10 minutes

MATERIALS

Prepared or blank "Build a Scientific Explanation" half-sheet student page copied from the end of lesson 1

BACKGROUND

Students master the process of science by *doing* science, and few scientific skills are as critical as the ability to reason from evidence. After all, scientific knowledge may only be advanced through the systematic process of proposing, testing, and refining scientific ideas. Proposing and defending scientific explanations allows students to understand concepts in-depth, and helps them develop analytical thinking skills. An essential goal of the Driven to Discover project, therefore, is to familiarize teachers and students with the development of scientific explanations.

The Driven to Discover program has adapted a framework developed by McNeill and Krajcik (2012) who recommend that students practice using evidence, claims, and reasoning as building blocks for constructing a scientific explanations.

EVIDENCE The scientific data from which to make a claim.

CLAIM A statement that expresses the answer or conclusion to a question or a problem.

REASONING A logical connection between the evidence and the claim, such as patterns, theories, and scientific principles.

When students are asked to make a claim statement, the claim must come from somewhere, preferably *not* pulled out of thin air. In fact, the claim should be drawn from data, whether the data are based in empirical research or even anecdotal experience. For the purposes of the Driven to Discover project, we want to emphasize that a claim should be based in evidence, so we have tweaked the McNeill & Krajcik (2012) model to position Evidence ahead of Claim in the model to reflect this sequence of thinking. More detail from the McNeill and Krajcik framework is referenced in the Appendix.

PROCEDURE

This is a template lesson you may use over and over in your classroom.

You will need to introduce the terms evidence, claim, and reasoning. Practice identifying examples of each. Then practice constructing simple explanations and progress to more complex variations, requiring more evidence, more sophisticated reasoning, and eventually, when called for, requiring rebuttals and alternative explanations.

Throughout the Driven to Discover process (and anywhere else in your science curriculum it fits), use the Student Page. You may seed the activity by filling in one of the three boxes with an example and ask students to complete the other boxes. See an example of a correctly filled-out student page in example 1 on the next page.

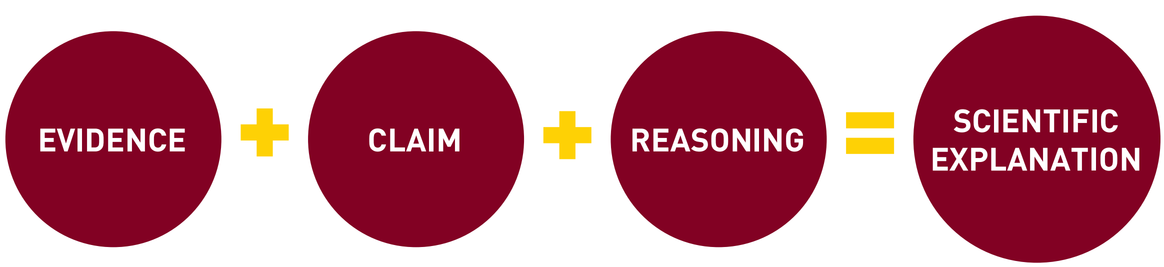
Suggested Uses of the Student Page

1. Provide an example claim and instruct students to consider what types of evidence they would need in order to justify making the provided claim.
2. Provide both evidence and claim, and ask students to suggest multiple examples of reasoning.
3. Provide sample responses in each box and ask students to find the flaw in logic (see example 2).
4. Provide sample responses in each box and ask students to generate alternative explanations and counter evidence (rebuttals to the claim).

   For example, a possible rebuttal to example 2: The observations only occurred on one day, so we can't be sure that the difference wasn't just due to random chance. We would want more data to make this claim, but the cat theory would be interesting to test.

Assessment Recommendation

Completed student pages serve as assessment for this activity. A grading rubric may be based on degree of completeness, clarity, and complexity of argument.



EXAMPLES

BUILD A SCIENTIFIC EXPLANATION WORKSHEET

NAME: EXAMPLE 1: GOOD EXPLANATION		
BUILD A SCIENTIFIC EXPLANATION		
EVIDENCE: scientific data that support a claim	CLAIM: a statement that answers a question	REASONING: a justification for why the evidence supports the claim using scientific principles
You observe birds in the early morning and afternoon over five days. On average, you see six kinds of birds in the morning and three kinds in the afternoon.	More species of birds are active in the morning than in the afternoon.	The insects that many birds eat tend to be more active in the morning. Or, birds of prey, which eat many other bird species, may be more active in the afternoon because they can catch thermals (warm air rising), which make it easier for them to fly. Thus, by being out early, smaller birds may be avoiding predators.

NAME: EXAMPLE 2: CONTAINS A FLAW IN LOGIC		
BUILD A SCIENTIFIC EXPLANATION		
EVIDENCE: scientific data that support a claim	CLAIM: a statement that answers a question	REASONING: a justification for why the evidence supports the claim using scientific principles
You see more female than male cardinals one morning at a bird feeder.	There are more female than male cardinals in our city.	Male cardinals are bright red, so predators have an easier time finding them, and there are a lot of people who let their cats outside in our city.

NAME

Build a Scientific Explanation Worksheet

BUILD A SCIENTIFIC EXPLANATION		
EVIDENCE: scientific data that support a claim	CLAIM: a statement that answers a question	REASONING: a justification for why the evidence supports the claim using scientific principles

BUILD A SCIENTIFIC EXPLANATION		
EVIDENCE: scientific data that support a claim	CLAIM: a statement that answers a question	REASONING: a justification for why the evidence supports the claim using scientific principles

LESSON 2

"I WONDER" BOARD

OBJECTIVE

This is a short exercise, to be repeated often throughout the Driven to Discover process, that will help students formulate questions about their study topic. You may use this activity at the end of each lesson to prepare students for their independent research. Students may struggle at first, but with practice they'll become adept at generating questions.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Science Practice 1: Asking questions

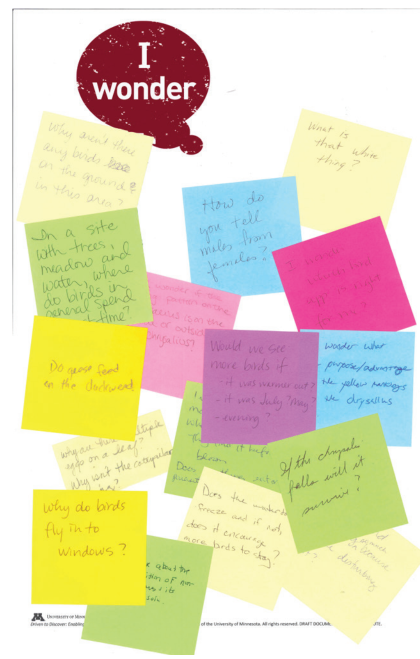
TIME REQUIRED

5–10 minutes

MATERIALS

- Sticky notes
- Chart paper, 11"x17" paper, or a special place on the wall or the board to put sticky notes
- Writing tools

BACKGROUND



Use the "I Wonder" board to track questions throughout your research experience. Questions will arise during each lesson that you may not be able to explore because of time constraints, because you are not sure how to address them, or because you want students to consider them in future sessions. Have students write their questions on a sticky note and place them on the designated "I Wonder" board.

Recording questions will eliminate pressure for you to provide immediate answers and encourage students to think about or answer some of the questions on their own. Also, you'll eliminate the problem of losing questions in the "That's a great question. Let's come back to that." vacuum.

Before your students choose their own independent research project, they will generate many questions as they observe the citizen science system. Capturing these questions, comments, and observations for future contemplation should be a part of every class. These questions will seed your research projects, ensuring that students are invested and actively engaged in the questions and methods that they develop. They may also be used to gauge student understanding and identify their directions of interest.

PROCEDURE

1. At the end of an activity or discussion, or whenever a question arises that does not need to be answered immediately, direct students to write the question on a sticky note or directly onto a large "I Wonder" poster. Each lesson may produce several questions added to the poster.

2. When your students begin their independent investigations, use these "I Wonder" questions as a springboard for their research questions.

Assessment Recommendation

Use the questions posted to gauge student understanding. Are they wondering about foundational lesson content or thinking ahead to next steps or alternate scenarios? Do the questions indicate points of confusion or misconceptions?

RESOURCES

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Scientists collect data in different ways. Top left: Dragonfly nymphs collected from a pond and placed in a bucket. Top right: An enclosure for monitoring dragonfly nymphs in a pond. Bottom left: A turtle trap. Bottom right: Dissecting scopes and data sheets for identifying and recording data about dragonflies.

University of Minnesota | Extension

Building Science Skills

DRAGONFLIES AND ODONATA CENTRAL

Skills for Citizen Science

BUILDING SCIENCE SKILLS

This section includes lessons designed to build skills that will enhance learning as students participate in Odonata Central, a citizen science project hosted by the University of Alabama. Lessons frame data collection skills in science content and utilize the evidence, claims, and reasoning framework.

Four lessons are included in this chapter. The first lesson focuses on observation and reviews dragonfly anatomy. The second lesson builds on those observation skills and teaches how to identify dragonflies. These two lessons support the NGSS core idea of interdependent relationships in ecosystems. The third lesson explores migration as a response to winter with an emphasis on dragonfly migration. The final lesson ties science content and process together by using adapted primary literature to develop scientific disciplinary literacy.

Lesson 1: Catch and Sketch

Lesson 2: Migratory Dragonfly Identification

Lesson 3: Migration As a Response to Winter

Lesson 4: Science Behind the Scenes

Students get a close look at a spiny baskettail dragonfly (*Epitheca spinigera*).

LESSON 1

CATCH AND SKETCH

OBJECTIVES

Students will catch dragonflies to observe their anatomy and make scientific drawings.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science Practice 1: Asking questions and defining problems

Cross Cutting Concept: Structure and Function

TIME REQUIRED

45 – 60 minutes

MATERIALS REQUIRED

- Aerial butterfly nets (at least one per three students)
- Aquatic nets (optional)
- One handout per student

BACKGROUND INFORMATION

Dragonflies and damselflies are fascinating insects. Some are large and some small, but they all have two compound eyes on their head, four large flat wings and six legs attached to their thorax, and a long abdomen with a pair of terminal appendages called *cerci*. Dragonflies and damselflies are in the same order, Odonata, but are in different suborders. Dragonflies rest holding their wings out like an airplane whereas damselflies generally hold their wings up and touching together behind their thorax and abdomen. Odonates are model creatures for teaching ecology because their life cycle requires both water and land.

Note the large eyes on the head, the four wings and six legs attached to the thorax, and cerci on the end of abdomen of this brush-tipped emerald *(Somatochlora walshii)*.

Dragonflies spend most of their lives in the water as aquatic nymphs — from a few months to a few years depending on the species. They live in all types of freshwater habitats including lakes, rivers, ponds, streams, and bogs. When they transition from an aquatic nymph to a terrestrial adult, dragonflies undergo incomplete metamorphosis. This is different from complete

Common green darner (*Anax junius*) exuviae.

metamorphosis because they don't pupate or create a chrysalis, like butterflies. Nymphs simply crawl out of the water and the adults hatch straight out of the baby-skin. The cast off skins are called *exuviae* and can be seen and collected by students walking along shorelines. As adults, dragonflies live for a few weeks to a few months.

On sunny warm days, adult dragonflies patrol waterways, feed in native gardens and prairies, or fly along the edges of mowed fields. On cooler days, they may roost in tall grasses or in trees. On cold days during winter, no adult dragonflies will be flying at all.

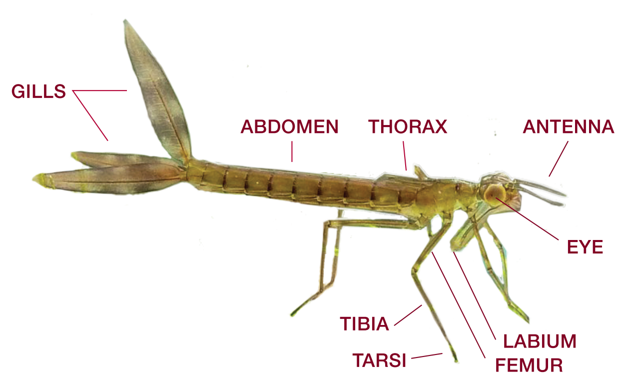
This lesson will give your students an opportunity to observe living dragonflies up-close. Catch them with a fast swing of an aerial butterfly net. Flick the end of the net over itself after a successful swing, or grab the net with your hand to hold it shut, so any captured dragonflies don't get away.

Take the dragonfly out of the net by holding it gently by the wings. Fold all four wings up, all-together, over the thorax, and carefully pinch the wings with your thumb and forefinger. It helps to trap the dragonfly in a small corner of the net first so it cannot fly around. If possible, pre-catch a dragonfly or two before your class to demonstrate this with a living dragonfly. A stuffed toy dragonfly also works well for demonstration.

Right after they emerge as adults, dragonflies are very soft-bodied and delicate. This is known as being in the teneral stage. Teneral dragonflies should not be caught in nets because it will damage their bodies. Your students can identify a teneral dragonfly because they are usually a light green color, their wings will appear to have an oily sheen and are often held together over their backs (not spread out like an airplane), and they won't fly away (or fly very far) when students get close.

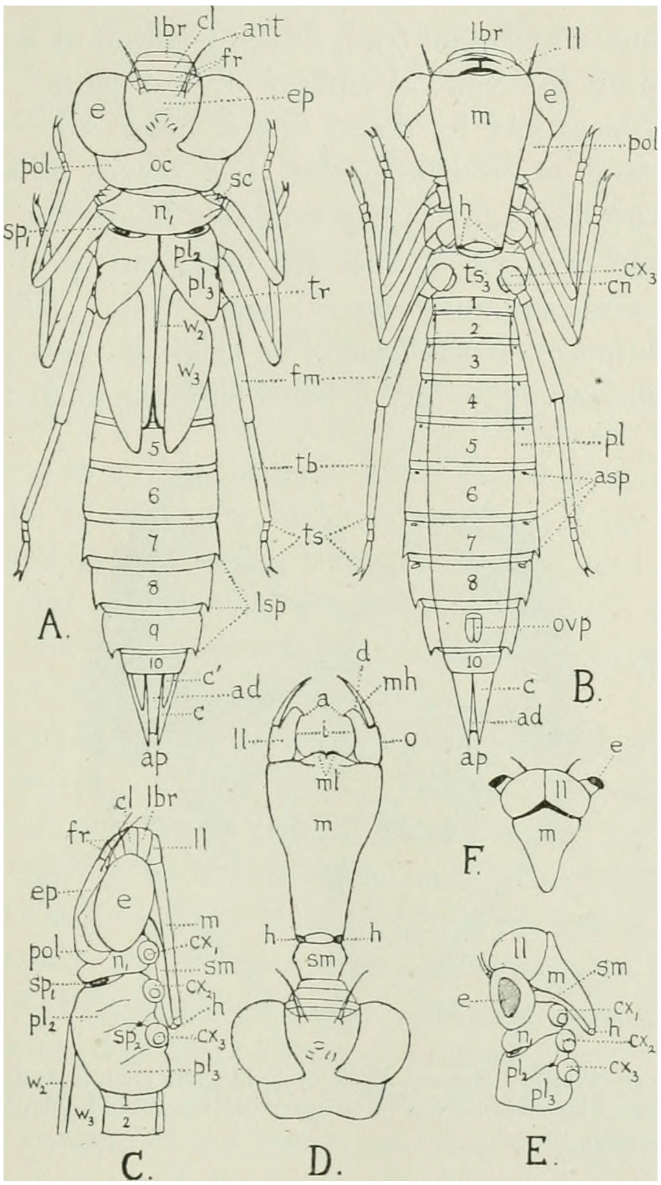
A newly emerged teneral dragonfly.

An aquatic dragonfly nymph.



An aquatic damselfly nymph.

Aquatic dragonfly nymphs can be collected from just about any body of water. Use an aquatic net with mesh large enough to let pond or river sediment wash out but small enough to collect aquatic insects the size of a jelly bean or larger. Many types of insects live in the water. Some aquatic insects have mouthparts that can give a painful poke, but dragonfly and damselfly nymphs are completely safe to handle. You can identify a dragonfly nymph by looking for stout bodies, large eyes, six legs, and their special flat or scoop-shaped labium (near their mouths). Damselfly nymphs are long and skinny, like a wiggly toothpick, and have three leaf-like caudal gills at the end of their abdomens. They also have large eyes, six legs, and the same unique labium.



Illustrations of dragonfly nymph anatomy. Note the stout bodies, large eyes, six legs, and the special flat or scoop-shaped labiums (labeled with the letter "m").

Large pond-collected dragonfly nymphs can be reared in the classroom for ongoing observation. They can be raised in full-sized fish tanks or in smaller jars or tubs. Nymphs from rivers are harder to rear because they need flowing water. Collect smaller aquatic creatures from ponds to feed them, keep the water clean by using a fish tank filter or by frequently replacing the water with dechlorinated tap water. Students can observe how nymphs feed, behave, and grow—they will occasionally shed their skin, like a snake, and leave an exuvia in the water. Put a rock, stick, plant, or piece of window screen partially submerged in the water so the nymphs can crawl up and out of the water when they are ready to metamorphose.

This investigation needs to be done during a time of year when dragonflies are flying. In areas that experience cold winters, dragonflies will be on-wing from about late spring to mid-fall. Warm sunny days are best for catching dragonflies. Dragonflies are attracted to bodies of water (for breeding), flowering prairie or native landscapes (for feeding on pollinating insects), and the edges of open fields (for shelter from the wind and for feeding on swarming insects like flies and mosquitos). Dragonflies are very safe for students to catch and handle: they do not sting or bite; although, they do have mouthparts that can pinch.

If the weather is uncooperative, this activity can be done with detailed photographs, identification guides, or preserved specimens. Additionally, living adult dragonflies can be safely stored in envelopes for a few days in the refrigerator.

PROCEDURE

1. Ask your students to draw a dragonfly from memory (no cheating). Instruct them to draw without worry about it being perfect, but they should still try to be as detailed as possible. How do dragonfly eyes look? How are their legs arranged? How big are their wings compared to their bodies? Students will later compare this drawing to another one they create after observing a living dragonfly.
2. Explain that the class will be going outside to catch and observe dragonflies. Be sure to clearly define your outdoor classroom rules and expectations.
3. Once outside, demonstrate how to use an aerial net to catch dragonflies. Tell students to swing with speed from behind the dragonfly (if possible) and flick the end of the net over to trap the dragonfly inside. Remind students to always be aware of their surroundings so they don't accidentally hit anyone with the net.
4. Describe and/or demonstrate how to take the dragonfly out of the net by grabbing it gently by the wings.
5. Distribute nets and the handouts. Students should closely observe the dragonflies they catch, look at their anatomy, record their observations, and draw another dragonfly based on their observations.
6. If you have the time and resources, you can repeat step 5 with catching and observing aquatic nymphs. Ask students to look for evidence, along the wetland, that shows how aquatic nymphs transform into terrestrial adults—maybe they will find some exuviae. (Great videos of dragonflies emerging are available on YouTube.)

ASSESSMENT

Either inside or outside, ask students to use their new knowledge and explain how their first drawing from memory was different from their second drawing based on observation. What did they get right from memory? What was wrong? Was one drawing easier to make than the other? Is being a good artist important for scientific observation? Why or why not? Did anything they observed surprise them? Why do dragonflies have such large eyes? And such large wings? Students should use evidence gained from their observations to support their answers.

ADDITIONAL RESOURCES

The *Dragonfly Curriculum Guide*, by Ami Thompson, provides additional dragonfly anatomy and ecology lessons including instructions on how to raise dragonfly nymphs in a classroom.

In the Appendix there is a lesson on keeping a science journal that expands on teaching science journaling and scientific drawing.

Exploring Dragonflies

Directions

1. Tips for catching a dragonfly

1. Swing fast, from behind the dragonfly if you can. Sometimes you can flop the net straight down on top of them if they are on the ground.

2. Dragonflies are hard to catch, so expect to miss more than you capture. Be careful not to hit anyone with the net.

3. End each swing with a flick that flops the net over itself to trap the dragonfly inside. Forget to flick and the dragonfly may get away.

2. How to take the dragonfly out of the net

1. Trap the dragonfly in a small corner of the net.
2. Reach a hand into the net, using your other hand to keep the net tight around your wrist so the dragonfly doesn't escape.
3. Very gently, using your forefinger and thumb, pinch all four wings up above the back of the dragonfly, like in the photo, and slowly pull it out of the net. This is the best and safest way to hold a dragonfly.

3. Take a close look

Look closely at the dragonfly. Draw it in detail on the back of this handout. Do a few drawings: some close-ups of different body parts and an overall picture or two from different angles. Label your drawing to clarify anything difficult to draw (like color or texture). Record any questions you think of while you are observing.

Guidance for Observing and Drawing

Very few people get to see a dragonfly this closely. What do you notice? Can you see the head, thorax, and abdomen? Where do the wings and legs attach? How many legs do you see? How many wings? Does anything surprise you? How does it sense the world? Do any questions or thoughts come to mind?

4. When you are done, let the dragonfly go

Place its legs softly on a plant and gently let go of the wings.

Carefully take the dragonfly out of the net by holding its wings.

Hold the dragonfly's wings by folding them gently up over the insect's back.

NAME

Drawings & Observations

LESSON 2

MIGRATORY DRAGONFLY IDENTIFICATION

OBJECTIVE

Students will learn to identify migratory dragonflies based on observations from photos and parameters from field guides. Their identifications will be justified to their peers with claims and evidence from the reference materials.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science Practice 1: Asking questions and defining problems

Science Practice 7: Engaging in argument from evidence

Cross Cutting Concept: Patterns, Structure and Function

TIME REQUIRED

45 minutes

MATERIALS

- Identification worksheets, one packet for each student
- Information handouts, one packet for each student
- Identification Guides

BACKGROUND

The citizen science website Odonata Central collects photos and observations of all dragonflies and damselflies across North America. Of particular interest to dragonfly researchers, in spring and fall, is when and where migrating dragonfly species appear as they progress on their journeys.

Common green darner (*Anax junius*).

This lesson focuses on five species of dragonfly that scientists have observed migrating. More species of dragonflies migrate, but these five are of special interest to scientists: common green darner (*Anax junius*), wandering glider (*Pantala flavescens*), spot-winged glider (*Pantala hymenaea*), black saddlebags (*Tramea lacerata*), and variegated meadowhawk (*Sympetrum corruptum*). We know very little about the details of dragonfly migration. How, when, and where do individual dragonflies migrate? Student citizen scientists who collect and report data about when they see which migrating species will be helping answer these important questions. Data collection over a large geographic area over many years is most feasible when done with the help of many volunteer citizen scientists.

Identifying the five migratory dragonfly focus species is easy and fun. Dragonfly identification, for the most part, requires looking at wing and body color, shape, and pattern. In some species, it is more difficult and requires looking for unique patterns of veins in their wings or at their reproductive parts with a microscope. Fortunately, all of the migratory dragonflies are easily identified with just our eyes and a little knowledge. Not all of these species may be found in your area, but the skills used in learning how to identify dragonflies are universal. Suggested guides for this activity include: *Dragonflies of the Northwoods*, by Kurt Mead, or *Dragonflies and Damselflies of the East*, by Dennis Paulson.

Your students can be citizen scientists by reporting the identification and location of any species of dragonfly or damselfly they observe to Odonata Central. However, focusing in on these five migrating species simplifies the amount of identification skills you and your students need. Dragonfly migration is also conveniently timed during spring and fall which matches up well with the timing of the conventional school session.

Spot-winged Glider (*Pantala hymenaea*).

In fall, mixed swarms of migrating dragonflies move South from Canada and the Northern United States towards Central America, to escape the cold winter temperatures. These dragonflies are often accompanied by migrating raptors who use the dragonfly swarms as a moving dinner buffet. In spring, when the south is often experiencing drought, the dragonflies migrate north towards wetter habitats but not in swarms. Individuals will wind their way north as the spring thaw begins to melt the snow and ice. Early migrating insectivorous birds, like purple martins, depend on migrating dragonflies as a food source. Migrating dragonflies arrive in the north before resident insects are warmed-up enough to begin flying around.

It's important to note that not all species of dragonflies migrate. In fact, most northern species overwinter as nymphs under the ice. The liquid water below the ice protects them from freezing, but the water temperatures are too cold for the dragonflies to grow. These nymphs just wait under the ice until spring when they warm up and then metamorphose into adults, completing their life cycle.

This lesson focuses on the identification of the five migrating dragonfly species. The next chapter highlights how to collect and enter citizen science data into Odonata Central.

PROCEDURE

1. Explain that while dragonflies love hot weather, they still live across all of North America, including in the far north. Ask your students how they think dragonflies survive the winter? (They can overwinter underwater as aquatic nymphs or eggs and sometimes the adults migrate.)

2. Explain that they will be learning to identify five migratory species of dragonflies in order to participate in the citizen science project, Odonata Central. Their participation will help scientists better understand when and where dragonflies migrate.

3. Distribute the field guides and explain to the students how the guide is organized. Usually, field guides have helpful information in the beginning including anatomy diagrams and definitions of scientific terms. Most dragonfly and damselfly field guides are organized taxonomically by suborder, family, and genus. Are there other helpful components like a glossary or section on dragonfly natural history? What sections of text or images are common to all of the species in the guide (description, habitat, range, photographs, etc.?).

