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Encouraging Students To “Think Like a Scientist” Through Picture Books Designed to Support Research-Based Science Education

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by

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Director of Thesis: ______________________________
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Second Reader: ______________________________
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For Logan and Trent, my eager explorers, for re-awakening my sense of wonder and shining a spotlight on dormant dreams, now perfectly timed to come true

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AUTHOR'S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

- Patterns
- Cause and effect
- Stability and change
- Structure and function
- Energy and matter
- Systems and system models
- Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It's helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world's richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists' fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: EARTHQUAKES, SHARKS, AND TORNADOES
SOLVING SCIENCE MYSTERIES WITH ENERGY

By Emily Mae Starr

Tag, you're it! You dash after your friend. Feet pound. Heart pumps. *Whew!* Running takes energy!

Energy is the fuel that allows things to happen. From plants growing to wind blowing to water flowing, energy is everywhere.

So is matter. Matter is anything that takes up space and has weight. Look around you. Everything is made of matter.

Energy moves from place to place through the vacuum of space and through matter on Earth causing light, heat, sound, and motion - like running!

Each of the scientists in this book studied how energy flows when things happen. Come look at the world through their eyes. See how you can use big ideas about energy to solve science mysteries about earthquakes, sharks, and tornadoes.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

EARTHQUAKES

Whirrr! Clunk! Crunch! Your quiet walk is interrupted by a massive excavator digging deep. You plug your ears and edge closer, peering through the fence into the vast, dark hole. *How far could the excavator keep digging? What would it uncover?*

THINK LIKE A SCIENTIST: How could you figure out what is deep inside the earth where you can't see?

[Sidebar: Energy Big Idea: Energy can move from place to place through waves.]

The Mystery of the Weird Waves

Hunched over a table in the middle of her backyard garden, Inge Lehmann scribbled on small cardboard squares torn from old oatmeal boxes. Earthquake calculations filled the neat stacks of thick paper.

Inge was a seismologist. In the 1920s, she was part of a team that set up recording stations to gather information about earthquakes. She studied how ground-rattling waves spread out from an earthquake's origin, carrying energy through the center of Earth, and setting off seismographs on the other side of the globe.
[Sidebar: A seismologist is a scientist who studies earthquakes. A seismograph is a device that measures movements in the ground.]

Intently focused in her leafy oasis, Inge worked to unravel a mystery. Waves from a big earthquake were not recording on seismographs where scientists expected. Energy follows the laws of physics, like rules that describe how energy typically behaves. So when the earthquake waves appeared to be breaking physics laws, Inge suspected they were not. As the waves traveled through Earth, something was happening to them.

THINK LIKE A SCIENTIST: What do you notice in these models of Inge's seismograph data?

[Illustration Note: A model of Earth as it was before Inge's discovery is shown. It depicts P and S waves moving through the ground from one side of Earth to the other. The diagram is labeled with the origin of the waves (the earthquake location), where the wave should have registered, and where the wave actually registered. The diagram also shows Earth with a liquid core. The examples here, need to be greatly simplified: https://www.lindahall.org/about/news/scientist-of-the-day/inge-lehmann]

Rip! Scritch-scratch. Rip! Scritch-scratch. Cardboard calculations piled high as Inge poured over her model of Earth. A solid crust rested on top of liquid and semi-liquid rock. She traced an S wave with her finger. It moved through Earth's crust and stopped, unable to cross the hot, molten liquid beneath.

Next, she carefully tracked a P wave. The wave traveled through the rocky crust, reached the liquid magma, and bent right where it should. Then, suddenly, it bent again. Near Earth's center, the P wave changed course, recording on seismographs in unexpected places. Impossible! P waves traveling through a liquid couldn't quickly change direction.

[Sidebar: Earthquakes cause two types of energy waves: P and S. P waves travel through solids and liquids. S waves only travel through solids.]

THINK LIKE A SCIENTIST: What do you think might be causing the P waves to behave differently than expected?

Puzzled, Inge changed her model of Earth, inserting a solid core surrounded by liquid. More cardboard squares. More careful calculations. An amazing discovery! In this new model, the P waves changed course at the core, landing in the exact spots where their seismic activity was recorded. Inge Lehmann discovered Earth's solid core.