4. Distribute the handouts and review the directions.

5. Students can work individually or in groups, depending on how many field guides you have and the dynamics of your classroom. Give

students time to complete the worksheets, helping them as needed to understand the directions and emphasizing the provided clues. Don't be concerned, at this point, about the accuracy of their identifications.

6. Ask students to share their identifications and explain what evidence they used in their decisions. Facilitate some discussion around claims and evidence. Can the classroom come to consensus on what they think the correct identifications are?
7. If the identifications are wrong, ask students to look back at the information in the field guide to direct them towards the right choice. For example, "Is the species you picked the same length as the species to identify?"

ASSESSMENT

After students have completed the worksheets, hand out the informational sheets. The information sheets summarize what they learned, act as a reminder of how to ID, and may lead into further discussion. Were any students confused by the similar species? Do the ranges of the migrating species include your school? When would the migrating dragonflies be seen near your school?

MYSTERY MIGRANTS ANSWER KEY

Mystery Migrant #1:
Common Green Darner
(*Anax junius*)

Mystery Migrant #2:
Black Saddlebags
(*Tramea lacerata*)

Mystery Migrant #3:
Variegated Meadowhawk
(*Sympetrum corruptum*)

Mystery Migrant #4:
Wandering Glider
(*Pantala flavescens*)

Mystery Migrant #5:
Spot-winged Glider
(*Pantala hymenaea*)

A dragonhunter dragonfly (*Hagenius brevistylis*).

Identify Migrating Dragonflies

Directions

1. Use a guide to identify these dragonflies based on the photos and provided clues.
2. Record both the common name and genus and species. (The genus name is always capitalized and the species name is not. When typing, both of these are italicized. Example: *Genus species*)

MYSTERY MIGRANT #1

Clues

1. This dragonfly is in the darner family.
2. The color of the thorax (where the wings attach) is unique to this genus within this family. This species has a bullseye mark on the top of its face (see photo).
3. This is a large dragonfly — about three inches long from the face to the tip of the abdomen.

Your Identification

Common name	
Genus and species	
Reasons for this identification:	

STUDENT PAGE NAME

MYSTERY MIGRANT #2

Clues

1. This dragonfly is in the skimmer family.
2. The color and pattern on the wings is unique among dragonflies.
3. This is a medium-sized dragonfly — about two inches long from the face to the tip of the abdomen.

Your Identification

Common name	
Genus and species	
Reasons for this identification:	

MYSTERY MIGRANT #3

Clues

1. This dragonfly is in the skimmer family.
2. The abdomen has a complicated color pattern and the thorax has two yellow dots.
3. This is a medium-small dragonfly — about 1.5 inches long from the face to the tip of the abdomen.

Your Identification

Common name	
Genus and species	
Reasons for this identification:	

STUDENT PAGE NAME

MYSTERY MIGRANT #4

Clues

1. This dragonfly is in the skimmer family.
2. The color and markings on top of the abdomen are important for identification.
3. The wings are very large, clear, and do not have spots.
4. This is a medium sized dragonfly — about 2 inches long from the face to the tip of the abdomen.

Your Identification

Common name	
Genus and species	
Reasons for this identification:	

STUDENT PAGE NAME

MYSTERY MIGRANT #5

Clues

1. This dragonfly is in the skimmer family.
2. The color and pattern on the abdomen is important for identification.
3. The wings are very large. The hindwings have an obvious dark spot near the body.
4. This is a medium sized dragonfly — about 2 inches long from the face to the tip of the abdomen.

Your Identification

Common name	
Genus and species	
Reasons for this identification:	

STUDENT PAGE NAME

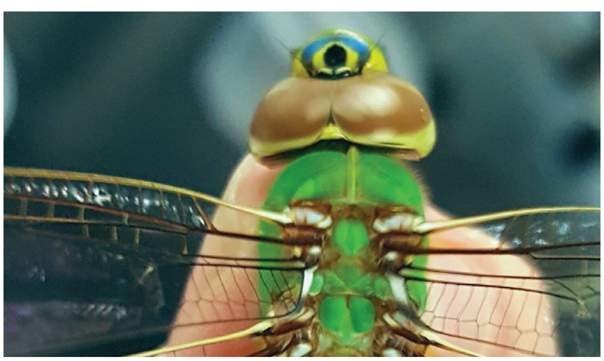
INFORMATION SHEET

Common Green Darner, *Anax junius*

This is the species that most people think of when they hear "dragonfly." They are beautiful, large, and quite common. They are also our most well-understood dragonfly migrant but there still is a lot to learn.

The color combination of the plain green thorax and blue abdomen are unique to adult dragonflies in this genus. Confirm the identification of the species by looking for the the bullseye pattern on the top of their face. Female and juvenile common green darners look similar but often have a gray or slightly pink abdomen. Juvenile dragonflies are the same size as mature ones; they do not start out small and get bigger.

A male common green darner (*Anax junius*).



Note the bullseye mark on the top of the face.

A female common green darner (*Anax junius*).

Similar Species

The comet darner (*Anax longipes*) looks similar to the common green darner but lacks both the bullseye mark and the the dark strip down the top of the abdomen.

The male Eastern pondhawk (*Erythemis simplicicollis*) also has a green thorax and a blue abdomen. However, at less than 2 inches long, it is much smaller than the common green darner and does not have the bullseye mark.

Eastern pondhawks change in appearance as they mature. When the males are young, they look smooth and a little shiny but when they are older, they look like they are covered in a chalky powder. The males also look very different from the females. Look them up in your identification guide.

The Eastern pondhawk dragonfly (*Erythemis simplicicollis*) looks similar to a common green darner but it is much smaller and does not have the bullseye mark on its face.

INFORMATION SHEET

Black Saddlebags, *Tramea lacerata*

The large black inkblot-like pattern on the hindwings is unique to this species. Some people think they look like the leather bags that hang off a western horse saddle. Also, look for a completely black thorax and yellow spots on top of the abdomen. Female and juvenile black saddlebags may have bodies that appear more brown than black.

A black saddlebags dragonfly (*Tramea lacerata*) in flight.

A black saddlebags dragonfly (*Tramea lacerata*) at rest.

Similar Species

The female and immature male widow skimmers *(Libellula luctuosa)* have black patches on their hind wings like the black saddlebags. However, the black marks have a smooth edge. They also have two yellow/orange stripes down the top of their abdomens.

Widow skimmers change appearance as they mature. Black patches on the front wings will darken as they mature. Males additionally get white bands on their wings next to the black bands. Look them up in your identification guide.

You may also see red saddlebags (*Tramea onusta*) or Carolina saddlebags (*Tramea carolin*). Both of these species have red patches on their wings, not black.

A female widow skimmer dragonfly (*Libellula luctuosa*) looks similar to a black saddlbags (*Tramea lacerata*), but notice that the skimmer's black wing patches have smooth edges and are also on the front wings.

INFORMATION SHEET

Variegated Meadowhawk, *Sympetrum corruptum*

These are exceptionally beautiful dragonflies with banded multi-colored abdomens and with two yellow spots on their thorax. The males have red bands and females have copper/yellow bands. They are very maneuverable flyers and are extremely hard to catch with a net.

Female variegated meadowhawk (*Sympetrum corruptum*).

Male variegated meadowhawk (*Sympetrum corruptum*).

Similar Species

Other species of meadowhawks (*genus Sympetrum*) have bodies that are nearly all red or all yellow, with some black triangles on the abdomen. The colorful and complex pattern combined with the two yellow dots on the variegated meadowhawk is unique. Look up other meadowhawks in your guide to compare.

Other meadowhawk dragonflies (in the genus *Sympetrum*) are all red or all yellow, like this one, with black triangles on their abdomens.

STUDENT PAGE | NAME

INFORMATION SHEET

Wandering Glider, *Pantala flavescens*

This species migrates across oceans and is the only dragonfly to be found on all earth's continents (except Antarctica). Look at how large their hind wings are. Large wings are perfect for surfing on strong winds. For identification, look for the large clear wings, with no spots, and the yellow abdomen with dark marks running down the top.

A wandering glider dragonfly (*Pantala flavescens*).

A wandering glider dragonfly (*Pantala flavescens*).

Similar Species

Another migrant, the Spot-winged Glider (*Pantala hymenaea*) looks similar but has a large dark spot each hindwing.

Spot-winged gliders (*Pantala hymenaea*) look very similar to wandering gliders (Pantala flavescens) except that they have spots on their hind wings near the abdomen.

INFORMATION SHEET

Spot-winged Glider, *Pantala hymenaea*

This dragonfly looks similar to the wandering glider with a yellow thorax and abdomen and large wings. However, the spot-winged glider has a rounded dark spot on each hindwing. Look closely because sometimes the spot is faint.

A spot-winged glider dragonfly (*Pantala hymenaea*).

A spot-winged glider dragonfly (*Pantala hymenaea*).

Similar Species

The wandering glider (*Pantala flavescens*), another migrant, looks similar but has clear wings with no spots. However, the wandering glider's wingtips may turn brown as it matures.

Wandering gliders (*Pantala flavescens*) look very similar to spot-winged gliders (*Pantala hymenaea*), except they do not have spots on their hind wings.

LESSON 3

MIGRATION AS A RESPONSE TO WINTER

OBJECTIVE

In this lesson students will discuss the different strategies animals and dragonflies use to survive winter.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS1: From Molecules to Organisms: Structure and Processes

Disciplinary Core Idea LS1.B: Growth and Development of Organisms

Science Practice 1: Asking questions and defining problems

Cross Cutting Concept: Patterns

TIME REQUIRED

45 minutes

MATERIALS

- How do Animals Survive Winter Handouts
- Dragonfly Migration Reference Material Handouts

Lesson adapted from the Monarchs in the Classroom Curriculum (Middle School Edition).

BACKGROUND

Temperate animals have developed strategies to survive adverse winter conditions when temperatures are cold and food is scarce. Some animals become dormant, either hibernating as the ground squirrel does or overwintering as a dormant egg or pupa as many insects do. Hibernation is a state in which an endothermic (warm-blooded) animal's metabolic rate is reduced, and the animal may enter a deep sleep, surviving on food reserves (fats) stored in the body.

Hibernation occurs along a continuum, from deep hibernation where metabolic rates are greatly reduced to a partial hibernation (or torpor) where rates drop but not as far as in deep hibernation. Ground squirrels, for example, enter a deep hibernation, with heartbeats dropping from 300 beats/minute down to 7 to 10 beats/minute. Respiration and body temperature fall greatly as well.

Black bears, on the other hand, enter a torpor, and although their respiration rate drops to 2 or 3 times/minute, their body temperature only drops to around 95° F. Other animals remain active, often developing thicker coats (e.g., deer and rabbits) or huddling together to keep each other warm (e.g., honey bees clustering in the winter hive). Still others migrate, leaving the adverse conditions behind and moving to other regions where the conditions are more suitable.

During winter, temperate animals hibernate, migrate, or stay active like this Northern cardinal (*Cardinalis cardinalis*).

Dragonflies use two of these strategies. A few species migrate from their temperate breeding grounds to warmer locations including the Southern United States, Mexico, and perhaps Central America. The dragonflies who migrate south will lay eggs and die in the warm winter location, and their offspring will migrate north again in spring. Most other temperate dragonflies overwinter as aquatic nymphs. A few overwinter as eggs. The cold temperatures force the nymphs to reduce their activity and stop growing.

In spring the nymphs will start growing again and metamorphose into adults to complete their life cycle.

Common green darner dragonflies are unusual because individuals of this species can utilize either migration or become dormant. Some individuals will emerge from the water in fall, metamorphose into adults, and migrate south. Other individuals will remain aquatic nymphs—becoming dormant for the winter and emerging into adults in spring.

Common green darner dragonflies can go dormant as nymphs or migrate as adults.

This lesson is divided into two portions: a small group discussion and a class discussion in which students assess what they know about overwintering strategies of different animals. Students will discuss their ideas using claims and evidence to practice argumentation. You may wish to give them time to research and/or provide additional reference materials.

PROCEDURE

1. Explain that this lesson is to explore the different ways animals survive the harsh conditions of winter. Ask students what special challenges animals face in winter. Examples include staying warm, getting enough food, access to liquid water, escaping predators, and getting enough oxygen (for aquatic creatures).

2. Divide the class into small groups and distribute a handout to each group. Students should create a list of temperate climate animals and then write how they think that each of these animals survives the winter. Challenge students to list many different survival strategies (not just many different animals). Examples include bear, sleep or hibernation; chickadee, stay active; robin, migrate. If students are having difficulty, prompt them by suggesting certain animals (e.g., how does a frog survive?). Small group discussions can last from five to ten minutes.

3. Ask each group to report their list and survival strategies. As students report, compile a master list for the entire class. If there is disagreement about how some animals survive, or if you think that some of the strategies students report are incorrect, ask for their evidence and reasoning. Facilitate discussion to develop their argumentation skills. If needed, assign students to do research to discover the correct answers.

4. Ask students to think of all the ways people prepare for, endure, and even enjoy the challenges of winter. They could do this for people in their own time or for people who lived before technological advances such as central heating and grocery stores. This step can be done in small groups or as a class. Furthermore, ask students how modern people are changing how animals respond to winter? For example, some American robins in urban areas don't have to migrate anymore because human behaviors, like putting up bird feeders and preventing water from freezing, allow the birds to survive all winter.

5. After this broad discussion, focus in on the phenomenon of migration as a response to winter. Discuss how bird migration might be similar or different to insect migration.

6. Have students read some or all of the provided dragonfly migration background materials.

7. Follow up with a discussion on dragonfly migration as a class. Topics for discussion include:
   - Why do dragonflies migrate?
   - How do we know dragonflies migrate north in the spring?
   - Why do some common green darners migrate and some go dormant during the winter? How do individuals choose which strategy?
   - Why is dragonfly migration important?

ASSESSMENT

Ask students what questions they still have about migration or about how animals survive the winter. How could they find the answers to these questions? Look it up? Ask an expert? Maybe design their own experiment? What would that look like?

Scientists search for dormant dragonfly nymphs under the ice on a frozen lake in Minnesota.

NAME

How do Animals Survive During the Winter?

NAME OF ANIMAL	WINTER SURVIVAL STRATEGY
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	

Thoughts and Questions:

SUMMARY OF DRAGONFLY MIGRATION

By the Migratory Dragonfly Partnership

Dragonfly migration is one of the most fascinating yet least well-known events in the insect world. Dragonfly migration has been seen on every continent except Antarctica, but most people are completely unaware of this phenomenon. The aptly-named wandering glider (*Pantala flavescens*), though less famed a migrant than the Monarch butterfly, easily dethrones the Monarch as a champion long-distance traveler. In North America, this widely distributed species is a regular migrant along the East Coast, but its annual flights across the Indian Ocean are truly remarkable. Riding the monsoon winds, the Wandering Glider island-hops from India to east and southern Africa; subsequent generations return by following the continental coastline back to India. This is a round trip of more than 11,000 miles (almost 18,000 kilometers) -- nearly twice the maximum distance of the monarch's migration.

Only about 16 out of 326 dragonfly species in North America are regular migrants; some make annual seasonal flights while others are more sporadic. The major migratory species in North America are common green darner (*Anax junius*), wandering glider (*Pantala flavescens*), spot-winged glider (*Pantala hymenaea*), black saddlebags (*Tramea lacerata*), and variegated meadowhawk (*Sympetrum corruptum*).

Migrations are seen annually in late summer and early fall when thousands of millions of insects stream southward from Canada down to Mexico and the West Indies, passing along both coasts of the United States through the Midwest. Some patterns have been detected in existing reports of massive dragonfly migrations in North America: (1) large migrations to the south occur between late July and mid-October with a peak in September observations; (2) flights tend to follow geographic leading lines such as ridges, cliffs, coastlines, and lake shores; and (3) many documented reports indicate large migratory flights after a large-scale cold front has passed an area. Movement of migrants back north is less obvious, but we know the return trip occurs because mature adult dragonflies appear early in spring at places where residents that overwintered as nymphs have not yet emerged.

A spot-winged glider dragonfly (*Pantala hymenaea*).

WHY DRAGONFLY MIGRATION IS IMPORTANT

By the Migratory Dragonfly Partnership

Dragonflies and damselflies are of great ecological importance. The aquatic nymphs and winged adults create an important link between aquatic and terrestrial ecosystems, and they play a central role in the food web of aquatic systems. Both nymphs and adults are voracious predators. As adults, they may consume up to 15% of their own body weight in prey each day, including pest species such as mosquitoes and biting flies. In turn, they provide a food source for a variety of other wildlife. The nymphs are an important food source for water birds and fish, and adult dragonflies and damselflies are eaten by many kinds of birds. Migrating hawks often feed on dragonflies during their journey.

Dragonflies and damselflies are also part of a suite of insects that can be used to understand the health of aquatic ecosystems. They are excellent tools for monitoring the current biological conditions of wetlands and for predicting future changes in those environments.

Despite the fact that it spans three countries (Canada, United States, and Mexico) and has been documented since the 1880s, North American dragonfly migration is a poorly understood phenomenon. Knowledge about migratory cues, flight pathways, and southern limits of overwintering grounds is still seriously lacking. This knowledge gap prevents development of international management plans and coordinated conservation actions to sustain and protect the migration. None of the species known to be migrants in North America is currently endangered, but identifying the habitats on which migration dragonflies rely for their transcontinental flights may help us better protect these important systems. Threats to wetland habitats, including pollution, urbanization, and global climate change, could alter environmental cues for migration, affect development and adult emergence times, disrupt migratory corridors, or render overwinter habitat unusable.

MIGRATORY DRAGONFLY PARTNERSHIP

A common green darner (*Anax junius*).

Dragonflies: Four Wings, Will Travel

An Introduction to the Natural History of North America's Migratory Dragonflies

Photo: © Dennis Paulson.

A tandem pair of Common Green Darners (*Anax junius*) laying eggs. The male (left) grasps the female (right) behind her eyes, guarding her as she oviposits.

Dragonflies are among the most easily recognized insects. Grouped in the order Odonata, a name that refers to their toothed jaws, they are dashing predators and aerial acrobats. Dragonflies are also strong fliers, and many species are known to migrate hundreds to thousands of miles, with some flying 90 miles in a day.

Because they are excellent fliers, we mainly notice adult dragonflies in flight, but they are truly aquatic insects, as their young inhabit wetlands, ponds, and streams. All North American species breed in fresh water except for one, the Seaside Dragonlet (*Erythrodiplax berenice*).

Dragonflies also need terrestrial habitats. Feeding occurs in open areas, and dragonfly swarms can sometimes be seen coursing back and forth through clouds of midges or mosquitoes. Open areas also provide warming sunlight and allow the dragonflies' superb vision to alert them to approaching predators or distant prey. Forests give shelter from storms or very high temperatures, and from open-country predators such as birds. When not at water, many dragonflies retire to the forest canopy or understory to feed or seek shelter. Without forest cover, forest-dependent species will be absent even if there are wetlands for larval habitat.

Natural History

Development

To understand dragonflies, you must first know their nymphs. Also called larvae or naiads, these animals look nothing like the colorful aerial insects to which they give rise. Their bodies are sleek and streamlined to slide through vegetation, or flattened to allow them to lurk in mud. Their abdomen is often tipped with three short stout spines, which surround a rectal gill chamber used to obtain oxygen from the water. They are voracious predators, with a remarkable hinged, toothed lower lip that shoots out at high speed to snatch prey, enabling them to feed on invertebrates, tadpoles, and even small fish!

MIGRATORY DRAGONFLY PARTNERSHIP

The Migratory Dragonfly Partnership uses research, citizen science, education, and outreach to understand North American dragonfly migration and promote conservation.

The Migratory Dragonfly Partnership steering committee members represent a range of organizations, including:

Ontario Ministry of Natural Resources
Peggy Notebaert Nature Museum
Pronatura Veracruz
Rutgers University
Slater Museum of Natural History, University of Puget Sound
Smithsonian Conservation Biology Institute
St. Edward's University
U.S. Forest Service International Programs
U.S. Geological Survey
Vermont Center for Ecostudies
The Xerces Society for Invertebrate Conservation

For information about the Migratory Dragonfly Partnership, please visit www.MigratoryDragonflyPartnership.org or contact:

Scott Hoffman Black
The Xerces Society
628 NE Broadway, Suite 200
Portland, OR 97232
(855) 232-6639
dragonfly@xerces.org

Depending on the species, dragonfly nymphs develop in the water for a month to several years, molting a dozen times as they grow. Dragonflies have simple metamorphosis, with the adult insect developing within the last larval stage. The nymph then stops feeding and comes to the surface to breathe air, signaling its readiness to leave the water and begin the next phase of its life.

Photo: © John C. Abbott/Abbott Nature Photography.

Nymph of Black Saddlebags (*Tramea lacerata*). Adults of this species are highly migratory.

The nymph crawls up on the shore or a convenient stem or leaf, splits its skin, and emerges as an adult within a few hours. The new adult looks quite rumpled until the wings expand and the body hardens. With many dragonflies, emergence occurs at night, but some of them emerge during daylight hours, when this amazing phenomenon can be easily seen.

The newly emerged adult, called a teneral, launches into its first flight and moves away from the water to finish maturing. The teneral has shiny wings, weak flight, and hardly any pigment. Its first flight may take it a long distance from the water, where it quickly develops a definitive color pattern (though still not its mature coloration). The insect may stay in a sexually immature stage for a few days to several months while away from the water. During the maturation period, adults concentrate on feeding.

Behavior

Flight

Dragonflies are classified as perchers or fliers. Perchers, such as most skimmers and clubtails, hold their abdomen horizontally when at rest. They are alert, move their heads frequently to look around, and may fly up suddenly to capture prey or chase another dragonfly. Fliers, including darners, emeralds, and some skimmers, fly back and forth while feeding or searching for mates and hang under branches with the abdomen closer to vertical when resting. They do not watch for prey or mates when perched, but are alert enough to escape a stalking predator or photographer!

Photo: © John C. Abbott/Abbott Nature Photography.

Head of Common Green Darner (*Anax junius*).

Dragonflies are the most accomplished insect fliers. Their wings are surprisingly complex and perfectly structured for their complicated flight maneuvers. Not only does each pair of wings work independently of the others, but so does each wing. Dragonflies can fly swiftly at about the same speed as small songbirds (30 miles per hour), stop suddenly and hover, make instantaneous right-angle turns, shoot straight up in the air, and even back up for a short distance.

Eyes

Dragonfly vision is the best in the insect world. The large eyes provide a wide visual field that allows the insect to see in all directions except directly behind the head. Each compound eye consists of up to 28,000 simple eyes (ommatidia) that give a mosaic view, which is especially good at detecting movement. Nerves from each simple eye are stimulated sequentially as an object moves across the visual field. The dragonfly's tiny brain calculates where a flying insect is headed and "leads" it to intercept at a predetermined point.

Temperature Regulation

Dragonflies lack internal temperature control; their body temperature is controlled by air temperature. On a cool morning, a dragonfly may rest perpendicular to the sun's rays to warm up, often perching on a pale surface that reflects sunlight onto its body. Fliers whirr their wings to warm up their thorax enough to help them lift into flight and warm themselves still more. To avoid overheating, fliers seek shade when their body temperature reaches a critical point. Perchers either point their abdomen up at the sun (obelisking) at midday or hang it down below them to avoid overheating.

Eating and Being Eaten

Dragonflies capture their prey in the air. Some fly like a swallow and pick insects out of the air, while others watch from a perch like a flycatcher and take off after insects flying by. They hold their spiny legs out like a basket to scoop up the insects they capture.

Despite being predators, dragonfly adults and nymphs can fall victim to a variety of animals. Birds eat dragonflies in great numbers, especially during breeding season when they can feed their young on tender tenerals. Bats eat them at dusk, frogs and fish jump out of the water after adults, spiders catch them in webs or hunt them down, lizards and robber flies stalk them in the uplands, and dragonflies hunt and kill each other. Fish are such active predators on nymphs that some dragonfly species breed only in fishless ponds.

Reproduction

All dragonflies must return to the water to breed. Males spend long periods at the water searching for potential mates—females carrying mature eggs that need to be fertilized. Females of most species lay eggs immediately after mating, often accompanied or guarded by the male.

Males of many species defend a fixed territory against other males of the same species. This provides them access to any female entering their territory, without interference from other males. Males likely defend territories in what females deem appropriate habitat, and we can use that information to infer where nymphs are likely to be found. Males of non-territorial species cruise around lake shores or up and down rivers actively searching for females. When they encounter another male of their species, there is a chase, but neither remains at that spot.

Photo: © Dennis Paulson.

Spot-Winged Glider (*Pantala hymenaea*) may be seen migrating in Texas from midsummer to fall.

Photo: © John C. Abbott/Abbott Nature Photography.

Nymph of Common Green Darner (*Anax junius*).

Dragonfly mating is a complex dance, and most dragonflies mate only a few times in their life. Before encountering a female, the male does something that sets him apart from all other insects--he transfers sperm from a pore near the tip of his abdomen to an organ (seminal vesicle) near the abdominal base, where it is stored for immediate use. When a male encounters a female, he attempts to clasp her head with the three appendages on the end of his abdomen, which act like forceps to get a firm grip behind her eyes. If the female is ready to mate, she swings her abdomen up to the base of the male's, and structures there lock the tip of her abdomen in position for copulation. The two individuals now form a circle, often called the wheel position.