THINK LIKE A SCIENTIST: Why do you think it is important to understand how P and S waves (energy) move through the earth (matter)?

Your first energy breakthrough! You followed earthquake energy waves to discover Earth's solid core.

[Sidebar: Energy Spotlight: Scientists can learn about the structure of things we can't directly see by studying how energy waves behave.]

No time to rest. From the depths of the earth to the bottom of the ocean, your next discovery awaits!

SHARKS AND STINGRAYS

Shafts of sunlight splotch the sandy bottom. You swim forward straining to see the shape emerging from the deep blue. Silently, a stingray glides into view. It cruises the sea floor, then abruptly halts over an empty patch of sand. The water clouds as the ray sucks in sediment. *Swoosh!* The ray lifts off the bottom, soaring overhead, a fish tail disappearing into its mouth. *How did the ray know that its lunch was cowering beneath the sand?*

THINK LIKE A SCIENTIST: How do you think the ray was able to detect a fish it couldn't see?

[Sidebar: Energy Big Idea: Energy can move from place to place through electric fields that our human senses cannot detect.]

The Mystery of the Hidden Lunch

Adrianus J. Kalmijn leaned over the inflatable wading pool and released a flailing flatfish. *Splash!* It zoomed to the bottom, burying itself in sand scattered there to mimic the ocean floor. As a biophysicist, Adrianus knew that sharks and rays recognize weak electric fields–invisible areas of energy. All creatures, including humans, produce weak electric fields–called *bio*electric fields because they come from something living. *Bio* means life.

We can't identify bioelectric fields with our limited senses. Sharks and rays, however, can detect electric fields using a sense organ called the ampullae of Lorenzini. These small openings on their heads are filled with a jelly-like substance that can sense electric fields. Adrianus wondered if sharks and rays use this super sense to hunt hidden fish.

[Sidebar: A biophysicist is a scientist that studies how the laws of physics can be applied to living things.]

THINK LIKE A SCIENTIST: How would you design an investigation to test if sharks and rays hunt using bioelectric fields and not just sight and smell?

[Sidebar: Variables are factors in an investigation that can change. You can think of them like different parts. The variables in your investigation are the different senses sharks and rays could use to locate a fish. Scientists test one variable at a time. What variable will you test? What other variables will you control so you know for sure which sense sharks and rays use to hunt?]

Back in the pool, Adrianus placed a special container over the fish hiding in the sand. Now the fish could not be seen or smelled, yet its bioelectric field could still flow through. Next, Adrianus released a shark. *Whoosh!* It circled the pool. Once, twice, then *zoom*! It dove for the container sensing a fish feast! For his next investigation, Adrianus released a ray. *Swish!* It soared through the water and swooped directly over the container. Fish found!

THINK LIKE A SCIENTIST: What variable would you test next to gather even more evidence that sharks and rays hunt by detecting weak electric fields? How would you test that variable and control the others?

Next, Adrianus placed a plastic sheet over the container, blocking the fish's bioelectric field. The shark didn't dive. The ray didn't swoop. With the bioelectric field contained, the fish was invisible!

Adrianus forged forward with investigation after investigation. During one test, he placed a piece of chopped up fish near the container. A rich bloody scent wafted from the soft fish flesh. A tempting treat! Would the ray slurp the snack? Would the shark munch the morsel? No! They ignored the easy meal and continued pursuing the caged catch they would never taste.
Adrianus J. Kalmijn had proven that electric sense, not sight or smell, is the primary hunting sense of sharks and rays.

THINK LIKE A SCIENTIST: How could the knowledge that sharks and rays respond to bioelectric fields be used to help protect sharks? How could it help protect humans?

Mystery solved. You discovered how sharks and rays detect electric fields to find their next meal.

[Sidebar: Energy Spotlight: Sharks and rays detect energy moving through electric fields - energy invisible to our human senses.]

Let's rise from the water and take to the sky for your next discovery!