Copulation lasts from a few seconds in flight up to several hours at rest. In some dragonflies, the wheel position breaks but the male still grasps the female behind the eyes and they set off in tandem to lay eggs. In many species, the male releases the female but accompanies her to prevent others from mating with her. In other species, the female goes on her solitary way to lay eggs.

Dragonflies deposit their eggs using a variety of techniques. In some species, the female uses her well-developed ovipositor to inject eggs into plant tissue. Other females drop their eggs in or near water; females of some species tap their abdomens repeatedly on the water to lay eggs produced in a ball at the tip, while those of other species lay eggs on dry land in seasonal wetlands that flood later.

One female can lay thousands of eggs, scattering them over a wide area to increase the likelihood of survival of both eggs and young. The cycle begins again as the egg hatches into a nymph that must go through the aquatic part of its life cycle before we see the adult dragonfly.

Migration

Only about 16 of the 326 dragonfly species in North America are considered regular migrants, and their flights can create one of nature's most impressive spectacles. Tens to hundreds of thousands of individuals have been seen streaming southward along coasts, lake shores, and mountain ridges in fall, but their origins and destinations are still poorly known.

Many fall migration episodes have been documented, but movement back north is rarely seen, presumably because it occurs over a wider front and longer time period. We know it happens because dragonflies appear early in spring in places where nymphs have not yet emerged.

The best-known migrant in North America is the Common Green Darner. This species appears in early spring at northern latitudes, often seen flying before any local dragonflies have emerged. These are migrants from the south, perhaps from Florida, the Caribbean, or Mexico. These individuals breed soon after they arrive in spring, and their nymphs develop quickly in wetlands warmed by the summer sun. Many adults emerge in August, and instead of maturing and breeding at the same site, they begin a southward movement that may take over a month. Their destination is at present unknown but presumably the same areas thought to produce spring migrants. Migrating individuals may breed along the way or at their final destination; their offspring migrate north in spring.

Other species with a similar seasonal pattern include some strong-flying skimmer species: Wandering Glider, Spot-Winged Glider, and Black Saddlebags. These also appear suddenly at high latitudes in spring or summer and breed in warm shallow wetlands. Flights of what are presumably their offspring are seen moving south at the same time as the larger darners. Additional species are suspected migrants in eastern North America, but information to confirm this is sketchy.

Common Green Darners migrate in the West as well, but not in the numbers seen in the East. Instead, the Variegated Meadowhawk is the predominant migrant. They appear in the Northwest in spring, and their nymphs develop rapidly and emerge in early fall. Tremendous numbers of these small reddish or brown dragonflies have been reported moving south along Pacific Northwest coasts and mountain ranges.

Dragonflies are a fairly well-known group of insects, but there is much yet to be learned about their ecology and behavior and especially one of the most amazing phenomena of nature—their spectacular annual migrations.

Photo: © John C. Abbott/Abbott Nature Photography.

Black Saddlebags (*Tramea lacerata*).

Photo: © Dennis Paulson.

Variegated Meadowhawk (*Sympetrum corruptum*).

Photo: © Netta Smith.

Wandering Glider (*Pantala flavescens*).

LESSON 4

SCIENCE BEHIND THE SCENES

OBJECTIVE

Students use adaptive primary literature (APL) to read and understand research published in a scientific journal. Students will learn the structure of a scientific article and understand how that relates to the process of science.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS2.A: Interdependent Relationships in Ecosystems

Disciplinary Core Idea LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science Practice 8: Obtaining, evaluating, and communicating information

Cross-Cutting Concept: Patterns, Stability and Change

TIME REQUIRED

Variable. One to three class periods based on how you choose to implement.

MATERIALS

Science Behind the Scenes Handout

BACKGROUND

Adaptive primary literature rewrites published journal articles in a way that students may easily understand. It focuses on familiarizing students with the universal text structure of scientific articles: abstract, introduction, methods, results, and discussion. Learning this structure is foundational to science literacy. This lesson also includes the following additional sections derived from the Natural Inquirer publications created by the USDA Forest Service: *Thinking About the Science, Thinking About the Environment*, and *Meet the Scientists.* These sections are meant to supplement the traditional APL format by encouraging moments of student discussion, critical thinking, and self-reflection.

The procedure outlined below includes reading and discussing all of the above sections. However, you may choose which of these sections to use in your classroom to most effectively support your students' learning. This lesson is flexible; it may last from one to three class periods. Facilitate small-group or class-wide discussions after reading each section. The discussions provide an opportunity to check understanding as well as to practice the evidence, claims, reasoning (ECR) framework.

The original journal article was published by the Royal Society Publishing and is available online and may require institutional membership or a fee to access: http://rsbl.royalsocietypublishing.org/content/2/3/325.

Understanding Null Hypothesis Testing

How do researchers use data to answer their research questions? They use statistics to determine if their data support an alternative hypothesis. Hypotheses are all the possible answers to a research question. The *null hypothesis* is the answer that indicates the response variable does not have a relationship to the predictor variable. The *alternative hypothesis* (or hypotheses) are the other possible answers to the question that demonstrate a relationship between the predictor and response variables.

In this paper, the authors wonder if dragonflies migrate following the same rules as songbirds. They make observations about dragonfly migration and compare them to what we already know about bird migration. Multiple related questions are asked such as: How does temperature affect dragonfly migration? Do dragonflies migrate on warmer days, on colder days, or does it not make a difference? The researchers wondered if the average daily high temperature would predict if dragonflies would rest or migrate on a particular day. The null hypothesis for this question is that there is no relationship between average daily high temperature and dragonfly migration. In this case, the average daily high temperature for resting and migrating days would be the same. The alternative hypothesis (or hypotheses) are the other possible answers to the question that demonstrate a relationship between the predictor (temperature) and response variable (type of dragonfly migration day: resting stopover day or active flying migration day). Evidence for an alternative hypothesis would be the average daily temperature on migration days is higher (or lower) than on resting days.

Making graphs is an important part of answering a research question. When one variable is quantitative and one variable is categorical, as in the example above, data can be graphed using a bar chart. If the null hypothesis is true, the bars will be equal in height. Another way to phrase this is the difference in values between the bar heights will be zero or a value close to zero. For an example of data that support the null hypothesis, see figure 1 in the "Science Behind the Scenes" handout (Average Change in Nighttime Temperature and Flying vs. Rest Days). Data supporting one of the alternative hypotheses would manifest as bars with different heights. See figure 2 in the "Science Behind the Scenes" handout for an example of data that support an alternative hypothesis (Average Change in Nighttime Temperature and Flying vs. Rest Days). A large difference in average temperatures (or bar heights) is strong support for an alternative hypothesis. However, the natural world is a complicated place and research methods are not perfect, so research projects don't always result in strong, easily-interpretable results. Frequently, differences in averages are small, and it is difficult to determine if there really is a significant relationship between the predictor and response variables.

How do scientists determine when a small difference is too small to indicate support of an alternative hypothesis? When comparing averages, as in this paper, data may be analyzed with a *t*-test that calculates a *p*-value. A low *p*-value (usually less than 0.05) means there is a very low probability that the averages are the same and we can say they are significantly different. If a *p*-value is above 0.05, the averages may be the same, and we cannot say they are significantly different. For example, the *p*-value comparing the difference between average daily high temperatures on flying days (24.3°C) and rest days (22.1°C) is 0.25. This is a large *p*-value, much higher than 0.05. So, we cannot say the two values are significantly different. Therefore, we cannot reject the null hypothesis.

"We cannot reject the null hypothesis"

Scientists carefully avoid stating that they accept a null hypothesis. Instead, you will see the statement "We cannot reject the null hypothesis." If the null hypothesis is true, scientists will not be able to find evidence for a relationship between the variables. Researchers only can find evidence to reject a null hypothesis by collecting data that supports an alternative.

Additional Resources

The United States Forest Service Natural Inquirer publications are a great resource for additional APL materials: http://www.naturalinquirer.org/all-issues.html.

PROCEDURE

1. Show students the "Process of Science Wheel" from chapter 1. Review each step in the wheel. What happens in each step? Why is it important? Ask students why they think the process is presented in a circle shape. What do the arrows indicate?

2. Introduce the text structure of published journal articles to students: abstract, introduction, methods, results, and discussion. Ask students to identify parallels between the investigation wheel and the text structure of scientific articles. Both tell a similar story of how science is done.

3. For each reading section listed below, provide time for students to read to themselves or aloud to a small group. Follow this reading with a facilitated discussion about that section.

4. Use the "Thinking About the Environment" section to introduce your "Science Behind the Scenes" article. This is the context the researchers were experiencing as they observed and wondered about the world. It led to the development of their research questions. What did the scientists wonder about?

5. Use the "Meet the Scientists" section to establish a human connection between students and the researchers. Ask students if they see themselves in these researchers. Why or why not? Explain that they are scientists because they have been studying the world through citizen science.

6. Go through each of the main text structure components of the article.

    - The ABSTRACT provides the reader with an overview of the paper, summarizing what the researchers studied and what they found.

    - The INTRODUCTION provides a review of literature that has been previously completed on the topic, provides a broader context for the work, and states the questions being addressed. Ask students to identify the research question as well as the null and alternative hypotheses.

    - The METHODS section explains how the experiment was done in enough detail to allow other scientists to repeat the study and verify the results. In ecology papers, the methods section usually describes where the work was carried out, under what environmental conditions, and how the data were collected and analyzed.

    - The RESULTS describe what the authors found with the statistical evidence that allows them to make claims. This section is where tables and graphs reside.

    - The DISCUSSION text directly answers the research question raised in the introduction. The discussion is where the authors pull together the full story. It puts the research results in context of the background from the introduction and suggests what should be studied next.

Assessment Recommendation

Use the "Thinking About Science" section to review your "Science Behind the Scenes" article.

- What inspired the research?
- What is the study question?
- Is the study observational or does it involve experimental manipulations?
- What are the alternative and null hypotheses?
- What are the advantages and disadvantages of carrying out an experiment that manipulates variables?
- What are the advantages and disadvantages of carrying out an observational study?
- Identify any dependent and independent variables.
- What do the data mean?

Optional Extension

Give students a copy of the original article. Ask them to find and highlight all the main text structure sections within the article. Compare and contrast the content in the "Science Behind the Scenes" sections to the original article. What parts of original article are most challenging for your students? Where are they finding success?

Provide opportunities to practice these skills by giving students copies of other primary science journal articles, and ask them to identify the text structure. PLOS ONE is an example of an open access (free) science journal that is a good source for additional primary literature articles.

Zebra clubtail dragonfly (*Stylurus scudderi*).

Science Behind the Scenes: Free Ride: Dragonflies Migrate Like Song Birds

PRIMARY ARTICLE SOURCE

Wikelski, M., Moskowitz, D., Adelman, J.S., Cochran, J., Wilcove, D.S., May, M.L. 2006. Simple rules guide dragonfly migration. Biology letters 2:325–9.

THINKING ABOUT THE ENVIRONMENT

Many animals migrate: wildebeests in Africa, salmon in Alaska, monarch butterflies in the United States and Mexico, and many more. Migration occurs when animals need to move to a new geographic area to access resources required to survive and to reproduce. Wildebeest migrate to access water and fresh plants to eat; salmon swim up streams to access spawning grounds; and monarchs migrate to access warm temperatures so they don't freeze during winter. Most migrations correspond with seasonal patterns like the rainy and dry season or fall and spring.

Animals migrate in patterns, sometimes over extraordinary distances, going back and forth between habitats or moving in a circular pattern always striving to access vital resources like warmth, water, and food. How do these animals know when and where to migrate? Scientists are still working on determining this. Learning about migratory movement will allow scientists to better track the spread of diseases, to understand how climate change is affecting ecosystems, and to provide advice about where to place protected conservation areas.

MEET THE SCIENTISTS

Dr. Martin Wikelski studies animal migration including how they survive and why they sometimes die. He is the director of the Max Planck Institute for Ornithology in Radolfzell, Germany and a Professor at University of Konstanz, Germany. He is also a Visiting Research Scholar at Princeton University.

Dr. David Moskowitz is the Senior Vice President of EcolSciences, Inc. He earned his Ph.D. in Entomology from Rutgers University. He has many areas of expertise including wetlands and threatened and endangered species.

Dr. James S. Adelman is a wildlife ecologist at Iowa State University where he studies how diseases impact both individual animals and entire populations. He studied Ecology and Evolutionary Biology at Princeton where he earned is Ph.D.

Jim Cochran is associated with Sparrow Systems, in Fisher, Ilinois. *Dr. David S. Wilcove* is a Professor of Public Affairs and Ecology and Evolutionary Biology at the Woodrow Wilson School at Princeton. *Dr. Michael L. May* studies dragonfly migration at Rutgers University.

ABSTRACT

Billions of insects migrate every year. Scientists have executed a lot of research exploring how groups of insects like dragonflies and butterflies move during migration. However, not many studies have looked at how individual insects decide when and where to migrate. The rules individual songbirds use to migrate are well known and the researchers wondered if

dragonflies would follow similar rules. To study how individual common green darner dragonflies migrate, the researchers glued tiny transmitters onto 14 dragonflies. The dragonflies were then tracked with receivers in cars and small airplanes. The results demonstrate that individual dragonflies do migrate using methods very similar to song birds.

INTRODUCTION

At least 25 species of dragonflies are thought to be migratory and dragonfly migration routes are known to occur on all continents except Antarctica. In this study, Wikelski and his team of scientists chose to look at the migration pattern of one species: the common green darner (*Anax junius*). Common green darners are a widespread dragonfly found throughout North America and have been observed migrating from Canada to the Gulf of Mexico. In fall, they migrate south away from the cold temperatures and frozen water of the North. In spring, they return to the northern United States and Canada to feed and reproduce during the warm summer months. Despite their abundance, not much research has been done studying their migration.

The researchers wanted to find out if individual dragonflies migrate following the same rules that individual songbirds follow when they migrate. We know a lot more about songbirds and their migration than about dragonflies. If they migrate in similar ways, it would help scientists determine what questions to ask and research to do to learn more about dragonflies.

Specifically, we know migrating songbirds typically

- have resting stopover days and active migration days,
- do not migrate on very windy days,
- migrate after two days of falling nighttime temperatures,
- allow the prevailing wind to determine their flight direction,
- prepare for migration days by accumulating fat, and
- reorient their migration direction when they hit an obstacle like the ocean.

The overarching research question is: do migrating common green darner dragonflies follow the same rules as migrating songbirds? To answer this question, the scientists compared what they learned about common green darner migration from this observational study to what we already know about bird migration.

METHODS

To learn about how individual common green darners migrate, Dr. Wikelski and his team captured 14 adult common green darner dragonflies (seven females and seven males) from five different sites in New Jersey during fall migration, between September 14 and October 30, 2005. The researchers weighed each dragonfly and glued a tiny 300 mg (0.03 g) radio transmitter onto each insect's thorax. The transmitters sent signals back to receivers in cars and airplanes so that the scientists could find them and know where the dragonflies were after they were released.

Dragonflies are surprisingly strong. Flying male common green darners often carry the females, who weight about 1.2 g, while they are mating. Knowing this, the researchers concluded that the small weight of the transmitter likely did not affect individual insect migration choices. Furthermore, none of the tagged dragonflies appeared to have any difficulty flying.

The dragonflies were released from Princeton University in New Jersey and were tracked at least twice a day both from the ground, using cars, and from the air, using small airplanes. The dragonflies were tracked for up to 12 days, or until they flew more than 140 km away from Princeton University. The researchers observed no evidence of the tagged dragonflies dying or being eaten by predators during the study period.

Temperature and wind data were collected through the National Oceanic & Atmospheric Administration (NOAA) automated weather stations. For each individual dragonfly, average values were calculated for the number of stopover days, number of days until first migration flight, distance traveled per migration flight, and direction traveled.

The data collected about dragonfly migration (timing, weather, distance, direction, and response to obstacles) were compiled and compared to what we know about songbird migration.

RESULTS

Of the 14 dragonflies tagged with transmitters, 13 were successfully tracked. Individuals were followed on average for six days and all were seen to move more than two kilometers from the location of release. Three dragonflies migrated on the day of release and the ten others migrated within four days following release.

The dragonflies exhibited a clear pattern of rest and migration. Migrating, on average, every three days. On resting days, dragonflies replenished their energy, traveling only short distances in search of food. On flying days, darners traveled an average of 58 km to the south-southwest.

The researchers suspected temperature may be a factor dragonflies used to determine if a day would be a resting or migrating day. When they compared the daytime high temperatures between flying and resting days, they found no significant difference. The high temperature on flying days was on average 24.3°C and the high temperature on resting days was on average 22.1°C (see figure 1).

These temperature values are close but are not exactly the same. How did the scientists determine that these values are not significantly different from each other? They used statistics! Researchers use statistics to help answer research questions that analyze quantitative, or numerical, data. If the temperature values were exactly the same, or if they were very far apart, it would be easy to determine if they were significantly different or not. However, the natural world is a complicated place and research methods are not perfect, so scientists often get values that are close and difficult to interpret.

A statistical test, called a *t*-test, was used to figure out if the two averages represent a true difference in daytime high temperature between flying and resting days. The *t*-test analyzed the data and calculated a *p*-value. A *p*-value is a number between 0 and 1. A low *p*-value (less than 0.05) means there is a very low probability that the two average values are the same. If a *p*-value is above 0.05, the averages might be the same, indicating no difference may exist in the daytime high temperatures between flying and resting days. The researchers ran a *t*-test on the average daytime high temperature data comparing flying and resting days and got a large *p*-value of 0.25. This is a *p*-value is much higher than 0.05, so the scientists concluded that the average

Average Daily High Temperature on Flying and Rest Days

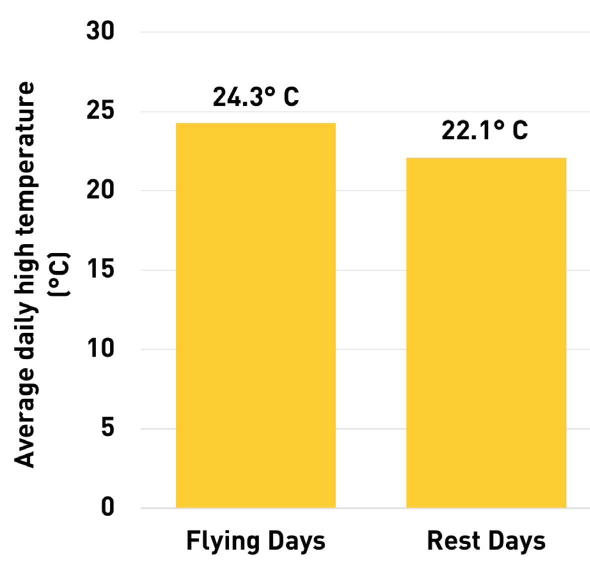


Figure 1: The average daily high temperatures on flying days was 24.3 (+/- 0.8) °C and on rest days was 22.1 (+/- 1.5) °C. A *t*-test comparing these means returns a *p*-value of 0.25 (*t*-value = 1.16) indicating the average temperatures are not significantly different.

temperatures between resting and flying days are not significantly different.

While daytime high temperature doesn't appear to affect whether or not dragonflies fly or rest on a given day, the researchers suspected nighttime temperature might be playing a role. We know birds will migrate after a night that is colder than the previous night. So they compared the average change in nighttime temperatures between two nights before a dragonfly's flying and resting days (see figure 2). Again, the scientists used statistics to determine if the average nighttime temperature change between the two nights before flying and resting days influenced dragonfly migration. If the average change in nighttime temperatures before flying days is different from the average before resting days, then there is evidence that dragonfly migration behavior responds to changes in nighttime temperature. A *t*-test comparing the average nighttime temperature changes generated a very small *p*-value of <0.0001 indicating the average change in nighttime temperatures are statistically different. On days when the second night was colder than the first night, the dragonflies had a flying migration day. On days when the second night was warmer than the first night, the dragonflies had resting day.

During the observation period, the scientists kept track of wind direction and speed. Dragonflies generally migrated on days when wind speed was low. No dragonfly migrated when the wind was gusting over 25 kilometers per hour. On the flight days, the wind was most often from the north, blowing towards the south. The dragonflies almost always flew with the direction of the wind.

Common green darners did change their pattern and fly in a direction different than the wind when they arrived at the open ocean at Delaware

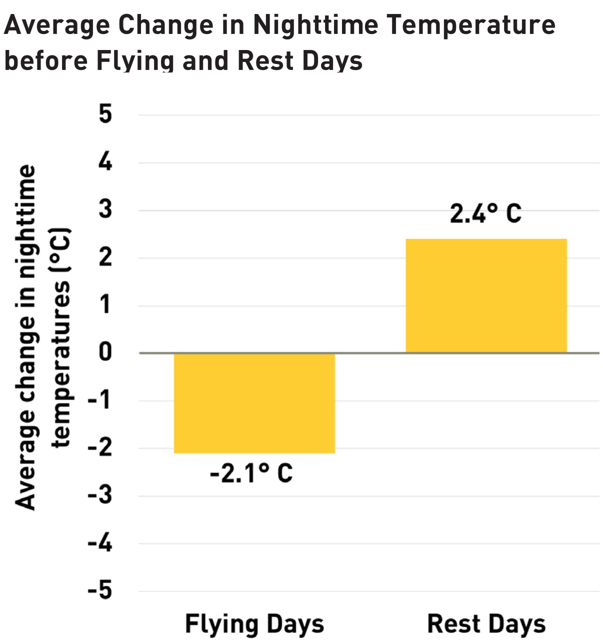


Figure 2: The average change in nighttime temperatures for the two nights before flying days is -2.1 (+/- 0.6) °C and before rest days is 2.4 (+/- 0.8) °C. A *t*-test comparing these means returns a *p*-value of <0.0001 (*t*-value = 4.7) indicating the average change in temperatures are significantly different.

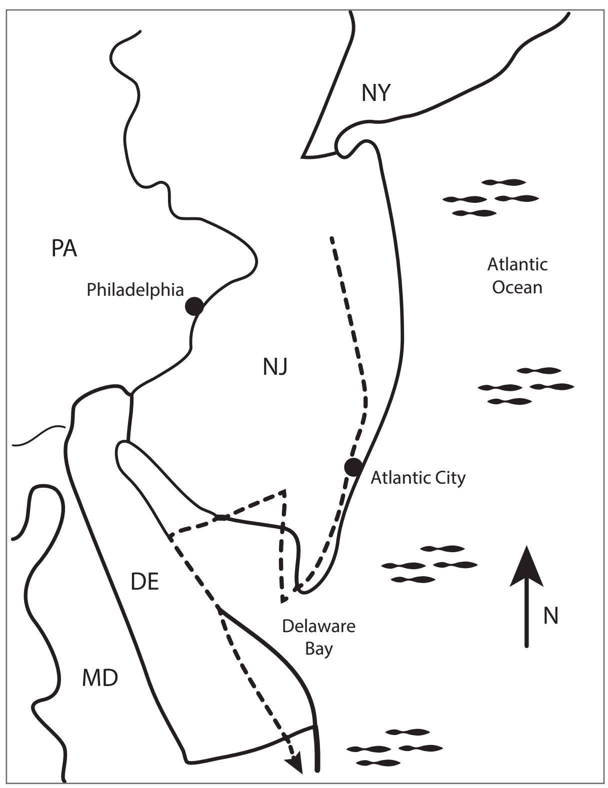


Figure 3: A map of the research area in the Northeast United States. The dashed line indicates a general migration path taken by four individual dragonflies. After they reached Delaware Bay, they all turned around to fly north and then followed the shoreline inland until they reached a safe location to cross south into Delaware.

Bay. The dragonflies were documented flying out over the water for about 5 kilometers and then turning around returning to the coast. Then they flew inland along the shoreline until they found a spot where the bay became narrow enough to safely cross (see figure 3).

DISCUSSION

Common green darners do migrate like songbirds. Both dragonflies and songbirds alternate between stopover and migration days. In both animals, stopover days are vital times for feeding and replenishing and energy reserves for future flight days. Nighttime temperature changes dictate which days will be stopover and flight days for both creatures. In fall, weather patterns that create two nights of consecutively colder temperatures trigger flight days in both birds and dragonflies, and usually also bring winds blowing from north to south.

Since bird and dragonfly migration flights both go along with the prevailing winds, flying on days with wind from the north carries them in the right direction. However, too much wind can be troublesome for both birds and dragonflies. Neither creature migrates on days with strong gusts. Finally, both songbirds and common green darner dragonflies respond the same way to encountering a physical barrier, like the ocean, while migrating. They both turn back against the wind and follow a geographic landmark, like a ridge or shoreline, until they find a safe pathway to continue their journey.

There is one large difference between the migration patterns of dragonflies and songbirds. With songbirds, the same individuals that fly south in fall will fly north in spring. Adult dragonflies do not live long enough to make the return journey. Instead, they will mate and lay eggs in the south during the winter and those offspring will fly north in spring to create the next generation of migrators.

THINKING ABOUT THE SCIENCE

Scientists conduct investigative research projects to answer questions about our natural world. Research questions develop as a result of thoughtful observation and wondering about the world around us. To answer research questions scientists design and execute appropriate research methods. There are two main types of research. An observational study is when a researcher observes naturally-occurring differences in the environment to collect data to answer their question. An experiment is when a researcher manipulates the environment to explore what effect one variable has on another. Both of these types of research have benefits and challenges.