TORNADOES

Images of destruction flood your screen–a tree toppled on power lines, an overturned semi-truck. This was definitely a tornado. Thankfully, most of the houses still stand strong. This isn't at all like the tornado in the news two months ago. That whirling windstorm replaced an entire town with piles of twisted metal and splintered wood. *Why was the damage from each tornado so different? Is there a way to compare one tornado to another?*

THINK LIKE A SCIENTIST: How are tornadoes the same, and how are they different?

[Sidebar: Energy Big Idea: Energy can move from place to place through motion and can be transferred from one form of matter to another.]

The Mystery of the Wild Wind

Ted Fujita pressed his forehead to the chilly airplane window. Far below, toothpick trees, stripped of their leaves, dotted the landscape. Boards, bricks, and bathtubs littered a path of chaos. Ted specialized in chaos. His mind naturally sought to bring order to seemingly random events. As a meteorologist, he delighted in data, an expert with tables, graphs, and diagrams. It was this mathematical mindset that drove Ted to study the destruction caused by tornados. In the 1960s, there wasn't a way to describe the difference between a tornado that caused minor roof damage and a tornado that wiped a town off the map. Ted was determined to find a way.

[Sidebar: A meteorologist is a scientist who studies the weather.]

THINK LIKE A SCIENTIST: Why would it be useful to categorize tornadoes? What characteristics would you use to determine the categories?

Ted, his wife, and a group of graduate students spent years documenting destruction in the wake of hundreds of tornados. They gathered weather reports. *How fast was the wind?* They conducted interviews. *What debris flew through the air?* They took photographs from the ground and from a helicopter. *How many buildings were destroyed?* Then, in 1971, Ted dove into the data in search of order. Wind speeds. Debris trails. Damage descriptions. He sorted, categorized, and organized.

THINK LIKE A SCIENTIST: How would you name these two categories of data? Why?

[Illustration Note: This illustration shows different types of data evidence in two "piles." In one pile are papers that illustrate wind speed data – charts, graphs, pictures of tornadoes with peak wind speeds noted. In the other pile are papers that illustrate tornado damage – photographs of destroyed buildings, aerial photos of debris trails, brief damage descriptions.]

Ted identified the two categories of data that, together, showed a tornado's fury: peak wind speed and type of damage done. Then, he made his thinking visual.

Ted Fujita created a table–the Fujita scale. It was the first attempt at a universal language to describe a tornado's destructive power.

THINK LIKE A SCIENTIST: Look at the visual Ted developed. How did he represent both energy and matter in his Fujita scale? According to the scale, what happens when different amounts of kinetic energy are transferred to matter?

[Sidebar: Kinetic energy is the energy of motion. Anything that is moving – like the air in a tornado (wind) – has kinetic energy. When a tornado hits a building, the kinetic energy in the tornado is transferred to the building. This transfer of energy can cause changes to the building, like torn siding, a missing roof, or worse!]

[Illustration Note: The graphic shows the Fujita scale–not the new enhanced F scale. The new scale will be explained in the backmatter. https://www.weather.gov/ffc/fujita]
Another energy discovery! You uncovered how more energy in a tornado results in more destruction to matter.

[Sidebar: Energy Spotlight: The Fujita scale helps scientists show the relationship between the energy in a tornado and its effects on matter.]

Congratulations, junior scientist! You made sense of our wondrous world by using ideas about energy flows. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Inge Lehmann

In 1929, a large earthquake near New Zealand provided the data Inge needed to make her discovery. She shared her findings in a 1936 paper titled P' (pronounced P prime). "P" was for the type of energy wave, and "prime" was for the unusual refraction she documented. It is the shortest title of any groundbreaking paper in the history of science. She was a pioneer at a time when few women entered the field of seismology and made her discovery through painstakingly detailed calculations (yes, written on cardboard torn from oatmeal boxes!). Today, these complex calculations are performed by computers.

Committed to her field, Inge spent 50 years after her retirement traveling around the world studying seismic events and visiting research institutions. Inge helped to form the constitution of the European Seismological Federation and was elected the group's first president in 1950. At the age of 98, Inge was the featured guest at a celebration of the 50^{th} anniversary of the publication of her revolutionary paper. She lived to be 105. Each year, the International Geophysical Union awards the Inge Lehmann medal "in recognition of outstanding contributions to the understanding of the structure, composition, and dynamics of the Earth's mantle and core."