This paper describes an observational study with a goal of learning more about dragonfly migration. The researchers explored an over-arching guiding question: Do migrating common green darner dragonflies follow the same rules as migrating songbirds? They did not set up a controlled experiment to see how one specific variable affects another. Exploration-style research like this is valuable because it builds a foundation of knowledge and inspires more defined questions for future research. What new questions does this paper leave you with? Could you set up an experiment to answer any of these questions?

NOTES

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Contributing to Citizen Science

DRAGONFLIES AND ODONATA CENTRAL

Contributing to Citizen Science

CONTRIBUTING TO CITIZEN SCIENCE

This section provides instructions on how to collect and submit student data for Odonata Central.

Experiences gained while contributing to citizen science will generate observations and questions that fuel student independent investigations.

ODONATA CENTRAL

Odonata is the order name for dragonflies and damselflies. Odonata Central was established to collect and "make available what we know about the distribution, biogeography, biodiversity, and identification of Odonata (dragonflies and damselflies) in the Western Hemisphere." Photos of dragonflies uploaded by citizen scientists are confirmed by experts and then compiled into the data set. Range maps for individual species and county lists are generated by the submitted data and can be downloaded from Odonata Central. Many counties in the United States are poorly surveyed for Odonates, so your classroom may catch a new county record. If you catch a dragonfly or damselfly species not on the Odonata Central county list, you have collected data that is new to scientists. However, all observation reports about any species are valuable to researchers striving to understand dragonfly diversity and distribution.

Of special interest to dragonfly researchers are species that migrate. Your students can help scientists better understand dragonfly migration by (1) monitoring the spring and fall movements of the five main migratory species of North America, and (2) collecting seasonal information on migratory species at local ponds throughout the year. Focusing on the five main migrating species is convenient for classrooms because it reduces the number of dragonflies students need to be able to identify. It's also valuable to researchers because collecting data on dragonflies as they migrate across the United States would be nearly impossible for scientists to do alone, but it is achievable with the help of many student citizen scientists working together across the country.

You may collect dragonfly data at a pond, marsh, stream, or other local wetland of any size that your classroom can safely access with permission from the landowner. Alternatively, dragonflies can often be observed and collected in school gardens, prairies, and open fields.

Newly emerged spiny baskettail dragonflies (*Epitheca spinigera*).

LESSON 1

COLLECTING AND REPORTING DATA WITH ODONATA CENTRAL

OBJECTIVE

Students participate in the process of science by observing and recording data, submitting the data to Odonata Central, and developing their own potential research questions.

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS2.A: Interdependent Relationships in Ecosystems

Disciplinary Core Idea LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science Practice 1: Asking questions and defining problems

Science Practice 3: Planning and carrying out investigations

Cross-Cutting Concept: Structure and Function

TIME REQUIRED

60–90 minutes

MATERIALS

- Something to take photos with (camera or smartphone)
- Aerial Nets
- Dragonfly field guides or the Migratory Dragonfly Identification Information Sheets from lesson 2 in chapter 2
- Computer or tablet to enter data online
- Notebook to record observations
- Clear envelopes in which to put dragonflies (optional)
- Pop-up insect cage (optional)

BACKGROUND

Your students have learned about dragonfly anatomy, identification, and migration. Now let's collect data. Odonata Central is an internet-based program for collecting citizen data about dragonflies and damselflies. It's a vibrant program that is growing and changing so the electronic interface evolves. Go to www.odonatacentral.org to find the most up-to-date instructions.

Register Online

Register for a username and password at Odonata Central: http://odonatacentral.org/. Click on the **My OC** tab and then **Register** link.

It may be easiest to create just one account for your classroom. Students may create their own accounts later if they wish to continue contributing citizen science observations on their own.

To participate in Odonata Central your students will need to

1. catch adult dragonflies,
2. accurately identify the dragonflies,
3. take photographs of the dragonflies, and
4. upload their data to the Odonata Central.

Images that show the dragonfly from the side and from the top are most helpful for identification of the migratory species. You may upload up to three photos with each specimen to help the reviewers confirm your identification.

Collecting Data

This curriculum suggests your student citizen scientists track the the spring and fall movements of the five best-known migratory dragonflies in North America: common green darner (*Anax junius*), black saddlebags (*Tramea lacerata*), wandering glider (*Pantala flavescens*), spot-winged glider (*Pantala hymenaea*), and variegated meadowhawk (*Sympetrum corruptum*). Collect and submit dragonfly migration data in fall and spring when dragonflies are migrating. Fall migrants may be observed from late July through mid-October and often travel in swarms. Spring migrants can be observed as early as mid-to-late March and often arrive individually. Collect these data as frequently as you like. Even just a single day of collecting will generate data valuable to submit to Odonata Central.

You and your students may, of course, observe, photograph, and report data on all of the Odonata species that you encounter at any time of year. The limitation is only in how many dragonflies you and your students can identify.

This activity is best done on a warm and sunny day when dragonflies like to fly. On cool, overcast, or extremely windy days dragonflies will hide, taking refuge in trees or tall grasses.

Right after they emerge (metamorphose into an adult) dragonflies are very soft-bodied and delicate. This is called being in the teneral stage. Teneral dragonflies should not be caught because it will damage their soft bodies. Your students can identify a teneral dragonfly because they are a light green color, their wings are often still held together over their backs (not spread out), and they won't fly away (or fly very far) when students get close.

A newly emerged teneral dragonfly.

Reporting Data

1. Log in at Odonata Central: http://odonatacentral.org/. Click on the **My OC** tab and then then enter your user name and password. Click **Log In**.
2. Click on the **Records** tab and the click on the **Submit Record** sub-tab.

3. Fill in the date and location information in the box labeled **Date and Jurisdiction**.
   - Clicking on the **Look Up Latitude/ Longitude** button will open an interactive map where you may select your location to auto-fill the latitude and longitude.
   - Be concise but specific in your location description. Notes about habitat or weather are helpful.
4. For each dragonfly observed at this location fill in the data fields in a box labeled **Record**.
   - You may submit up to ten records per location at one time.
   - You may leave the notes section blank or include a few words to explain something special about the specimen.
   - When you are all done click the **Submit** button at the bottom of the page.
5. Review your submissions. Click on the **My OC** tab and then click on the **My Records** sub-tab.
   - You will see a list of all your submissions.
   - All submitted specimen identifications are vetted by an expert. The people who vet are all volunteers, so this sometimes takes a few days.
   - The status of your specimens' review is listed on the right under the **Vetted** column.
   - Only one specimen of each species needs to be submitted per day or per class. You may add a note about the abundance of that species on that day if you like.

After being checked by an expert, your specimen will be confirmed or not. If your submission is not confirmed, it could be because your identification is incorrect or because your photographs don't show what needs to be seen in order to confirm the identification. Don't be concerned if sometimes your specimens are unconfirmable. That is how we learn.

See what other Citizen Scientists have submitted to Odonata Central

Odonata Central allows users to examine data submitted by other citizen scientists in two ways.

1. Generate a list of dragonfly species observed in a county.
   - Click on the **Checklists** tab
   - Type in your county of interest or click on your area of interest in the expandable list.
   - A list of all Odonata species observed in your selected county will be generated. Click **View Printable Version** if you would like a list to print out.
2. See range maps of which species have been reported where.
   - Click on the **Maps** tab.
   - Type the name of the species you are interested in (you must choose a single species, the software is not able to map more than one species at a time).
   - After you select a species, dots will appear on the map. Each dot represents a submitted specimen.
     - Green dots represent confirmed specimens submitted by citizen scientists. Yellow dots represent unconfirmed specimens submitted by citizen scientists. Blue dots represent specimens that were imported from other collection databases when Odonata Central was first established.
     - Clicking on a dot will bring up that specimen's information.
     - Can you find a dot for a specimen your classroom submitted?
   - You can filter the map results by location or specimen status using the tools along the top of the map. You can also alter the map type/background.

PROCEDURE

1. On a sunny and warm day, explain to your students that they will be citizen scientists and collect dragonfly data for Odonata Central. Define Odonata (the order name for dragonflies and damselflies) and introduce the program's goals. If you have time, show them some range maps from the website. Explain that each dot represents data contributed by a citizen scientist and that they will be collecting data to add more dots to the maps.

2. As citizen scientists, students will be catching and identifying dragonflies. For every dragonfly they catch, they should record its identification and the location where they caught it.

   Distribute paper, science notebooks, or a data sheet for recording data. Students may create their own data sheets or you may create and provide one.

3. Take students outside to your collection site either in a field, prairie, or wetland. Remind students how to safely catch and hold dragonflies (see lesson 1 in chapter 2).

4. Distribute aerial nets. Students may need to share depending on how many aerial nets you have. If they are working in groups, students may take turns catching dragonflies and recording the data.

5. They may work together to identify the species. Have dragonfly field guides or the Migratory Dragonfly Identification Information Sheets, from lesson 2 in chapter 2, available as tool for identification. Students should take pictures of the dragonflies they catch, at least one shot from the side and one from above.

6. It can be helpful to place dragonflies in clear envelopes while they are being observed for identification. This will prevent them from flying away and protect them from the wear and tear of being handled. Dragonfly researchers use special envelopes called *Odonata envelopes* for this. (You can find them online through a Google search.) But any transparent envelope will do.

7. You may want to temporarily place captured dragonflies into a pop-up insect cage until the end of your collection period. This way students won't catch the same insect more than once. Release them all after you are finished surveying.

8. Back in the classroom, discuss how the data collection went. Where did your students find dragonflies? Did they seem to prefer a certain type of habitat? What challenges did they face? If you are focusing on migratory species, discuss where in their migration the species you observed (or didn't) are; are they still coming your way, have they passed you, or are they going to miss you completely? Range maps from Odonata Central or from dragonfly identification guides will help with this discussion.

9. Enter the data into Odonata Central. Using smartphones, tablets, or computers, your students may log into Odonata Central to enter their data and upload their photos. If needed, you may demonstrate how to enter the data for the first specimen on a smart board or projecting from your computer.

ASSESSMENT

Ask students to discuss why researchers need the help of citizen scientists. How do they help researchers gather data? How might they hinder research? In which steps of the process of science do citizen scientists participate and contribute? In which steps do they not participate? If your students were to create their own citizen science data gathering program, how would they set it up?

LESSON 2

INTERPRETING ODONATA CENTRAL DATA

OBJECTIVE

Students analyze a map created with the Odonata Central citizen science collected data following the "Identify and Interpret Strategy."

NEXT GENERATION SCIENCE STANDARDS CONNECTIONS

Disciplinary Core Idea LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science Practice 4: Analyzing and interpreting data

Cross-Cutting Concept: Patterns, Stability and Change

TIME REQUIRED

45 Minutes

MATERIALS

- The map of migratory dragonflies reported to Odonata Central in 2014.
- "Identify and Interpret Strategy" lesson from chapter 4

BACKGROUND

Analyzing data is a key part of the process of science. The map on the student page shows the location and time of year that migratory dragonflies were reported to Odonata Central during spring of 2014.

Things to note about this map

1. Each dragonfly icon represents an observation made and reported by a citizen scientist.
2. Each dragonfly icon indicates that one of the five main migratory species of dragonflies was reported at that location. The five species include common green darners (*Anax junius*), black saddlebags (*Tramea lacerata*), wandering gliders (*Pantala flavescens*), spot-winged gliders (*Pantala hymenaea*), and variegated meadowhawks (*Sympetrum corruptum*).
3. The color of the dragonfly icon indicates the time of year the observation was made.
4. The map shows a trend of dragonflies migrating in spring by moving from the southern United States to the northern United States and into Canada.
5. What are the limitations of interpretation that can be made from this map?
   - The map only shows data collected from January through May of 2014. Fall migration and spring migration in other years may look different.
   - The map doesn't indicate which of the five migratory species were observed where. Different species may be migrating differently.
   - The map doesn't show the movement of any other migratory dragonfly species other than the five focus species.
6. How might the map look different for different years? How might the graph look different during fall migration?
   - Spring migrators move north at different times in each year depending on spring temperatures across the country.

The earlier spring heat melts the snow and ice off northern ponds and lakes, the earlier dragonflies can migrate north. How would the map look different if it represented a year with a harsh, cold spring?

- In fall dragonflies migrate south in swarms, as opposed to trickling north as individuals in spring. How might that change the appearance of the map?

7. What does the number of dragonfly icons tell us? Does it reflect the abundance of dragonflies in those areas?
   - The number of icons only tells us the number of submitted citizen science observations. It does not indicate the number migrating dragonflies in an area.
   - For example, an area with many dragonfly icons could represent one citizen science volunteer who was very active and went out and caught a lot of dragonflies in the spring of 2014.
   - On the other hand, an area with no icons could indicate that no dragonflies were there to observe or simply that no citizen scientists were out looking.

PROCEDURE

1. Distribute this map to your students. Ask them where the data to make map came from. What do the dragonfly icons represent?
2. Follow the "Identify and Interpret Strategy" lesson from chapter 4. Ask students to identify what they see in the map and what it means. Then write a new caption for the map.
3. Answer questions about the map components as needed.
4. Ask students to share their captions.

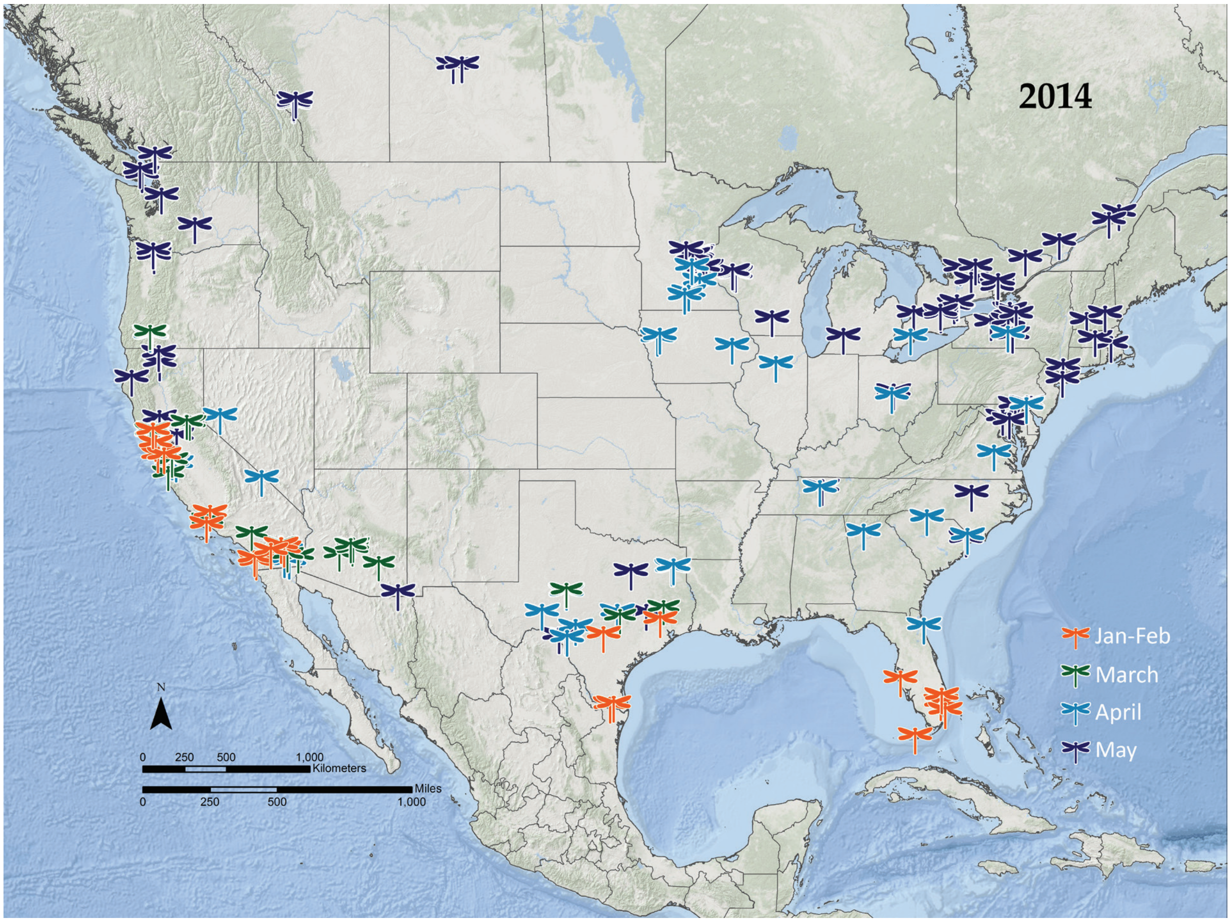
ASSESSMENT RECOMMENDATION

Facilitate discussion about the map:

1. What might be causing any trends you see in the map?
2. How does the way the data were collected influence the map?
3. What does the graph tell us about dragonfly migration? What does it not tell us?
4. Would you change anything about this graph if you could recreate it?

Citizen scientists collecting and identifying dragonflies.

The Xerces Society for Invertebrate Conservation created this map using data from Odonata Central. It represents citizen scientist observations of the five focal migratory dragonfly species reported January–May of 2014.



Write a caption for the map:

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Conducting Independent Investigations

DRAGONFLIES AND ODONATA CENTRAL

Conducting Independent Investigations

After students are familiar with the science skills required to carry out their citizen science projects and have collected and submitted data for these projects, they are ready to engage in their own research. You may do a single experiment with your entire classroom, or you may generate several questions tested by small groups.

The following activities are separated into lesson plans for each step depicted in figure 1, but each lesson is not intended to fill a whole class period. You can decide how much class time to dedicate to each step as you work your way through the process. How long you spend on each step depends on your students' prior knowledge and your goals for your students. But it works best to follow the sequence in the order it appears.

The Driven to Discover materials are designed to support a largely verbal, interactive process intended to be engaging and thought provoking. Throughout the process, encourage students to record their ideas and decisions in a notebook or science journal. They will need to refer to these details when writing conclusions and preparing to share their findings.

The process of developing and implementing an investigation requires explanation and guidance at first. But once they learn the steps, your students will have the skills to design science investigations on their own.

OBJECTIVES FOR INDEPENDENT INVESTIGATIONS

- Students will conduct a scientific investigation based on observations and questions from their experiences as citizen scientists.
- Students will collect, analyze, and interpret data to formulate answers to a science question.
- Students will record notes about their planning process, data collection, and data analysis.
- Students will communicate their findings.

NGSS SCIENCE PRACTICES

- Asking questions
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Encourage students to continue adding to the "I Wonder" board throughout the research process.

THE PROCESS OF SCIENCE

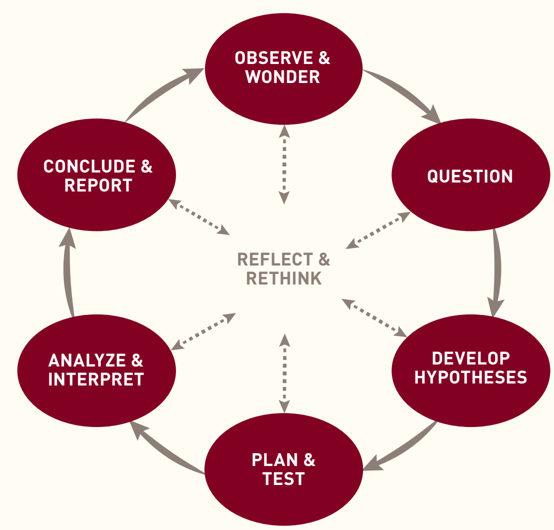


FIGURE 1. Scientific discoveries are made through the process of investigation, though scientists often use the terms "research" or "the scientific method" to describe what they do. Investigations involve detailed examination of phenomena with the goal of discovering and interpreting new knowledge, whether the knowledge is new to humankind, to a small group of people, or just to the person doing the research.

LESSON 1

MINI-INVESTIGATIONS

OBJECTIVE

Students will practice steps in the process of doing science.

NEXT GENERATION SCIENCE STANDARDS

Science Practice 3: Planning and carrying out an investigation

MATERIALS

- Mini-Investigation worksheet
- Pen/Pencil
- Supplies for specific investigation

OUTDOOR/INDOOR & TIME OF YEAR SUGGESTIONS

A mini-investigation can take place outdoors or indoors any time of year, but the investigations will be different based on these factors. Outdoor investigations can allow students to collect observational data if the season is right. For example, don't plan to observe pollinator behavior outdoors in winter, but bird behavior is observable any time of year. Indoor investigations might focus on analysis of existing citizen science data.

TIME REQUIRED

1–2 class periods

PROCEDURE

The Mini-Investigation worksheet is designed to help you conduct a short investigation to give students a chance to practice the many steps in planning and carrying out an investigation. They are meant to be quick, collaborative, and fun. To expedite the process of developing an investigation, a question of your choosing is provided to students.

1. Introduce the question.
2. Work with students to develop hypotheses based on the question provided.
3. Discuss how to test the question with a step-by-step plan for collecting data and making sure the process will result in fair, accurate data.
    - How will you collect data?
    - How much data do you need to collect?
    - What should data collectors do, look for, or count/not count so everyone is doing it the same way?
    - What materials will you need?
    - How will you record the data you collect? Make a data recording sheet.
4. Collect the data. Since this is meant to be a practice exercise, be sure to keep this fun while still working carefully.
5. Use the graph paper on the back of the Mini-Investigation worksheet to make a graph that represents the data you collected. Be sure to label the axes on the graph and give it a title.
6. Write a conclusion by answering the questions in the "Conclude & Report" box on the worksheet.
7. Discuss these questions.
    - Which hypothesis was supported by our data?
    - How did our planning work make the data collection easier or harder?

- How would our findings be different if we collected data on a different day? In a different place? Using different methods?
- What did this activity teach us about conducting investigations?

Assessment Recommendation

The Mini-Investigation worksheet may serve as assessment for this activity. A rubric may be based on the degree of completeness, clarity, and complexity of thought.

IDEAS FOR MINI-INVESTIGATION QUESTIONS

Birds

- Where in our field site are most birds found? (Extensions: try gathering data in a variety of ways, comparing, for example, different geographical locations, different habitat types, locations with varying habitat complexity or degree/percent of hardscape, etc.)
- Does talking during a bird count affect the number of birds observed?
- What method of observing birds – sight, sound, or sign – produces the most observations?
- How many bird calls do you hear with your eyes open versus eyes closed?
- Which bird feeder type (or location) do birds prefer? (Feeders would have to be put out a few days earlier if they aren't already available at your site.)

Phenology

- How much variation in phenophase timing occurs within a single tree species found at our site?
- Do different tree species show different levels of variation in phenophase at our site?
- Does the phenophase of a common plant at our site vary on different sides of a building, on different sides of a hill or in locations with different amounts of sun and shade?
- How many different life stages of a particular animal (bird or insect) are present at our site?

Pollinators

- Does the number (or diversity) of pollinators visiting flowers vary between flower colors?
- Do more pollinators visit flowers in the sun or shade?
- Does talking during a pollinator count affect the number of pollinators observed?
- Does sitting close to flowers affect the number of pollinators observed?
- How long do pollinators spend at individual flowers? Does this vary for different flowers or different pollinator species?
- Are some flower species more likely to be visited by fly (or bee) pollinators than other species?
- Do teachers (or students) in your school know the difference between a honey bee, bumble bee, and flower fly?

Dragonflies

- Is the sex ratio of male and female dragonflies different near the water vs. away from the water?
- Are there differences between damselfly and dragonfly habitat? If so, what are they?
- Does time of day affect the number of dragonflies students see?
- Does weather affect the number of dragonflies students see?
- How many species of dragonflies are at your site in spring, in fall?

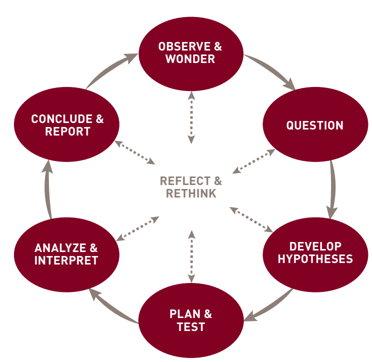
Scientists collect data in many different ways.
Top: Preserved specimens of dragonflies raised at different temperatures as part of a controlled experiment.
Bottom: Dragonfly nymphs collected to be observed and measured and then released.

Mini-Investigation

The following pages contain a fun project that will help you practice planning and carrying out a research investigation.

Use the space below to record any notes, sketches, or ideas important to the investigation.

The Process of Science



Mini-Investigation

CONCLUDE & REPORT

Summarize the results, including which hypothesis was supported by the study.

What did you learn by doing this investigation?

OBSERVE & WONDER

AFTER INVESTIGATION

What observations made during your investigation have led to new questions?

REFLECT & RETHINK

ANALYZE & INTERPRET

Describe the results of what happened. Use graph paper to make a chart to summarize your data.

PLAN & TEST

Create a step-by-step procedure for your investigation. Remember to think about materials, methods, sample size, and constants. Use graph paper to make a table to record data.

BEFORE INVESTIGATION
What observations led to your research question?

QUESTION

Write your testable question in this space.
.

DEVELOP HYPOTHESES

What are the possible answers to the research question?

DATA TABLE

Use this space to make a table to record data.

RESULTS

Use this graph paper to make a chart that summarizes your data.

LESSON 2

SCIENTIST ROUNDTABLE

OBJECTIVES

Students will sharpen research planning skills.

Students will practice working together to help each other improve their investigations.

NEXT GENERATION SCIENCE STANDARDS

Science Practice 1: Asking questions and defining problems

Science Practice 3: Planning and carrying out investigations

Science Practice 7: Engaging in argument from evidence

Science Practice 8: Obtaining, evaluating, and communicating information

MATERIALS

(Optional) Large sheets of paper taped to the wall.

TIME REQUIRED

20–60 minutes

BACKGROUND

Scientists often need help thinking through their ideas. The open exchange of ideas helps scientists consider all angles to their plans and helps them anticipate—and therefore prevent or prepare for—problems they may encounter with their investigation.

Focus on keeping the process constructive for all the young scientists. Pay special attention to fostering an emotionally safe and supportive atmosphere to lay the groundwork for the roundtable. This will encourage students to experiment with new ideas and think aloud together. Talking through their research plans helps them sharpen their research skills by analyzing multiple research plans instead of just their own. By holding roundtables multiple times throughout the Driven to Discover experience, collaborating with others becomes the norm. The students get help developing their research plans, gain confidence in their science skills, and feel a sense of investment in all the class's projects.

An important feature of this process is to allow the presenting scientist(s) to begin their presentation with a statement about the type and the amount of feedback they are seeking from the group. It may be difficult, at first, for students to accept even the most constructive feedback from their peers in a public forum. The teacher's role is to help the students clarify the feedback they are seeking and help the group stay on task to do their best to provide feedback. This process may seem stilted, forced, and it may take longer than anticipated at first. The class may need a higher level of involvement from the teacher initially as they model the process. The investment in building these skills with students is worth the effort, even in small steps.

With practice, students will gain confidence in their projects and in their ability to think on their feet and to provide constructive input to their peers.

PROCEDURE

As students plan investigations, have them present their research plans to each other one at a time during a scientist roundtable. The goal of the roundtable is to provide constructive feedback and point out potential problems or issues with research designs. If peers have trouble coming up with ideas for their fellow scientists, consider using this feedback process:

1. PRESENT One scientist presents a research plan, even if it isn't fully thought out yet. They should state their research question, hypotheses, and plans for data collection.

2. PRESENTER ASKS The presenting scientist asks specific questions, for example, "How would you decide on the sample size for this project?" or "How can I set up a data sheet for this project so that it makes the most sense?" or "What have I missed?" Encourage constructive suggestions.

3. PEERS ASK Invite peers to ask questions, for example, "What is your independent variable?" or "How will you keep your data collection protocols consistent?"

4. PEERS SUGGEST Invite peers to make additional suggestions, for example, "Another hypothesis you could list is…." or "Your data would be more consistent if you made your observations at the same time each day." Only use this last level of feedback if the presenting scientist is willing to accept additional input beyond what he or she asked for.

Assessment Recommendation

Wrap up the discussion with reflective questions like these for the entire class.

- How was it helpful to discuss your project with other scientists?
- What kind of input was most helpful to you? Least helpful?
- How were our investigations improved by this discussion?
- How do you benefit by helping other scientists with their projects?

This activity adapted with permission from a process developed by Driven to Discover club leader Kristina McCullough.

I wonder

Repeat this process multiple times throughout the investigation phase of your Driven to Discover experience. Keep the "I Wonder" board handy as new questions may arise.

OBSERVE & WONDER

THE PROCESS OF SCIENCE: OBSERVE AND WONDER

NEXT GENERATION SCIENCE STANDARDS

Science Practice 1: Asking questions and defining problems

MATERIALS

- "Observe and Wonder" Student Page (optional)
- The sticky notes from the "I Wonder" board

TIME

5–10 minutes to reflect on experiences collecting citizen science data and generating "I Wonder" questions.

PROCEDURE

Throughout this project, students have been collecting observations and questions on your "I Wonder" board. Now, you will use these observations and questions to springboard into an independent research project of their own.

To help students reflect on all they've done and seen during the "Building Science Skills" and "Contributing to Citizen Science" portions of the Driven to Discover project, ask them to complete the "Observe and Wonder" student page. Keep this page handy as they prepare to work through the rest of the process.

Assessment Recommendation

Student questions may serve as assessment. A rubric may be based on number of questions, creativity, analytical thought, thoroughness, and observation skills demonstrated by questions.

Step 1: Observe and Wonder

INVESTIGATIONS BEGIN WITH OBSERVATIONS

While collecting citizen science data, you may have noticed things in nature that sparked your curiosity. You may use these observations as the foundation for your own research. This observation phase of a research project is key. Scientists focus their attention on the world around them and use their senses to experience what's there. They may compare what they see to what they already know or to other things they see. Just like you, they often record notes or illustrations about their observations in a journal.

THE SPECIES OR NATURAL PHENOMENON THAT I WILL STUDY

TEN THINGS I NOTICED ABOUT MY SPECIES OR NATURAL PHENOMENON

SOME THINGS I WONDER ABOUT MY SPECIES OR THE PHENOMENON I AM STUDYING

I wonder

QUESTION

THE PROCESS OF SCIENCE: QUESTION

NEXT GENERATION SCIENCE STANDARDS

Science Practice 1: Asking questions and defining problems

MATERIALS

- “Question” Student Page (optional)
- The sticky notes from the “I Wonder” board

TIME

15–60 minutes

BACKGROUND

In this part of the science process, students generate and winnow research ideas as their thoughts progress from the general (What am I curious about?) to the specific (What variable will I change and how?). As they work their way through this process, they will learn the concepts of independent and dependent variables as well as the difference between observational and experimental studies.

Every question is a good question. Not every question is testable. ?

Which of the following categories best describes your question?

LOOK IT UP

Question has been answered authoritatively. Use reference material or ask an expert.

EXAMPLES:
What are bird egg shells made of?
What countries are monarch butterflies found in?

NOT ANSWERABLE

Often “Why” questions. May depend on coincidence or an observation that can’t be replicated.

EXAMPLES:
Why are there so many kinds of sparrows?
Why did that monarch fly away?

TESTABLE BUT NOT PRACTICAL

Good research question but not feasible to test with the time/materials available.

EXAMPLE:
Do robins vocalize more in their summer breeding season than in the winter?

TESTABLE

Questions whose answers are observable, measurable, and repeatable.

EXAMPLES:
Do monarch females prefer to lay eggs on the top side or underside of the milkweed leaf?
Which type of feeder do birds prefer?

PROCEDURE

1. Identify testable questions

In this step, sort the questions into the four categories shown on the previous page. How you do this depends on how you have been keeping your "I Wonder" board. You may need to cut the questions apart or copy them onto index cards or Post-it notes. The end result is to have each question on a separate piece of paper.

Display the questions from the "I Wonder" board on a table and gather students around them.

Sort the questions into the categories described above.

Discuss.

- Why did you categorize the questions as you did?
- How could you convert a "not testable" question into a "testable question?"
- What is the benefit of investigating a question that might have been studied before by someone else?
- Are any of the questions we classified as "testable but not practical" something you could pursue on your own outside the classroom? What would it take to do this?

Remind students that questions declared "not testable" are not bad questions. They may just not work for this particular situation. Generally, things such as size, location, and behavior (e.g., crawling, reacting to stimuli, flying, or feeding) are easier to study. It is important to acknowledge and encourage their "why" questions because these questions demonstrate wonder and curiosity — an essential component of science. Unfortunately, "why" questions are often difficult to convert into a testable question for investigation purposes.

If you'd like to go further, consider having students characterize their testable questions as descriptive, comparative, or correlative. This will give them a sense of the type of study they are undertaking and the nature of the data they will need for their investigation.

DESCRIPTIVE QUESTION

What is there?
How many?
What happens?
How frequently?

EXAMPLE:
How many bee species come to our garden?

COMPARATIVE QUESTION

Is there a difference between two things such as techniques, weather, locations, time, etc.?

EXAMPLE:
Do we see (or hear) more birds in the morning or afternoon?

CORRELATIVE QUESTION

What is the relationship between two variables such as time, temperature, etc.?

EXAMPLE:
Do lilac bushes right next to the south side of our school produce earlier buds than lilac bushes on the north side of our school?

2. Identify dependent and independent variables

Note: Identifying variables only applies to comparative and correlative questions, as defined above. If students ask a descriptive question such as, "How many bird species live in my yard?" there will not be dependent and independent variables.

Examine the questions classified as "testable." Point out that the questions focus on characteristics of their study system (an organism, group of organisms, or natural phenomenon) or relationships between their study system and the environment. Help students select a specific characteristic or relationship to study.

For example, the characteristics of the comparative and correlative questions illustrated in the table above include bird songs, lilac phenology, and the numbers of bee species in their garden.

The characteristic the students want to study will be the *dependent* or *response variable* in their investigation: something they are interested in exploring and whose value might change or vary in response to different conditions.

Ask the student investigators to brainstorm things that might affect the characteristic they selected. They should try to list at least four or five things, but it's okay if they can't come up with this many.

Things that affect the characteristic they want to study are called *independent variables.* A way to distinguish the independent variable in the investigation is to remember: "The variable I manipulate (or that is manipulated naturally) is the independent variable." See examples in box on this page.

If students are having problems thinking of factors that might affect the characteristic they want to study, it's fine for them to choose another characteristic.

Choose one independent variable to test in an investigation. Remind students that this should be something that is feasible given the available time, setting, and materials. You may steer them toward questions that make sense. For example, if you were studying spiders, and they decide to study how temperature affects spiders' ability to fly, you would probably discourage them since spiders don't have wings, and thus they don't fly under any circumstances.

3. Specify whether you will conduct an experimental or observational study

OBSERVATIONAL STUDY In an observational study, students collect data that document or interpret the natural world. In this case they will not change the independent variable themselves, but it might vary naturally. For example, if they

DEPENDENT VARIABLE	INDEPENDENT VARIABLE
(CHARACTERISTIC)	(THINGS THAT MIGHT AFFECT THE CHARACTERISTIC)
Number of bees in our garden	Number of flowers present
	Number of flower species present
	Time of day
	Time of year
Number of birds we observe	Species of bird
	Time of day
	Temperature
	Time of year

are interested in how the color of a flower affects the number of bees that visit it, they would probably use flowers that are growing in their garden. If they were interested in earthworm habitat preference, they may look for worms in wet and dry soil (independent variable) and count the numbers of worms (dependent variable). Here they are working with naturally-occurring habitat variation. Observational studies are an important way for scientists to learn about the world. Scientific studies do not need to involve manipulations by the experimenter.

EXPERIMENTAL STUDY In an experimental study, students alter their independent variable. If they were interested in how shade affects the number of bees that visit flowers, they could hold umbrellas over some of the flowers in the school garden. If they were interested in whether robins foraged more on the ground after it rained because there were more earthworms close to the surface, they could water a lawn plot and see if more robins come to it. Encourage the students to be as specific as possible in describing how they will vary or change the independent variable.

4. Finalize the research question

Finally, put all of these steps together into a question. In most cases, it will be easiest if you use this format: How does ____________________ (independent variable) affect ________________________ (dependent or response variable)? Examples of questions include

- How does the temperature a lady beetle larva experiences affect its ability to catch prey?
- How does whether a flower is in the shade or not affect the number of bees that visit a flower?
- How does soil moisture affect robin foraging behavior?

In some cases, questions will not fit this format. This is okay. Examples include

- Do aphids prefer one type of milkweed plant over another? Aphid preference is the dependent/response variable, and the type of plant is the independent variable.
- Do butterflies show any preference for type of flower? Butterfly preference is the dependent variable, and the type of flower is the independent variable.
- How do robins respond to different noises? Robin behavior is the dependent variable, and the type of noise is the independent variable.

If you are going to conduct an investigation as a whole group, choose from the questions the group generated. Compile a master list and, with your leadership, have students evaluate questions on the list. An important criterion to consider is whether you may realistically investigate the question. Using consensus, choose one or more questions to investigate.

Assessment Recommendation

Student-generated questions can serve as assessment for this lesson. A rubric may be based on correct categorization of question type, appropriate phrasing of testable question, appropriate use of variables, and specificity of their assignment of dependent and independent variables.

Step 2: Question

IS MY QUESTION TESTABLE?

One of the hardest things about the process of science is to ask questions in a way that makes them suitable for an investigation. If a question is not testable, that doesn't mean it's not a good question. It just isn't something you'll be able to study.

Testable questions

- ask about objects, organisms, and events in the natural world;
- can be answered through experiments, observations, or surveys;
- are answered by collecting and analyzing evidence that is measurable;
- relate to scientific ideas rather than personal preference or moral values; and
- do not relate to the supernatural or to nonmeasurable phenomena;

NOT TESTABLE	TESTABLE QUESTION
How do birds fly?	How close can I get to a robin before it flies away?
Why do monarchs eat milkweed?	How does the size of a monarch larva affect how much it eats?
Why do chickadees eat seeds?	What type of bird feeder attracts the most chickadees?
What do flowers look like to a bee?	What color flowers attract the most pollinators?

WHAT ARE MY VARIABLES?

DEPENDENT OR RESPONSE VARIABLE	INDEPENDENT VARIABLE
The thing you choose to test in an experiment. Its value might vary or change depending on something else.	The factor that you vary or change in the experiment or that varies naturally. You will choose one independent variable to test in your experiment.

 NAME

CHOOSE A CHARACTERISTIC TO STUDY

(This will be the *dependent variable* or the thing that might change due to the independent variable.)

LIST THINGS THAT MIGHT AFFECT THE CHARACTERISTIC I WANT TO STUDY

(This is my *independent variable* or the thing I change or that changes naturally.)

MY INVESTIGATION WILL BE (CHECK ONE)

- ☐ OBSERVATIONAL (learning from what I see)
- ☐ EXPERIMENTAL (learning what happens if I change something)

MY QUESTION WILL BE (CHECK ONE)

- ☐ DESCRIPTIVE (describes what is or what happens)
- ☐ COMPARATIVE (compares two things)
- ☐ CORRELATIVE (finds how things influence each other)

THE QUESTION I WILL TRY TO ANSWER IN MY INVESTIGATION IS

Hint: Use this format if possible.

How does ____________________ (independent variable) affect _____________________ (dependent variable)?

LESSON 5

DEVELOP HYPOTHESES

THE PROCESS OF SCIENCE: DEVELOP HYPOTHESES

NEXT GENERATION SCIENCE STANDARDS

Science Practice 1: Asking questions and defining problems

MATERIALS

"Hypotheses" Student Pages

TIME

5-20 minutes

BACKGROUND

A common definition of a hypothesis is that it is a prediction or an educated guess about what might happen in an investigation. However, a more accurate definition is that a hypothesis describes one possible outcome to an investigation or one possible answer to your question. Scientists regularly use multiple hypotheses when conducting an investigation. Using multiple hypotheses teaches students that there are several possible outcomes or answers to their question, and these hypotheses will either be supported or not supported by the data. One hypothesis that should always be considered is the null hypothesis. This acknowledges that the independent variable might not affect the dependent variable at all, or that there will be no difference between experimental groups.

Encouraging students to generate multiple hypotheses before they conduct an investigation is not only a better representation of how scientists work, it is also a way to help them avoid feeling like they were wrong if the investigation doesn't turn out the way they expected it to. In general, hypotheses clarify the question being addressed, help direct the design of the investigation, and help the researchers maintain their objectivity.

In the case of a descriptive research question, hypotheses may not be necessary. For example, if your question is "What species of birds will we observe at our meeting site?", it would be okay to skip the hypotheses and simply document and report what you see. It would also be appropriate to write a hypothesis that lists the species you expect to see. Then, your conclusion may describe any surprises.

PROCEDURE

1. Collect information

Before developing a hypothesis, students should learn as much as they can about the question they developed in the previous activity. They can use the library, their past experience, the Internet, or other resources.

2. Provide examples of hypotheses

Present an example to ensure students understand how to form multiple hypotheses. For example, suppose that your question is "Do robins spend more time on the ground in the morning or afternoon?" There are three possible outcomes:

- Robins spend more time on the ground in the morning.
- Robins spend more time on the ground in the afternoon.
- Robins spend the same amount of time on the ground in the morning and afternoon.

The third outcome (hypothesis) is called the *null hypothesis.* It is the one that acknowledges that there might not be an effect of the independent variable.

3. Develop hypotheses for selected research question

Discuss the question your class has chosen and brainstorm possible answers. Have students write reasons that one hypothesis or another is more likely to be supported. For example, they might think that robins spend more time on the ground in the morning because the soil is wetter, and worms are more likely to be near the surface. At this point, it is reasonable for the students to refine their original question to one that is more specific if necessary. In the above example, they might decide to compare the amount of time robins spend on the ground after a rain to the time they spend on the ground when the soil is very dry.

An example of this process follows.

The group has chosen the question "How does temperature affect the number of bees we see in our garden?" The students have studied and thought about many different areas related to this question, such as insect metabolism and effects of temperature on flower blooming.

a. List the following hypotheses:

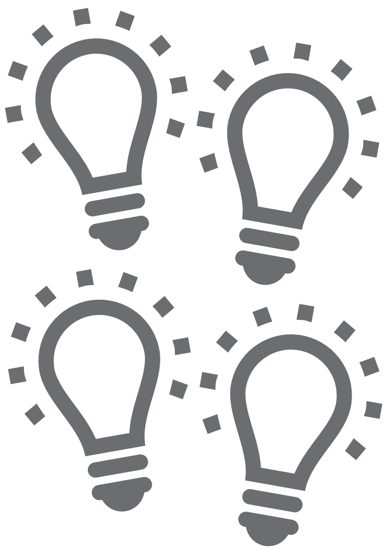
- We will see more bees when it is warmer (this could be true if bees are more likely to forage when it is warm because their metabolism speeds up so they need more food).
- We will see more bees when it is cooler (this could be true if bees are more likely to forage when it is cool because they need more energy to warm themselves up).
- The number of bees we see will not be affected by temperature (this is the null hypothesis which could be true if honey bees are the main bees that come to the garden, and for the most part, honey bees are collecting nectar to turn into honey to store for their colonies so temperature might not be important).

b. At this point, it might make sense to reflect and rethink. As the students develop hypotheses, they will probably come up with ideas that require clarification. For example, they may decide that it would make sense to limit the temperature range of their study. Clearly, they would not expect to see bees if the temperature was below freezing. So, they could change their question: "Within the range of 60 to 80 degrees F, how does temperature affect the number of bees we see in our garden?"

Assessment Recommendation

Student hypotheses and the reasoning behind them can serve as assessment for this lesson. A rubric may be based on appropriate delineation of possible answers, appropriate use of null hypothesis, thoroughness, and clarity.

Step 3: Develop Hypothesis



WHAT ARE MY HYPOTHESES?

Hypotheses are possible answers to your research question. Be sure to list all possible outcomes, including the possibility that you will observe no differences or relationships in your study subjects.

For example, if you are studying which species of flower monarch butterflies land on, your hypotheses might include (1) monarchs land more often on flower A; (2) monarchs land more often on flower B; (3) monarchs land more often on flower C; or (4) monarchs land on all flower species equally often. This last one is called a *null hypothesis*. If your findings support your null hypothesis, it does not mean your research didn't work. Finding no pattern is just as important as finding a pattern.

Use the space below to brainstorm some ideas. List your best hypotheses on the next page.

WHAT ARE MY HYPOTHESES?

What are the possible answers to my questions? List your hypotheses here (H1, H2, H3, and Null, depending on what your question needs). Include reasoning for each hypothesis (why it might be true). You might not need all the boxes.

H1

H2

H3

Null

PLAN & TEST

THE PROCESS OF SCIENCE: PLAN AND TEST

NEXT GENERATION SCIENCE STANDARDS

Science Practice 3: Planning and carrying out investigations

MATERIALS

"Plan and Test" Student Page

TIME

30 minutes to 2 class periods

BACKGROUND

After generating hypotheses, the next step is to design an investigation to test them. This is a time to pay close and careful attention to all the details, both before starting the investigation and during the period of data collection. The steps described below will help students think of as many details as possible when planning their investigation. There are three important scientific concepts to discuss before you design an investigation: 1) replication or sample size, 2) constant conditions, and 3) controls.

PLAN: DESIGN AN INVESTIGATION

Decisions for Investigations

Replication or sample size

The best way to explain replication is to use an example. Let's say a scientist is interested in how many children there are in families that live in different places. If she only counts the children in one city family and one farm family, random chance will greatly affect her results. She might happen to pick two very large families, two very small families, a large farm family and small city family, or any other combination. Instead, if she counts the children in 100 farm families and 100 city families, she will get a much better picture of the average number of children in farm vs. city families. Scientists have to use a large enough sample size to accurately test a hypothesis, while taking into account things like cost, availability of experiment subjects, and time.

With students, though, the scientific truth may not be our highest priority. We want them to understand the process and enjoy themselves. If more replicates become tedious, or if it's difficult to get a large sample size for some reason, keep it simple. Understanding how to go about answering a question may be more important than the veracity of the results. You may always discuss how additional replicates might affect your results and conclusions.

Constant Conditions (or a Fair Test)

The second scientific concept to consider is the importance of holding everything but the independent variable constant. This is an essential part of an experiment. For example, if you want to study temperature effects on the number of bee visitors to your garden, you should visit the garden at the same time each day and should conduct the study over a short enough time period that flower availability is constant. Likewise, the scientist studying family size wouldn't want to study farm families where the parents were 40-50 years old and city families where the parents were 25-35 years old.

Controls

Again, we will use an example to illustrate this concept. Let's say you want to test the hypothesis that loud music causes high mortality in monarch caterpillars. Your team members may suggest keeping a group of monarch caterpillars in a room with loud music going constantly. However, if all the caterpillars die, you won't know if the music killed them or if there was something wrong with them in the first place. In this experiment, you need a control. Place half of the group in a normal environment (control group) and half in with the loud music (experimental group). If more die in the room with the loud music, your hypothesis is supported. Again, it is important to hold constant conditions between the two groups. The conditions the larvae are exposed to in the two groups should be as similar as possible. Controls are used in experimental studies, not observational studies.

Not all experiments need controls. It's likely that most of the experiments you do for this project will be done outside under natural conditions and won't involve manipulating the independent variable. Then you usually don't need a control. If, for example, you want to find out if earthworm density is the same under pine trees as deciduous trees, you may simply measure the density in the two soils and compare them. There is no need to have a separate control treatment in which earthworms aren't under either pine trees or deciduous trees.

You do want to hold other conditions constant, however. For example, you wouldn't want to sample the earthworms under the pine trees just after a rainy day unless you also sampled the deciduous tree worms on the same day.

PROCEDURE

1. Discuss the issues of sample size, constants, and controls.
2. Work with students individually or in groups to complete the "Plan & Test" Student Page.
   a. Discuss how they will apply the concepts of variables, sample size, controls, and constants to their particular investigation.
   b. Have them plan the steps to the investigation, asking questions or playing devil's advocate as necessary.
   c. Make a complete list of materials.
   d. Design a data table to record the data. Students often need more space to write down all the data they collect, so once they are satisfied with the design, they may prepare a larger table on a separate sheet of paper to use during their actual data collection.
3. Conduct a Scientist Roundtable (see lesson 2) to help students ensure that their investigation plans are sound.

TEST: COLLECT DATA

Now is the time for students to carry out the protocols they designed for their investigations. Allow time for them to collect enough data as well as to solve any problems that come up.

The teacher's role at this point is to observe, to support, to encourage methodical work, to prepare the students to analyze and interpret their data, and finally, to share their findings. As much as possible, describe what behaviors they are demonstrating that qualify as good science process skills. For example, if you see them debating the best way to count the number of birds that come to a feeder, you might tell them, “You’re doing a good job of explaining the procedure you have in mind. By speculating which plan would work better and listening to each other’s ideas, you really are being scientists.”

Assessment Recommendation

Assessments for this component of the investigation may be based on design of investigation (appropriate decisions about sample size, constants, and controls, as well as appropriate data sheet) and conscientiousness of data collection (fidelity to research plan, consistency, fairness, thoroughness). Consider offering bonus points for any demonstrated “Reflect and Rethink” activity.

Dragonfly nymphs and a data sheet recording their sizes.

Step 4: Plan and Test

SAMPLE SIZE
What sample sizes will I use?

CONSTANTS
What do I need to hold constant in this investigation?

CONTROLS
Do I need a control? What will it be?

METHODS
What steps will I take in my investigation? Write directions so someone else could replicate the investigation by following this procedure.

MATERIALS
List all of the materials and tools needed to conduct the investigation.

DATA TABLE
Use this space to design a table to record data. Use another page if more space is needed.

LESSON 7

ANALYZE & INTERPRET

THE PROCESS OF SCIENCE: ANALYZE AND INTERPRET

NEXT GENERATION SCIENCE STANDARDS

Science Practice 4: Analyzing and interpreting data

Science Practice 5: Using mathematics and computational thinking

Science Practice 6: Constructing explanations

MATERIALS

"Analyze and Interpret" Student Pages

TIME

30-90 minutes

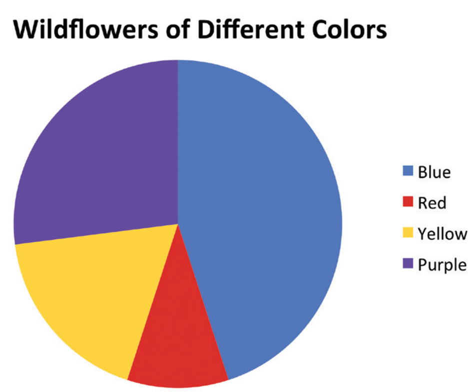
BACKGROUND

By now the students have a pile of data — perhaps a bunch of tally marks and numbers — and it is time to make sense of what they have found.

Often the best way to organize data is to use a graph. Graphs allow people to visualize the results of an investigation in a way that is often difficult in tables. In this lesson, you will discuss three kinds of graphs that are commonly used by scientists. There are samples of each kind of graph described in the Student Pages.

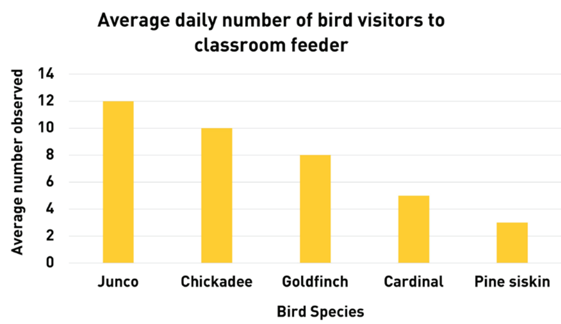
Before having your students interpret their own data, you may choose to use the next lesson, Using the Identify and Interpret Strategy, which focuses on graph interpretation skills.

Types of Graphs

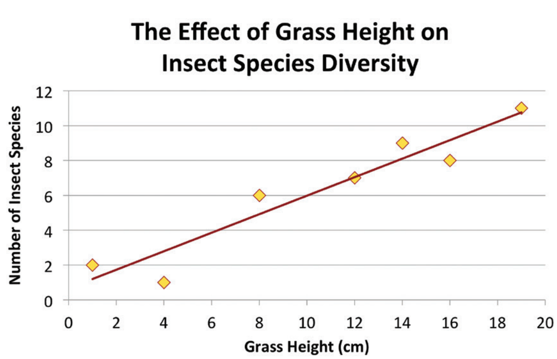


PIE GRAPHS are usually used to compare proportions. They look like a pie cut into different sized wedges where the size of each wedge represents a different category of data. For example, you could use a pie graph to compare the proportion of birds you observe that are eating, singing, or flying or observe the proportion of flowers of different colors that are in your garden.

BAR GRAPHS are used to compare counts or averages of discrete groups or categories of data. Each group is represented by a bar whose height represents something about that group. Usually each group is represented along a horizontal (or *x)* axis and the vertical (or *y*) axis represents the data collected about each group. A bar graph could be used to compare the average heights of boys and girls in your class or the numbers of individuals of different species of birds you observe. It is rarely appropriate to illustrate each individual with a separate bar. You wouldn't graph the height of each student on the graph, just the averages for males and females.

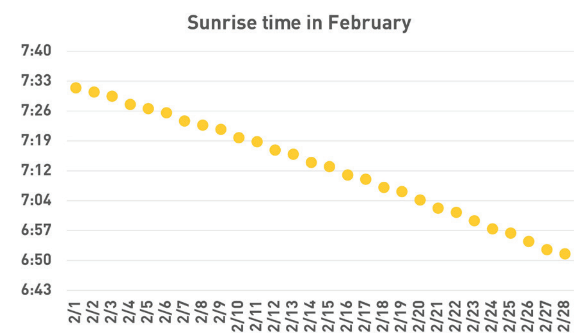


SCATTER PLOTS are used to look for a relationship between two numerical variables, often an independent variable and a dependent variable. They tend to be difficult for students to understand because they aren't used as commonly in schools, but they illustrate patterns that other graphs can't illustrate. They usually have the independent variable represented on the *x* axis and the dependent variable on the *y* axis. A scatter plot might be used to graph the relationship between height and shoe size or how the height of grass in a prairie affects the number of insect species. Each dot represents one sample, for example, one person's height and shoe size or one prairie site showing both grass height and insect diversity for the site.



LINE GRAPHS are set up like scatter plots, but there is usually only one *y* value for each *x* value. Both *x* and *y* values are continuous or numerical as on a time line or continuum. You would use a line graph to show how temperature or day length change over the course of a year, plotting days on the *x* axis and temperature or day length on the *y* axis. You would then connect the dots to visualize the relationship. (In a scatter plot there might be multiple *y* values for each *x* and you would not connect the dots.)

If you wanted to show temperature or day length over time comparing three different cities, for example, you might put days (or weeks) of the year on the *x* axis, plot the information for each city, and connect the dots for each city, so that the graph has three distinct lines comparing the data from the three cities. You might also graph day of the summer and the number of birds observed using a line graph with each dot representing one day and the number of birds observed on that day.



PROCEDURE

Direct students to study the sample graphs on the Student Pages. Discuss the reasons you might choose one or another format to analyze and to present your findings.

Determine which type of graph will suit your data best and make the graph on Student Page with graph paper.

Assessment Recommendation

Student-generated tables, graphs, or charts may be used as assessment for this lesson. The rubric may be based on appropriate choice of graph type, appropriate construction of graph, inclusion of graph labels, and other features of the graphs that you would like to emphasize.

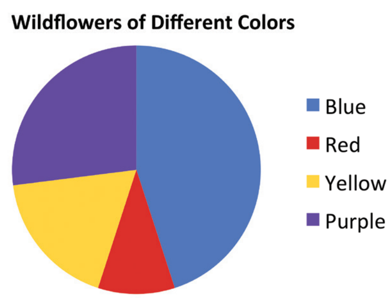
Step 5: Analyze and Interpret

GRAPHING DATA

Graphs help you see patterns and trends that are hard to notice in a data table. Some types of graphs will be better suited to your data than others. If you use a graph with an *x* and *y* axis, like the bar, line, and scatter plots below, put your independent variable on the *x* axis and the dependent variable on the *y* axis.

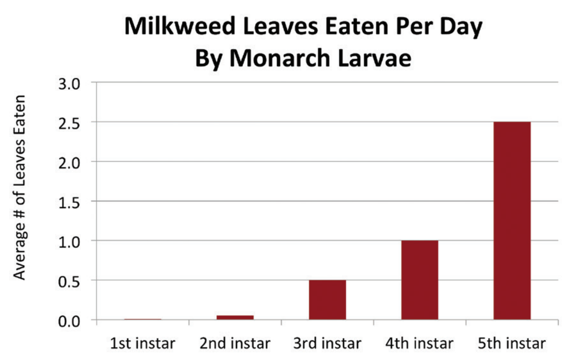
PIE CHART

- Use when comparing proportions or percentages.
- All the pieces together make up 100%.
- The wildflower chart quickly shows you that almost half of the flowers are blue; about a quarter are purple; and fewer are yellow or red.



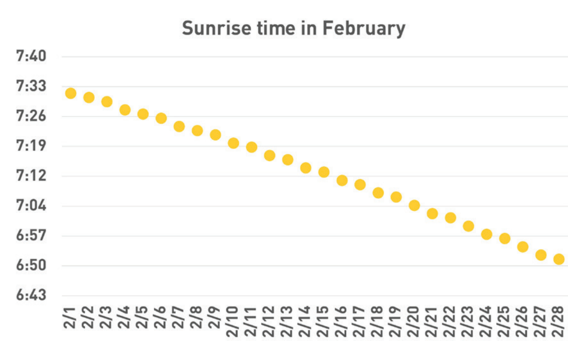
BAR GRAPH

- Use when comparing categories or groups.
- Each bar represents a separate group.
- Groups are on the *x* axis (horizontally), and each bar represents a speарate group.
- Data collected about groups are on the *y* axis (vertical).
- The data on the *y* axis may either show averages, or numbers.



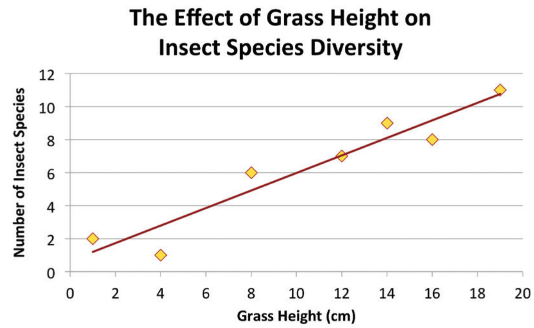
LINE GRAPH

- Use when the independent and dependent variables are both measured in numbers.
- Plotted points show changes over time.
- Individual points are plotted and then connected with a line.



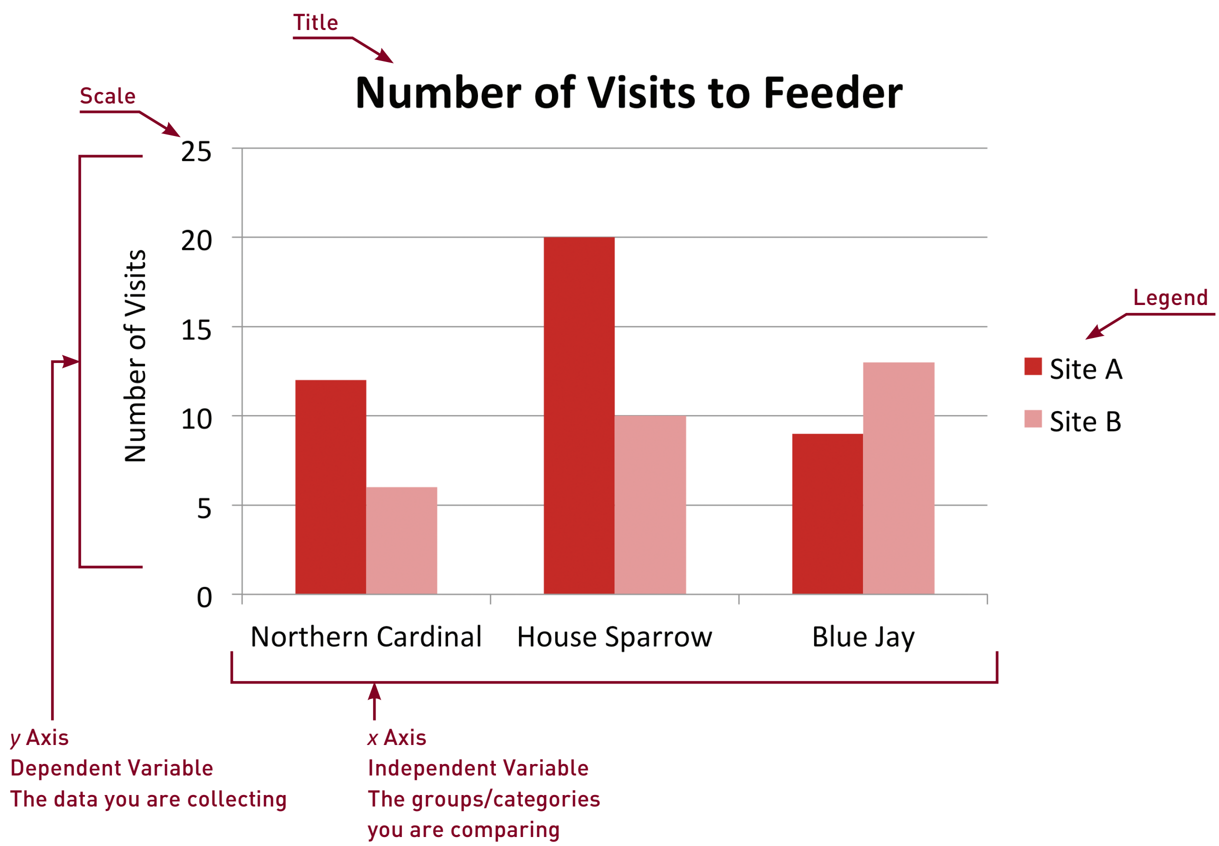
SCATTER PLOT

- Use when both variables are measured in numbers.
- Individual points indicate a relationship between variables.
- A trend line may be used to show the relationship.
- This graph shows that there tends to be more insect species in taller grass.



REMEMBER TO LABEL THE FOLLOWING PARTS OF YOUR GRAPHS:

- Title
- *x* axis
- *y* axis
- Legend (if needed – in the example below, you need a legend to compare the two sites, but if you were only collecting data at one site, you wouldn't need a legend)
- Scale of axis



RESULTS

Describe the results of what happened. Don't explain them here; just calculate.

GRAPH

Design a graph (or multiple graphs) that illustrate your results. The *x* axis, horizontal line, is usually the independent variable, and the *y* axis, vertical line, is usually the dependent variable.

LESSON 8

DATA ANALYSIS: USING THE IDENTIFY AND INTERPRET STRATEGY (I^2)

OBJECTIVE

Students will examine data presented in a graph and break it down into understandable parts.

NEXT GENERATION SCIENCE STANDARDS

Science Practice 4: Analyzing and interpreting data

Science Practice 6: Constructing explanation

MATERIALS

Sample graph of citizen science data

OUTDOOR/INDOOR & TIME OF YEAR SUGGESTIONS

Indoor, any time of year

TIME REQUIRED

45 minutes

BACKGROUND

Students often become overwhelmed when they try to interpret graphs, figures, or data tables that have been created by other people, much less create their own graphs. The Identify and Interpret (I^2) strategy is a way to help them make sense of the information by breaking it down into smaller parts.

In the I^2 strategy, students first identify changes, trends, or differences that they observe in a graph. They draw an arrow to each observation and then write a "What I see" (WIS) comment. These comments should simply be what the student observes, such as a positive slope on a graph, increasing numbers in a data table, or a difference between two bar heights on a bar graph. After students have made their observations and written their WIS comments, they should interpret the meaning of their observations by writing a "What it means" (WIM) comment for each WIS comment. Once students have mastered WIS and WIM comments, ask them to create a caption for the graph, figure, or table. A caption summarizes all of the information and helps illustrate students' understanding.

PROCEDURE

To use the I^2 strategy, distribute a handout of the graph, figure, or table that students will interpret. They should draw the arrows and write their comments on and around the image. This helps them make the connections between the graphical information and their ideas. They should write the caption on the same page to help remind them of the interpretation.

1. Model this strategy for students. They will learn by watching you do a "think-aloud" as you complete the strategy on a graph, figure, or table. At first, you may want to ask students to complete the WIS and WIM comments without writing a caption. They will likely need help understanding what they should be looking for on the graph. Some students do not add enough arrows and WIS comments to interpret all the information. Other students add too many arrows and comments. These students soon find that they cannot interpret the meaning of some of their WIS comments. For

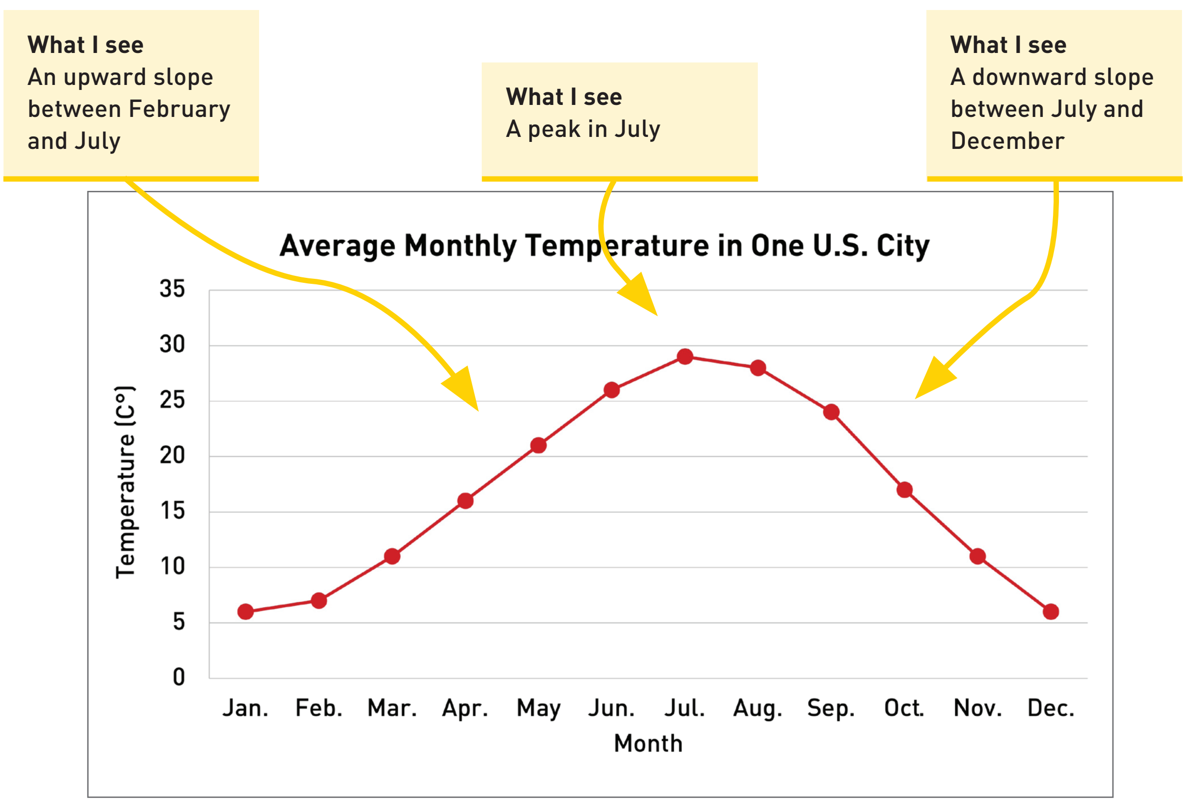
example, if they identify that a graph is printed in black ink, they will discover that they cannot assign meaning to this WIS comment. This stage helps students begin to filter their observations and identify those that are significant.

Once students have become proficient at writing WIS and WIM comments, ask them to add a caption. The caption is a coherent paragraph that interprets all parts of a graph, figure, or table. Later, when students have had practice with this strategy, the ultimate goal should be for them to write a caption without listing their WIS and WIM comments. Eventually, these comments become a habit of mind, and students should be able to notice all the pieces of a graph or figure to come up with a complete interpretation. Developing these habits of mind to identify and interpret data in many forms will benefit students in all subjects, in their jobs as they get older, and in becoming scientifically literate citizens.

For example, your think-aloud process might look like this:

STEP 1: IDENTIFY ("WHAT I SEE" COMMENTS)

- Identify any changes, trends, or differences you see in the graph or figure.
- Draw arrows and write a "What I see" comment for each arrow.
- Be concise in your comments. These should be just what you can observe.
- Do not try to explain the meaning at this point.



For this example, there are arrows drawn that point to the two trends and the change. Notice that the arrows point to the general upward and downward trends, not to each data point. A "What I see" comment describes what each arrow points to on the graph.

STEP 2: INTERPRET ("WHAT IT MEANS" COMMENTS)

- Interpret the meaning of each "What I see" comment by writing a "What it means" comment.
- Do not try to interpret the whole graph or figure.

What I see
An upward slope between February and July

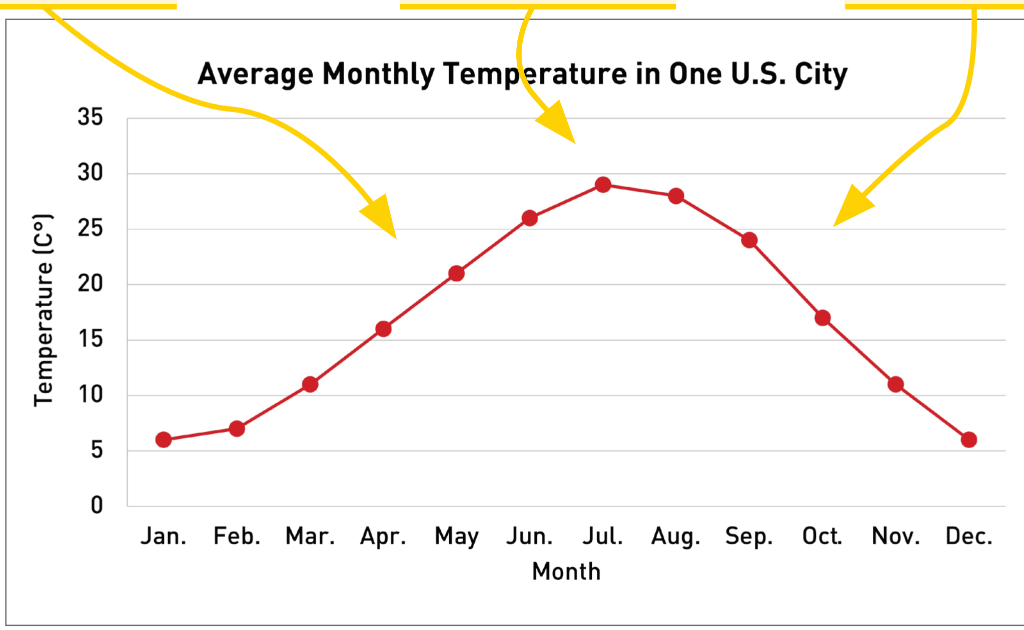
What it means
The average temperature in the city increases between February and July.

What I see
A peak in July

What it means
The hottest average temperatures in the city happen in July.

What I see
A downward slope between July and December

What it means
The average temperature in the city decreases between July and December.



In this example, "What it means" comments were added to each "What I see" comment. The "What it means" comments explain the changes, trends, and differences that were identified in step 1.

STEP 3: CAPTION

- Write a caption for the graph or figure.
- Start with a topic sentence that describes what the graph or figure shows.
- Then join each "What I see" comment with its "What it means" comment to make a sentence.
- Build a coherent paragraph out of your sentences.

What I see
An upward slope between February and July

What it means
The average temperature in the city increases between February and July.

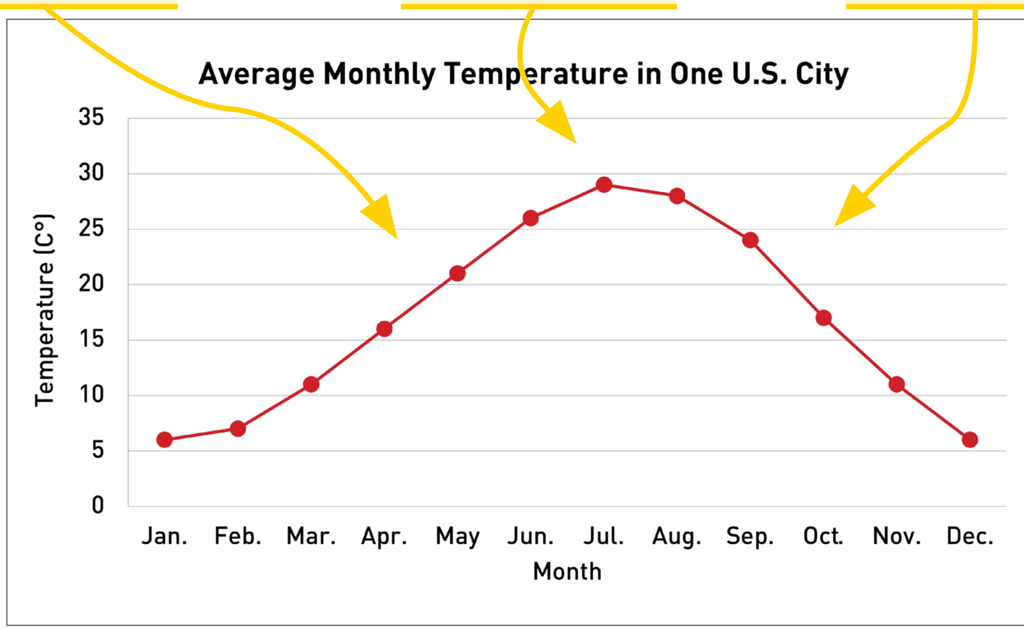
What I see
A peak in July

What it means
The hottest average temperatures in the city happen in July.

The city must be in the northern hemisphere.

What I see
A downward slope between July and December

What it means
The average temperature in the city decreases between July and December.



This graph shows the average temperature in a city over a year. There is an upward slope from February to July showing that there is an increase in the average temperature during these months. There is a downward slope from July to December which means the average temperature decreases during this time. There is a peak in July which shows that the hottest average temperature in the city happens in July. The peak in July also means that the city must be in the Northern Hemisphere.

In this example, the first sentence of the caption describes what the graph shows. Then each "What I see" comment was combined with its "What it means" comment to form complete sentences. Those sentences make up a paragraph that describes each part of the graph.

2. After the think-aloud demonstration, present a graph of citizen science data. Instruct students to complete the I^2 process with these data, either alone or in small groups. These steps could be projected on the board:

Steps to Identify and Interpret Data

STEP 1: IDENTIFY

- Identify any changes, trends, or differences you see in the graph or figure.
- Draw arrows and write a "What I see" comment for each arrow.
- Be concise in your comments. These should be just what you can observe.
- Do not try to explain the meaning at this point.

STEP 2: INTERPRET

- Interpret the meaning of each "What I see" comment by writing a "What it means" comment.
- Do not try to interpret the whole graph or figure.

STEP 3: CAPTION

- Write a caption for the graph or figure.
- Start with a topic sentence that describes what the graph or figure shows.
- Then join each "What I see" comment with its "What it means" comment to make a sentence.
- Build a coherent paragraph out of your sentences.

3. When students have finished analyzing and interpreting the citizen science data, show them how to transfer these ideas to the "Build a Scientific Explanation" tables. See page 1-13 to review suggestions for using these tables throughout this unit.

- Evidence box: Summarize the "What I see" comments.
- Claim box: Summarize the "What it means" comments.
- Reasoning box: The summary paragraph goes here, along with any additional scientific principles that apply.

Assessment Recommendation

Students can turn in their labeled graphs as the assessment for this lesson. A group discussion of the process could include reflection questions such as

- What makes data easier/harder to interpret?
- Why go to the bother of dissecting data in depth?
- What is the difference between analyzing and interpreting data?
- Explain the relationship between analyzing data and constructing scientific explanations.

 NAME

Build a Scientific Explanation

EVIDENCE scientific data that can support a claim (What do you see on a graph, or during a scientific investigation?)	**CLAIM** a statement that answers a question (What claim can you make based on what you see? What does it mean?)	**REASONING** a justification for why the evidence supports the claim using scientific principles

LESSON 9

CONCLUDE & REPORT

THE PROCESS OF SCIENCE: CONCLUDE AND REPORT

NEXT GENERATION SCIENCE STANDARDS

Science Practice 4: Analyzing and interpreting data

Science Practice 6: Constructing explanations and designing solutions

Science Practice 8: Obtaining, evaluating, and communicating information

MATERIALS

"RERUN" Student Page

TIME

20-60 minutes

CONCLUDE: WRITING CONCLUSIONS WITH THE RERUN METHOD

BACKGROUND

When you have finished your research, it is time to draw conclusions about your findings. Conclusions place the results into a larger context and explain why they are interesting or significant. They are also a place to discuss any problems with or caveats to the experiment. Using the RERUN method described here, students will learn how to write clear and concise conclusions for an experiment or data analysis. You may choose to do this after or before writing the more detailed research report (lesson 10). It may be used either as an abstract to the report (at the beginning) or a conclusion (at the end).

PROCEDURE

1. Present the RERUN method for writing conclusions. RERUN is a short paragraph used to summarize the results from a scientific study. The RERUN paragraph should be a minimum of five, well-written, complete sentences. RERUN is an acronym for five types of information a conclusion should include.

RERUN	
R = RECALL	Briefly describe what you did.
E = EXPLAIN	Explain the purpose of the study.
R = RESULTS	State the results, including which hypothesis was supported by the study.
U = UNCERTAINTY	Describe uncertainties that exist, if any.
N = NEW	Write two new things you learned

2. You may have inconclusive results. This is not a problem. An investigation in which the null hypothesis is supported may be just as interesting. For example, participants may hypothesize that insects prefer a particular species of plant over another or

that flowers are larger on the sunny side of the building. They may find no difference in size or no plant preference. If the study supported the null hypothesis instead of another hypothesis, this does not mean that the investigation didn't work.

Example of a RERUN Paragraph for a Study of Pollinator Plant Preferences

We studied whether more pollinators came to native (asters and coneflowers) or non-native plants (hostas and day lilies) in our garden. We observed groups of ten flowers in each species at time and counted the number of pollinators (bees, butterflies, and flies) that came to the ten flower in ten minutes (RECALL). We were trying to determine if there really is an advantage to planting native flowers if your goal is to help pollinators (EXPLAIN). On average, native plants had 0.4 visitors per ten minutes, and non-native plants had 0.1 visits per ten minutes. Our hypothesis that pollinators prefer native plants was supported by this study (RESULTS). However, when we looked at the individual species, many more pollinators came to the asters than the coneflowers, and coneflowers didn't have more visitors than the non-native species. So, we can't conclude that all native plants attract more pollinators (UNCERTAINTIES). Two things we learned are that flowers that are starting to get dried up don't get as many pollinators visiting them and that there are a lot of pollinator species in our garden (NEW).

Note: If students are confident about the results of their study, they don't have to include uncertainties.

Bee pollinating a flower.

Assessment Recommendation

Student-generated paragraphs may serve as the assessment for this lesson. A rubric may be based on completeness, clarity, logic, readability, or other features that you would like to emphasize.

NAME

Step 6: Conclude

Once you have the results of your research, it's time to tell others about it. First, you should write a conclusion summarizing your project and explaining what you found out. Then, use the guidelines on the following pages to prepare a poster/display, oral report, or written report.

RERUN

RERUN is a way to help you remember what to include in a summary of the results from a scientific investigation. The letters in RERUN are an acronym for five types of information a conclusion should include. Write at least one complete sentence for each letter. It's okay to include more information if you think it is necessary.

R = Recall	Briefly describe what you did.
E = Explain	Explain the purpose of the study.
R = Results	State the results, including which hypothesis was supported by the study.
U = Uncertainty	Describe uncertainties that exist, if any.
N = New	Write two new things you learned.

R:

E:

R:

U:

N:

Remember: If the experiment supported your null hypothesis instead of another hypothesis, this does not mean the experiment "didn't work."

LESSON 10

CONCLUDE & REPORT

THE PROCESS OF SCIENCE: CONCLUDE AND REPORT

NEXT GENERATION SCIENCE STANDARDS

Science Practice 8: Obtaining, evaluating, and communicating information

MATERIALS

Report materials on Student Pages

TIME

20-90 minutes or more

REPORT: PRESENTING RESULTS OF INVESTIGATIONS

BACKGROUND

Once your students have designed an experiment, carried it out, analyzed the data, and come to conclusions about what their results mean, they should present their results. Scientists communicate the results of their research in three main ways: written reports, poster presentations, and oral presentations.

The information included in all of these presentation types is similar, although posters and oral presentations usually don't go into as much detail as written reports. Every presentation should include clear sections that

- introduce the topic,
- explain the methods,
- present the results, including visual representations such as graphs or pictures, and
- interpret the results (the RERUN conclusion).

Written presentations

Scientists need to be good writers to communicate their findings. Sometimes a scientist will write a report for their boss, a funder, or the public about what they found out through their research. This report may come in the form of a quick e-mail message, or a 50-page report — and anywhere in between. Some scientists write up their findings for a magazine or professional journal.

Poster presentations

Science fair-type events provide venues for displaying posters. A poster describing research done by a Driven to Discover class or school may be displayed in the lobby of a nature center, school hallway, community center, or even a place of business.

Each poster typically presents one complete investigation on a three-sided cardboard display, though large format printers make huge printouts feasible. It's a good idea to make a mock-up of the poster on notebook paper before working on the final product. See Student Pages for more information about poster presentations.

Oral presentations

Oral presentations require clear verbal communication as well as visual aids. You might want to celebrate your research experience with an oral presentation to your local Audubon Society, park board, community group, or parents, depending on who you think might be interested in your results. You should set a time limit of 5–15 minutes for each presentation and help your students decide on the most important aspects of their investigations to cover in the talks. They should include visuals that describe their results (graphs, pictures, etc.) which might be overheads, drawings on a whiteboard, handouts, PowerPoint slides, or large drawings held up in front of the group. Encourage students to practice their oral presentations with each other or at home. See Student Pages for more information about oral presentations.

PROCEDURE

Decide which kind of presentation students will make. The students should feel proud of their work, so provide multiple opportunities for them to present their work if possible. Presentation preparation may be done in class or as homework, and likely a combination of both. Adults may be able to help type the text for the displays and possibly even provide scrapbooking resources or other supplies to help make the displays attractive.

Assessment Recommendation

Student-generated reports, posters, and presentations can serve as the assessment for this component of the investigation. A rubric may be based on clear communication, thoroughness, understandability, or other features that you would like to emphasize.

Step 6: Report

MAKING A DISPLAY OR POSTER ON A RESEARCH PROJECT

Your display will represent all of the work you have done on your research project. It will consist of a backboard and other things that represent your project, such as photographs, or examples of the items you studied. It should tell about your project in a way that attracts viewers and gets them to stay and look at it closely. It should be as simple as possible while still being thorough enough to accurately present your work.

1. Before starting your display, make notes about your project: what was your question; what were your dependent and independent variables; what hypotheses did you have; why did you choose the hypotheses; how did you test your hypotheses (the methods); and what did you conclude? Decide what graphs or tables you will make to present your results.

2. Decide what kind of backboard you will use, or use PowerPoint to make a large poster. You may also use a three-sided display, sturdy cardboard, or wooden panels cut and hinged together.

3. Plan your layout. See the example on the next page.

4. Use neat, bold lettering for all of the headings, and make all of the letters the same color. You may use stencils, words printed on a computer, or neat printing. It is best to make the title stand out by using letters larger than the other headings. The title should be short and catchy.

5. It is important to be concise (short and to-the-point). Use large type or printing. People should be able to read it from a few feet away. Be sure you don't have any spelling or grammatical errors.

6. Computer-generated graphs and photographs are excellent ways to represent your methods and results. Color illustrations, graphs, charts, and photos are more eye-catching than black and white.

7. Lay everything out before gluing anything to your backboard. Make sure things are evenly distributed all over the board. Don't leave large empty spaces.

8. When you are sure the poster is just how you want it, glue everything to the backboard using rubber cement. This will allow you to change components around if necessary.

SAMPLE DISPLAY OR POSTER LAYOUT

Title ❹
If you can't think of anything catchy, it's okay to use your question as your title. Be sure to include your name under the title.

Question ❶
State your research question in large type. You want viewers to find this easily.

Background ❷
Optional. Explain what led you to your question, or what you learned about your topic in preparation for your research.

Methods ❺
Explain what you did. Mention the steps you took to keep your data fair and accurate.

Data ❻
Give each bar chart, graph, and table a title and be sure to label your axes. After the title, sometimes this is all a viewer will read, so make sure it is easy to understand.

Results ❾
Describe what happened.

Conclusion ❿
Use your RERUN paragraph here.

Hypotheses ❸
List the possible outcomes of your research. Specify which hypothesis you thought was the most likely and your reasons why.

Graphics ❼
Photos, clip art, or illustrations of your subject are always helpful. Photos of you doing your research are great to include.

Props ❽
You may want to show some tools you used or a specimen you studied. When you prepare to display your poster, check to see if there are any restrictions on what you are allowed to bring.

References ⓫
List any sources you used, including websites, books, etc. You may also thank experts you learned from or others who provided special help with your project.

PREPARING AND GIVING AN ORAL PRESENTATION

If you give an oral presentation, you must be well-organized to cover your research in a limited amount of time. You will need to explain everything, from your question to your conclusion in a few minutes. If possible, it is good to use charts, graphs, models, experimental subjects, or slides.

During the presentation, stand up straight and look at your audience. Speak loudly and clearly, smile, and be polite. At the end of your talk, thank the audience, and ask them if they have any questions. If you don't know the answer to a question, don't make one up. Say that you don't know the answer.

You may use the following script as a guide.

My name is ____

The title of my project is ____

I was interested in doing this project because ____

____

____

The question I asked was ____

____

The hypotheses I formed were ____

____

The procedure I used to test my hypotheses was to ____

____

My results were ____

____

These results supported (which) hypothesis because ____

____

The conclusion I reached was ____

____

If I were to do this investigation again, I would ____

____

A WRITTEN RESEARCH REPORT

Write up your research in report form. Include the following sections in your report, and check it carefully for spelling and grammatical errors. Have at least one other person read it, and ask them if everything was clear. You should go through at least two drafts before making your final copy.

- **INTRODUCTION**
  This section should include the problem you investigated, why you were interested in the problem, the hypotheses you formed, and why you formed these hypotheses. If you did background research, describe what you found and where you found it.

- **MATERIALS AND METHODS**
  Describe exactly what you did to test your hypotheses. Include a description of the controls and sample sizes you used and what materials you used.

- **RESULTS**
  Tell what happened during your experiment. Include detailed, neat and clear tables and graphs to represent your results.

- **CONCLUSION**
  Use the RERUN method to summarize your investigation. You might also include what you would do next time.

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Appendix

DRAGONFLIES AND ODONATA CENTRAL

NOTES

Constructing Scientific Explanations Through Citizen Science

OBJECTIVE

Students master the process of science by doing science, and few scientific skills are as critical as the ability to reason from evidence. After all, scientific knowledge can only be advanced through the systematic process of proposing, testing, and refining scientific ideas. Proposing and defending scientific explanations allows students to understand concepts in depth, and helps them develop analytical thinking skills. An essential goal of the Driven to Discover project, therefore, is to familiarize teachers and students with the development of scientific explanations.

The Driven to Discover program follows a framework developed by McNeill and Krajcik (2011). Content from that publication is referenced here. For further reading, examples, and background information, please see their full text Lab out Loud (2015) which contains a great introduction to their work.

BACKGROUND

Scientific knowledge is built through "a process of reasoning that requires a scientist to make a justified claim about the world," (Sampson & Clark, 2008, p. 448). Scientific inquiry as an inductive process is based on transformations of data into evidence, evidence into patterns, and patterns into explanations. Students participating in scientific inquiry acquire a basic understanding of the nature of science as an iterative process of formulating theories and validating them with evidence. A central goal of science education must therefore be to help students develop their ability to develop scientific explanations. An emphasis on scientific explanations will "help shift their view of science away from a science as a static set of facts to science as a social process where knowledge is constructed" (McNeill & Krajcik, 2008, p. 54).

SCIENTIFIC EXPLANATIONS

McNeill & Krajcik (2011) describe four components of the Science Explanations Framework:

CLAIM a statement that expresses the answer or conclusion to a question or a problem. A claim concludes a scientific investigation by answering the research question.

Example: In the stalk-eyed fly (*Drosophila heteroneura*), larger males have a higher reproductive success than smaller males (see figure 1).

EVIDENCE the scientific data that support the claim. Data include observations and measurements that come from natural settings or controlled experiments and may be either quantitative or qualitative. They may be represented in multiple ways, from a figure to a detailed description. To support a claim, data need to be appropriate, sufficient, and scientifically-relevant.

Example: Figure 1 shows a positive correlation between male head size and the number of successful copulations in the stalk-eyed fly (Boake, DeAngelis, & Andreadis, 1997).

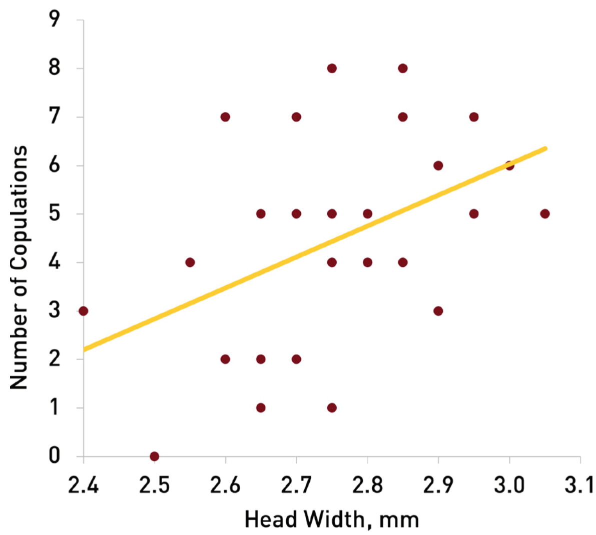


Figure 1: Male fly head size in relation to reproductive success. Recreated from Boake et al. 1997.

REASONING provides a logical connection between the evidence and the claim. Reasoning relies on patterns, theories, and scientific principles to justify why the evidence supports the claim.

Example: A larger body size is advantageous when male stalk-eyed flies fight for access to females. In species that engage in mate choice and competition, larger males tend to win more fights than smaller males (Boake, DeAngelis, & Andreadis, 1997).

Which comes first — the claim or the evidence?

When students are first asked to make a claim statement, the claim must come from somewhere, preferably not pulled out of thin air. In fact, the claim should be drawn from data, whether the data are based in empirical research or even anecdotal experience. For the purposes of the Driven to Discover project, we want to emphasize that a claim should be based in evidence, so we have tweaked the McNeill & Krajcik (2011) model to position Evidence ahead of Claim in the model to reflect this sequence of thinking.

ALIGNING SCIENTIFIC EXPLANATIONS WITH SCIENTIFIC INQUIRY AND CITIZEN SCIENCE PROJECTS

Scientific explanations arise at all points of the scientific process, from hypothesis formation to data analysis. Students can therefore practice their explanation skills at every stage of the Driven to Discover project, using the Evidence, Claims, Reasoning framework. Here are some examples:

1. Questions and Hypotheses

- Given what you've learned as you made citizen science observations, what *questions* popped in your head?
- What *evidence* might support your hypotheses?
- What *reasoning* would lead you to favor one hypothesis over the others?

Unlike questions (e.g., "Do bumblebees prefer nectar with higher sugar concentrations?"), hypotheses make clear predictive statements that can be supported or falsified by evidence (e.g., "Bumblebees will forage longer at flowers that produce nectar with higher sucrose concentrations"). Teachers should encourage their students to propose multiple testable hypotheses (possible answers to their questions). Hypotheses, like claims, make verifiable statements about a given phenomenon.

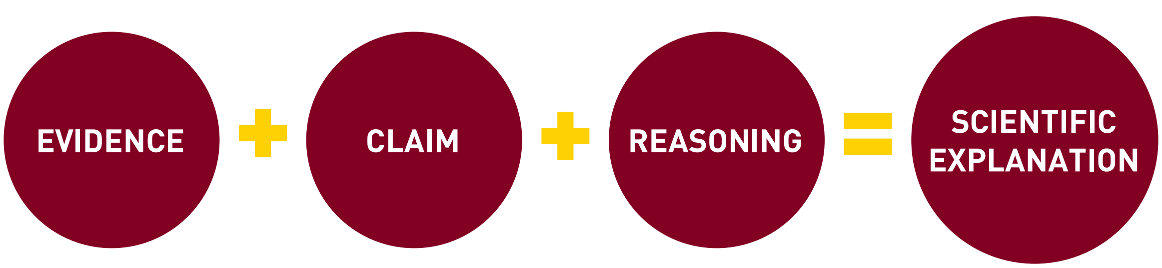


Figure 2: Revised McNeill and Krajcik model of scientific explanation.

2. Plan and test

- What is the *reasoning* behind your research design?
- What *observations* and potential limitations influenced your choice of research design?
- How did you take into account your *understanding* of sample size, the need for constant conditions, or the need for controls?

The methods chosen for any study need to be carefully planned. They should directly relate to the question and, once carried out, should be able to support one of the hypotheses. The methods section of a scientific report needs to be clearly written and logically consistent to enable other scientists to replicate the results. By asking students to engage critically with their proposed methodologies, a teacher may assess their ability to reason logically.

3. Analyze and interpret

- What *claim* may you make given your data?
- What is the *evidence* for your claim, and why does this *evidence* support your claim?
- What *reasoning* connects your *evidence* and *claim*?
- Which *hypothesis* do your data support?
- Given these *results*, how may your methodology be improved, or were you able to answer my question with the methods?

Science is fundamentally about explaining the world around us. Scientists use observations and evidence to support their scientific explanations. Students, therefore, need experience working with all types of data, from qualitative observations to statistics and figures. The Driven to Discover project allows students to generate, manipulate, and analyze their own datasets. As such, it also allows students to use their own data to construct scientific explanations.

4. Conclude and report

- Did your *results* support or falsify your *hypotheses*?
- Given your *results*, what new questions arise?
- What might be other *explanations* for your data?
- Are there *limitations* in your methods or results?
- How are your findings relevant to science knowledge or to problems that need solutions in the real world?
- Be clear with your *reasoning*.

Scientists continuously grapple with uncertainty in their research and conflicting opinions in their field. Students must become comfortable working with incomplete information. After all, science is an iterative process, and reflection and revision play integral roles within scientific inquiry. Students refine their ability to construct scientific explanations whenever they practice reconciling conflicting or incomplete evidence. Allow students the time to grapple with the limitations of their research project, to identify new questions, and to develop future research directions.

Scaffolding

If this process of constructing scientific explanations is new for your students, you may wish to provide scaffolding. Begin with simple examples of claims, evidence, and reasoning then progress to more complex variations, requiring more evidence, more sophisticated reasoning, and eventually requiring, rebuttals and alternative explanations.

Practice

Help your students build scientific explanation skills by working them through the process in a variety of ways. Use the Student Page template found in chapter 1 as daily or weekly practice by filling in one of the three boxes with an example from your citizen science topic and asking students to complete the other boxes.

RESOURCES

Lab Out Loud (2015) Using the Claim, Evidence and Reasoning Framework: http://laboutloud.com/2015/04/episode-127-claim-evidence-reasoning/.

Boake, C.R.B., DeAngelis, M.P. and Andreadis, D.K. (1997). Is sexual selection and species recognition a continuum? Mating behavior of the stalk-eyed fly Drosophila heteroneura. PNAS, 94(23):12442-12445.

McNeill, K.L. and Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. Journal of Research in Science Teaching, 45(1):53-78.

McNeill, K. L., & Krajcik, J. S. (2011). Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing. Pearson.

Sampson, V. and Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendation for future directions. Science Education, 92(3):447-472.

A scientist reporting on her research and results.

LESSON

KEEPING A SCIENCE JOURNAL

OBJECTIVE

This lesson helps students record observations related to their citizen science work, while also encouraging them to question, theorize, and share opinions.

NEXT GENERATION SCIENCE STANDARDS CONNECTION

Science Practice 1: asking questions and defining problems

MATERIALS

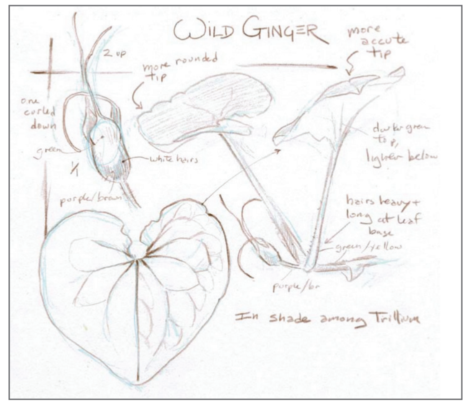
Field journaling requires no special equipment. Fancy paper and drawing pencils can make students feel that they need to create art instead of record science, but some field supplies are useful. The most important thing is a good journal. If you can afford them, bound hard cover notebooks that students can use throughout the year and that will stand up to field use lend dignity to the process of taking notes. You can also make your own journals as part of a class project.

- #2 pencils
- Hand-held pencil sharpeners
- Science Journals or paper
- Colored pencils (optional)
- Magnifying lens (optional)

TIME REQUIRED

15 minutes plus additional journaling time, flexible

BACKGROUND



Sample journal sketch and entry

While record keeping and measurement are the foundation of good science, the keen observation that comes from spending time looking at natural phenomena often leads to the best questions for scientific inquiry. This activity may be used throughout your school year to help students practice good scientific record keeping as well as encouraging them to think critically about their observations, to think like a scientist. While presented here as one activity, we encourage using a science journal as a component of activities in the curriculum as often as possible.

Many great scientists and thinkers recorded (and still record) their observations in a journal format. Some of these include Charles Darwin, Gallileo Galilei, Leonardo DaVinci, James Audubon, Aldo Leopold, and Maria Sybilla Merian. In their writings, they made scientific observations, recorded measurements, and also questioned, wondered, proposed theories (and were sometimes wrong), and offered opinions. The scientist's journal includes all of these things. A science journal is a great opportunity to help students develop as writers and observers of the natural world.

In their journals, students practice observation and description skills using words and drawings. Each student may have his or her own organism to observe, or you may have groups of students share an organism. If you include information on Maria Sybilla Merian or other naturalists who have kept journals, students will gain historical perspective on the art of journaling and the role it plays in science.

Some students tend to make brief entries unless they are provided prompts and descriptive words from which to choose. Some teachers ask students to focus on a specific area each day to help students pass these hurdles (see Observation Prompts).

PROCEDURE

1. Show students examples of scientists' logs, records, or publications. A sample from Maria Merian's journal of insect observations is provided. Ms. Merian was a 17th-century Dutch artist and naturalist.

   Show and read this description of a caterpillar by Merian:

   > "[It has] fifty shining red warts. Von Leeuwenkhoek (inventor of microscope) is of the opinion that these are eyes. To date, I have not been able to accept this opinion...; in my view, they would then be able to find their food from behind and from the sides, which I have not observed to be the case; they have no eye-sockets there."

2. Ask students to analyze Ms. Merian's passage. Possible questions to prompt discussion include the following.
   - Which phrases are fact (direct observation)?
   - Which are opinion?
   - What does she wonder about?
   - How does she use evidence to support her theory about caterpillar eyes?
3. Next, share additional journal entries from Ms. Merian (provided at the end of this lesson). Again, ask students to decide which are factual observations and which are comments, questions, or opinions. From all of the samples you provide, see if your students can formulate more questions. For example: Why do watermelons have hard skin? Why do tadpoles have tails, but frogs don't?
4. Tell students that they will keep a scientific journal—a record of the many changes in their study system over time. It will be a place to record careful observations, with both words and drawings (and even photos, if you choose), as well as reflections, questions, opinions, and feelings.
5. Provide time for journaling whenever you have an activity involving your citizen science system. Journaling time may also be used when there is only sufficient time to visit your site but not complete any other activities.
6. The provided sentence starters for journal writing might be useful to your students. You might post them for regular observation, or you might provide several each day to help focus their observations.
7. Encourage (or require) your students to include drawings in their journals. There is a section on nature drawing technique at the end of this lesson. Stress that journaling is not about making pretty pictures, and try to avoid saying, "That looks great!" when a student shows you his or her work. This kind of feedback emphasizes and gives positive reinforcement to drawing skills and not careful observation.

Positive reinforcement needs to be given in a way that advances the goal of the curriculum. You have told the students they are to observe and carefully record what they have seen. Give positive reinforcement when you find accurately observed details in their work. "I see you have shown hairs on the stem. Details like that are important to botanists when identifying and studying plants." Give positive reinforcement to scientifically useful information that students add to their observations such as date, location, time and weather information, size or scale information, color notes, multiple views of the same subject, or behavior or interactions with other species. "You have put a scale next to your drawing. That will really help you remember this plant when you review your notes."

Refrain from saying

- "That is really pretty."
- "What a good drawing."
- "You are a great artist."
- "That looks so realistic."
- "You are really good at shading."

Do describe what the students did well

- "The way you use both writing and drawing to describe this flower is really clear."
- "I see you measured the distance between the branches and added a scale."
- "Oh, you found a spider on top of the flower. Great observation!"
- "The insect damage on that leaf you have illustrated really helps me pick out which flower you are looking at."

ADDITIONAL IDEAS

Sentence Starters for Journal Writing

- I noticed...
- I think maybe...
- I am surprised that...
- I would guess...
- I suspect...
- I discovered...
- I'd like to know...
- I wonder...
- What if...
- It's amazing that...
- I'm disappointed that...
- I now realize that...

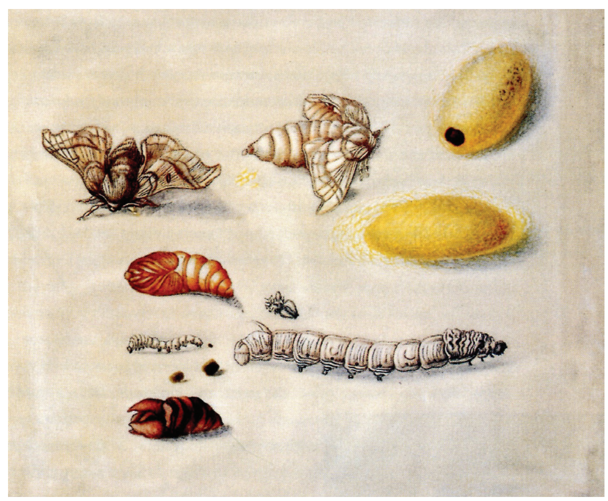
JOURNAL EXCERPTS FROM MARIA SIBYLLA MERIAN: 17TH CENTURY ARTIST AND NATURALIST

In 1660, at the age of 13, Maria Sibylla Merian made her first journal entry. In this, written eight years before most people even knew that insects hatched from eggs, Merian used words and paintings to record the stages of silkworm metamorphosis from caterpillar

> "...they are green with a yellow stripe over their whole body; on each segment there are four round orange-yellow beads covered with little hairs"

to moth

> "with a pattern on each wing like a piece of Moscow glass."



Maria Sibylla Merian's drawings of a caterpillar's metamorphosis into a moth.

Her fascination with metamorphosis, which she was the first to describe, led her to a lifelong study of the natural history of insects and other small animals. Daughter of a Swiss artist, stepdaughter of a Dutch painter, and great-granddaughter of a famous engraver, Merian wrote, drew, and painted in her journal for the next 50-plus years. She self-published portions of her journals, creating books of richly annotated engravings of insects on their host plants.

A brilliant and adventurous person (at the age of 52, she set off on a two-year journey to Surinam to collect and draw tropical animals), Merian earned an impressive reputation and a great deal of respect in a time when most women were not welcome in the professional realm. One of the first people to study insects and other animals in depth, Merian's drawings and paintings and her insights into the animals' natural history made a lasting contribution to both science and art.

Merian observed, described, and commented on her observations in detail. About a caterpillar's behavior, she wrote, "It is their way, to roll together, when they are touched, and thus to remain like a ball." A different caterpillar "as soon as touched, turns its head quickly to and fro, as if in anger, and that it did about ten times one after the other."

She also wrote that watermelons in Africa

> "...grow on the ground like cucumbers in Holland. They have a hard skin which gradually becomes less hard towards the inside of the fruit. The flesh is shiny and melts in the mouth like sugar; it is healthy and has a very pleasant taste; it is very refreshing to the sick."

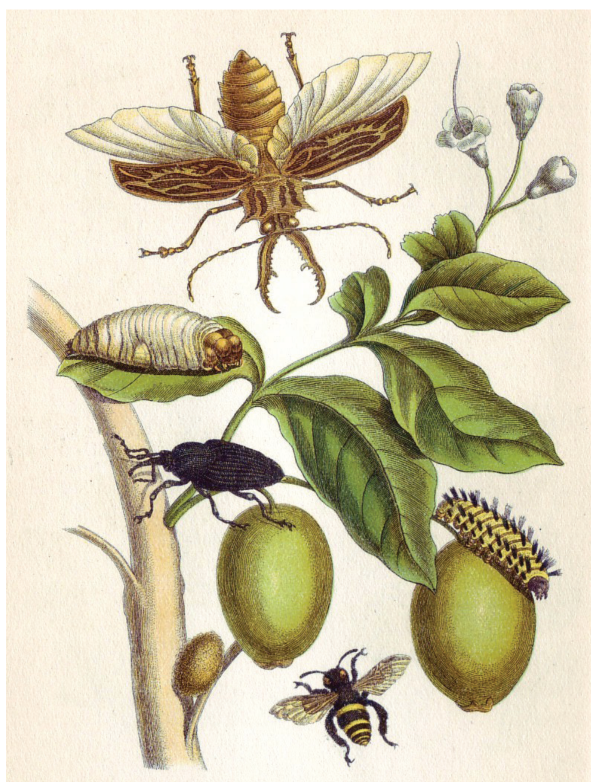
She also described how she found the animals she drew and observed. In Surinam, this process was sometimes complicated.

> "Since the tree is tall and hollow, it is not possible to climb up it and I therefore had it cut down to get hold of the caterpillars."

With careful observation over time came new understanding about the natural world. Merian learned a great deal not only about insects and their biology but also about other animals, including frogs.

> "After several days the black grains began to show signs of life and fed on the white slime that surrounded them. They even grew little tails so that they could swim in the water like fish. Halfway through May they grew eyes; eight days later two little feet emerged from the skin at the back and after a further eight days two little feet at the front, and they began to resemble small crocodiles. Thereafter the tail rotted away and they became proper frogs and jumped onto the land."

Merian's work served as a valuable source of information and inspiration for many scientists and artists, including Swedish botanist Carolus Linnaeus; German poet Goethe; and English naturalists Eleazar Albin, Mark Catesby, and Moses Harris. Royal families in Russia, England, and Denmark collected her paintings and drawings, while scientists cited her notes. Forgotten for nearly a century, Merian's role in improving scientific understanding in the 17th century has recently been rediscovered.



Maria Sibylla Merian's drawings both informed and inspired.

DRAWING TECHNIQUE

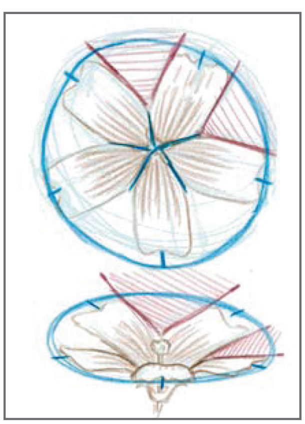
The purpose of field sketching is not to make pretty pictures, but there are techniques that you may share with your students that will help them more accurately render what they see.

Shape Before Details

When you start drawing, ignore the details and go for shape and proportions. Once you have sketched these in, turn your attention to detail. Start a drawing with fast "ghost lines," lines that are so faint that they will hardly show in the final drawing. Sketch the whole form loosely and lightly. Accent the shapes that you like as they begin to emerge. Focus on trying to capture the basic shape and proportions at the start instead of focusing on details. Check your proportions early on. If you wait until you have added details, you might not be able to make changes without erasing significant amounts of work. The quick lines also help students get over the fear of putting the first mark on blank paper. Once you have the basic form, draw over the ghost lines to add detail. For example, when drawing a leaf start by getting the basic shape and proportions (length vs. width) and then add toothed edges over the shape. Draw the leaf veins last going from the mid rib to the tip of each tooth. Use a regular graphite pencil and draw lightly.

Sketch vs. Portrait

Students typically draw a single picture then continue working to improve. Instead, encourage them to make several sketches of the same subject each next to the other on the same page. They are not obliged to finish every sketch. Rough sketches may contain important information. Their impressions may be used for reference to make a more finished drawing later if they wish, but that is not the objective. The object is to focus on seeing accurately and recording what was seen. Their field sketches will not be perfect. Nor is there a need for them to correct their sketches by comparison to a field guide. Let their field notes stand for themselves as their best impression of what they saw on the spot. Altering the notes at a later date risks replacing observation with less reliable memory.



Rough sketch of a flower

Erasing

Discourage erasures. When students erase a picture, cross it out, or tear it from their notebook, they are destroying information that they have collected. If part of the sketch is inaccurate, they may instead add written notes or draw another detail of that part.

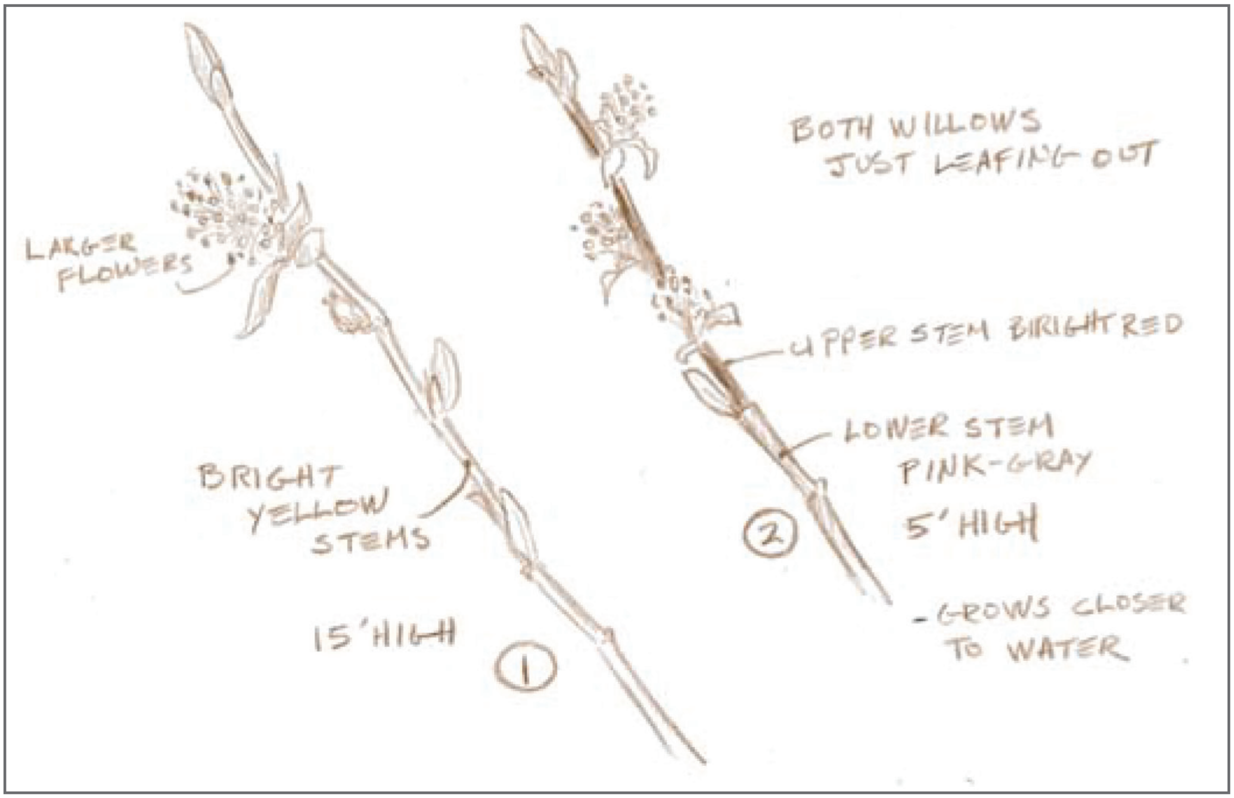
Moving Subjects

When drawing a moving animal, work on one drawing until the animal moves to a different position, then start another drawing on the same page. If it moves again, start another drawing. If it returns to a position you have already started to draw, go back to that drawing. The drawing on which you get the furthest along will probably capture the animal's most characteristic posture.

Size

Many students will draw very small pictures. It is difficult to see or add detail to these cramped drawings. Encourage them to work larger, perhaps making enlargements of the objects that they are drawing. You may have to specify, "I want the flower or bird drawn at least as large as your fist." In contrast, some students will undertake too large a landscape drawing. Halfway through the project they tire of drawing trees. They will find smaller thumbnail landscapes perhaps 1" x 2" or 2" x 3" to be much more manageable.

This section is from the California Native Plant Society's *Opening The World Through Nature Journaling* by John Muir Laws, used with permission.



Draw a subject from various angles and add written notes if necessary.

success. The more that students draw, the more they will see. However, students who are more comfortable drawing should include writing in their notes as well, while students who prefer writing should include sketches and diagrams with their writing. Combining writing and drawing gives the pages less of the feel of an art project and more of a place where information is collected. Spelling should not count either. Worry about spelling or punctuation in field notes only impedes the flow of data recording about art.

Set an Example

Keep your own field journal and sketch while the students do. You may help them see sketching as a part of what a scientist does instead of just an assignment. Many adults are afraid to draw. If your journals are free of pretty pictures, your work reinforces what you have told the students, that the project is not about art. Nonetheless, as you continue to keep a field journal, you will discover that your drawing will rapidly improve and that the more you sketch, the faster that improvement will occur. Drawing is a skill developed by practice. Journaling is that practice.

Connecting with Art Lessons

If you are interested in developing art lessons to supplement science journaling, get a copy of *Nature Drawing: a Tool for Learning* by Clare Walker Leslie. The book contains a series of lessons and drawing projects that you may do alone or with your class. The basic drawing exercises at the start make an excellent beginning for any art class and the separate chapters on drawing birds, flowers, trees and more are very helpful.

Assessment Recommendation

A teacher may qualitatively assess work in field journals. If students are given clear expectations for a journaling project, you may make an assessment rubric to tally the number of required elements that students included in their work. Of course, some of the most exciting elements of journaling can only be evaluated qualitatively. Use the example rubric, at the end of this lesson, as a starting point and adapt it for your needs. Students may submit their entire journals or use their journaling time as a way of completing formative assessments throughout this curriculum.

Name: Date:

Check the required items for this journaling project. Add up the total points possible and put this number at the bottom of the page. Then have a classmate score your sketch and you score their sketch. Circle the point or points by the required items your classmate included. Add up the total points received and put the number on the line at the bottom.

Baseline Data

____Date (1 point)
____Place (1 point)
____Weather/temperature (1 point)
____Time (1 point)

Sketch and Description

____Likeness of object (1 point)
____Notes and descriptions (1 point)
____Detail of interesting part (1 point)
____Label parts (1 point or more ____)
____Color or notes about color (1 point)

____Identify object sketched (1 point)
____Habitat sketch (1 point)

Measurements

____Indicate size of object sketched (1 point)
____Indicate parts that are life-sized (1 point)
____If magnified, indicate magnification (1 point)

Other Things to Include

____Connections (1 point)
____Questions (1 point)
____Other-specify (1 point or more ____)

Total points received:
Total points possible:

Example Journal Rubric

RESOURCES

This lesson is adapted from the California Native Plant Society's *Opening The World Through Nature Journaling* by John Muir Laws and from the Monarchs and More Curriculum from the University of Minnesota.

Drawings by John Muir Laws from the California Native Plant Society's *Opening The World Through Nature Journaling* guide. Insect plates by Maria Sibylla Merian.

Tips For Taking Students Outside

On the days you are planning to take students outdoors, you may want to have an extra adult or two with you. This person could be a school aide, other staff, or a parent volunteer. More important than having extra adults is setting firm boundaries and expectations for student behavior. It is important that students understand that going outside is exciting, but is NOT recess time. And, as always, make sure safety is the number one priority. Be aware of student allergies or other limitations. Make sure to have the appropriate first-aid and other necessities with you and during your time outside, and follow any rules that your school has for notifying the office or other authorities.

BEFORE YOU HEAD OUTDOORS

1. Explain to students the structure of the outdoor activities. Give the students clear directions of what they will be accomplishing outside. The lesson you conduct outside should directly tie in with what is being studied in the classroom.

2. Make sure students are properly dressed for the weather. Staying warm enough while standing/sitting/observing is different from staying warm while physically active. Discuss what you mean by properly dressed. Students who are cold or concerned about getting their brand new jeans dirty will have difficulty focusing.

A U.S. Fish and Wildlife Service educator leading students outside.

3. Gather necessary materials, such as clipboards, data sheets, trash bags to sit on, extra pencils, nature journals, study tools.

WHILE YOU'RE OUTDOORS

1. Create small group Discovery Teams for doing outdoor work. These groups could remain the same for the year and should include rotating roles for each student. The continuity of small groups is important for getting outside and starting activities quickly. Giving each student a specific job will help keep them focused when they are outside.

   Sample Roles:

   - ACTIVITY EXPLAINER
     Responsible for explaining directions and keeping group on track
   - DATA RECORDER
     Record data in a notebook
   - TOOL TRADER
     Responsible for any equipment or instruments needed by the group
   - REPORTER
     Shares the group's data with the class

2. Form circles when explaining activities outside or when students report their data. A large circle allows everyone to see and hear each other. Make sure you are the one facing into the sun so the students are not distracted by squinting into the sunlight.

3. Use ambulators when walking from place to place. Ambulators are activities that students may do while they are on the move. For example, have students keep track of the number of different bird calls they hear as they walk or the number of insects they observe.

4. Have a signal for getting students' attention. It is difficult enough to talk over the students when you are indoors and even more difficult outdoors. Use a whistle when gathering the group. Raising a hand or hooting like an owl when you want the group's attention will be more effective and also spare your voice.

5. Set clear and identifiable boundaries for exploratory activities such as scavenger hunts.

6. Tap into the magic and mystery that most people, especially kids, feel around nature. Treat going outside as a valuable part of learning but also as the adventure that it truly is. The attitude will create an atmosphere of anticipation and excitement to encourage students to heighten their observations and questioning while outdoors.

7. Think in advance how you will engage and accommodate students with physical disabilities.

Keep in mind that learning outdoors may be a new experience for students, so the first time or two you take them out, they will be energized by the novelty of the experience. But over time students will become more comfortable and settle in to focusing on the subject of study.

RESOURCES

Grant, T. & Littlejohn, G. Eds. (2014). Teaching in the Outdoors: a Green Teacher eBook. Niagara Falls, NY: Green Teacher. ISBN: 978-1-46894-755-7.

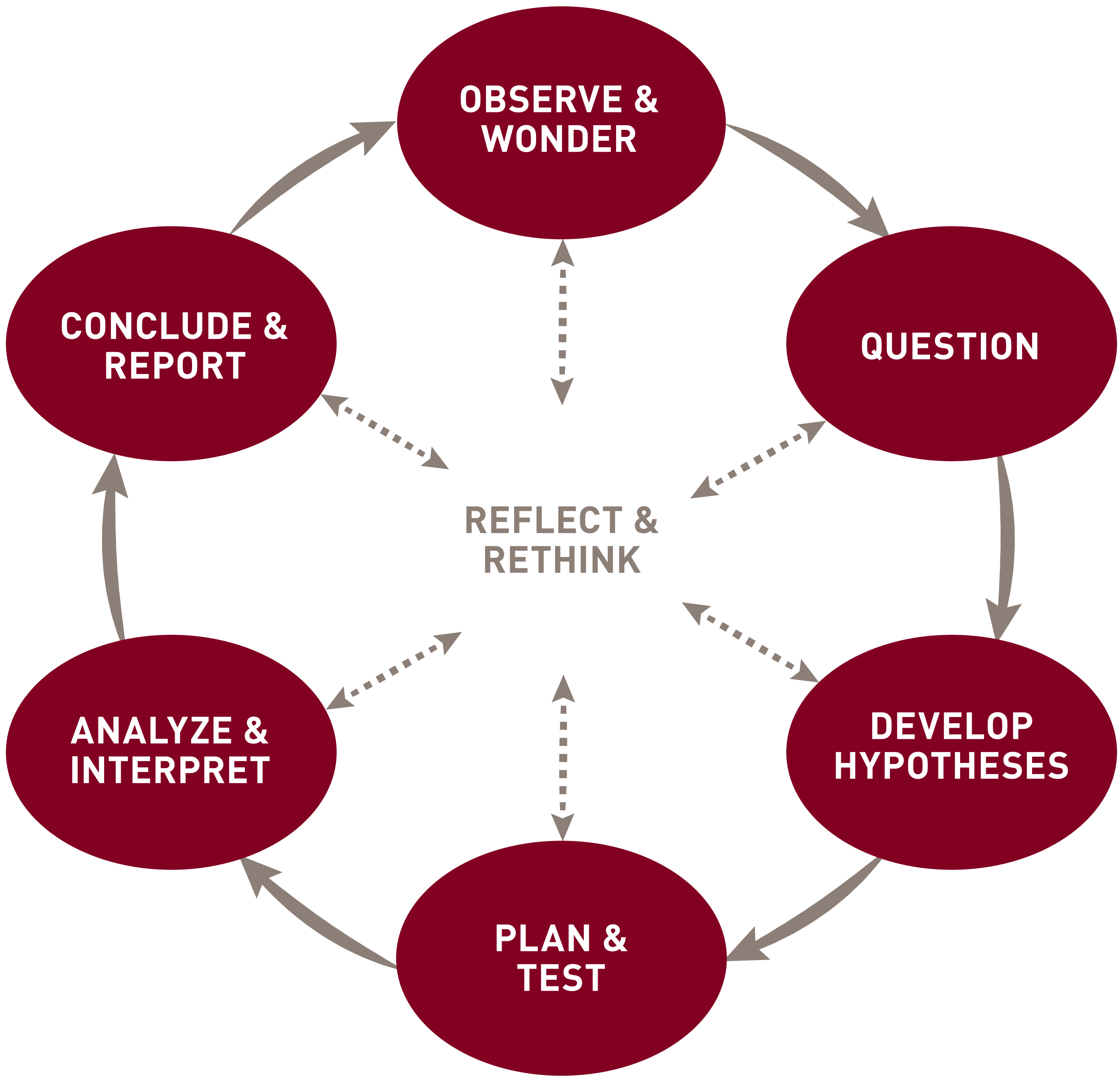
Hammerman, D., Hammerman, W. & Hammerman, E. (2000). Teaching in the Outdoors: 5th Edition. Upper Saddle River, NJ: Prentice Hall. ISBN: 978-0813431802.

The Ecology School. (2006). The ABC's of Ecology: An Educator's Guide to Learning Outside. Saco, ME: Ecology Education Inc. ISBN: 978-0977842100.

TABLE OF NEXT GENERATION SCIENCE STANDARD CONNECTIONS

CHAPTER	LESSONS	Science Practice 1: Asking Questions and Defining Problems	Science Practice 2: Developing and Using Models	Science Practice 3: Planning and Carrying out Investigations	Science Practice 4: Analyze and Interpret Data	Science Practice 5: Using Mathematics and Computational Thinking	Science Practice 6: Constructing Explanations	Science Practice 7: Engaging Arguments from Evidence	Science Practice 8: Obtaining, Evaluating, and Communicating Information	Disciplinary Core Ideas: MS-LS2 Ecosystems-Interactions, Energy, and Dynamics OR from MS-LS1 From Molecules to Organisms: Structures and Processes	Cross-Cutting Concepts
Introduction	Lesson 1: Constructing Scientific Explanations through Citizen Science						X				
	Lesson 2: "I Wonder" Board	X									
Building Science Skills	Lesson 1:Catch and Sketch	X								MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Structure and Function
	Lesson 2: Migratory Dragonfly Identification	X						X		MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Patterns, Structure and Function
	Lesson 3: Migration as a Response to Winter	X								MS-LS1 From Molecules to Organisms: Structure and Processes MS-LS1.B: Growth and Development of Organisims	Patterns
	Lesson 4: Science Behind the Scenes								X	MS-LS2.A: Interdependent Relationships in Ecosystems MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Patterns, Stability and Change
Contributing to Citizen Science	Lesson 1: Collecting and Reporting Data with Odonata Central	X		X						MS-LS2.A: Interdependent Relationships in Ecosystems MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Structure and Function
	Lesson 2: Interpreting Odonata Central Data				X					MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Patterns, Stability and Change
Conducting Independent Investigations	Lesson 1: Mini Investigations			X							
	Lesson 2: Scientist Roundtable	X		X				X	X		
	Lesson 3: The Process of Science: Observe and Wonder	X									
	Lesson 4: The Process of Science: Question	X									
	Lesson 5: The Process of Science: Develop Hypotheses	X									
	Lesson 6: The Process of Science: Plan and Test			X							
	Lesson 7: The Process of Science: Analyze and Interpret				X	X	X				
	Lesson 8: Data Analysis with Identify and Interpret				X		X				
	Lesson 9: The Process of Science: Conclude and Report				X		X		X		
	Lesson 10: The Process of Science: Conclude and Report								X		

THE PROCESS OF SCIENCE



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