Learn more: Scientist of the Day: Inge Lehmann (Linda Hall Library)
https://www.lindahall.org/about/news/scientist-of-the-day/inge-lehmann

Adrianus Kalmijn

Adrianus's expertly designed investigations proved that when sharks and rays are hunting, their electromagnetic sense is more important than sight or smell. He went on to conduct additional research in natural ocean environments, finding that sharks and rays also use their electromagnetic sense for navigation using Earth's magnetic field.

An innovator in his field, Adrianus built the first electromagnetic research facility in Woods Hole, Massachusetts. Here, at the Woods Hole Oceanographic Institution, scientists and engineers continue to conduct advanced ocean research. Later, he improved his design and built a larger facility in San Diego, California. Magnetic coils in the walls allow researchers to control interference from Earth's magnetic field within the building. This engineering feat enabled the success of Adrianus's carefully controlled investigations.

Learn more: Adrianus Kalmijn: 1993-2021 (Scripps Institution of Oceanography)
https://scripps.ucsd.edu/news/adrianus-kalmijn-1933-2021

Tetsuya "Ted" Fujita

Ted's Fujita scale is still the official tornado rating system used by the National Weather Service – though it has been upgraded to the new Enhanced Fujita (EF) scale. The EF scale takes into account more variables when assigning a tornado's wind speed rating, such as a building's materials and method of construction. The Fujita scale was just one of Ted's meteorological accomplishments. While examining strange marks left by tornadoes in cornfields, he realized that a tornado may be composed of multiple smaller vortexes (funnel-shaped areas of whirling air) circling one another rather than one large funnel. This explained why one house could be completely destroyed in a tornado event while the house next to it remained untouched.

Arguably, Ted's most important contribution to meteorological research was his discovery of microbursts– sudden, powerful downdrafts that burst forth from thunderstorms. With winds as strong as tornados, microbursts were identified as the previously unknown cause of multiple airplane crashes. Ted's year-long quest to prove their existence–while battling resistance and ridicule–saved hundreds of thousands of airplane passengers' lives. Although Ted, also known as "Mr. Tornado," had surveyed the damage from hundreds of tornadoes, it wasn't until more than a decade after creating his Fujita scale that he actually had the opportunity to view a real tornado (from a safe distance of course!)

Learn more: *How one scientist reshaped what we know about tornadoes* (University of Chicago News) https://news.uchicago.edu/story/how-one-scientist-reshaped-what-we-know-about-tornadoes

Questioning Guide (For Grown-Ups)

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

How could you figure out what is deep inside the earth where you can't see?

This question introduces children to the problem of investigating something we can't see and asks them to wonder about a solution. Children may think of mechanical methods such as drilling a hole or technology-assisted methods such as using sonar or x-rays. At this stage, children most likely will not be thinking of studying earthquake waves to learn information about Earth's structure. If needed, you can prompt them with additional questions: *What are some other things we can't easily see? What tools do people use to learn about them? Do you think any of those tools could be used to figure out what is deep inside the earth? Why or why not?*

What do you notice in these models showing Inge's seismograph data?

This question allows children to practice analyzing data–just like Inge–with the added advantage of seeing the data visually. At this point, children may notice that the P waves are not landing on the other side of the globe where physics laws say they should or that the waves appear to be bending when they get to a certain point near the center of Earth. If needed, you can prompt them to use a finger to trace the path of an S wave and then a P wave on the diagram and ask: *What do you notice about the wave paths? Where do they begin? Where do they end? Describe the path each wave travels. How are their paths similar? How are they different?*

What do you think might be causing the P waves to behave differently than expected?

This question places children in the same position as Inge, trying to figure out the mysterious P wave movement. Children may be able to draw the conclusion that Earth's core is solid by using information from the sidebar about waves moving through solids and liquids and combining that information with their previous analysis of P and S wave paths. If needed, you can prompt them with additional questions: *What did you learn about P and S waves in the diagram? What did you learn about P and S* *waves in the sidebar? What conclusion can you draw by putting these two pieces of information together?*

Why is it important to understand how P and S waves (energy) move through the earth (matter)?

This question gives children the opportunity to apply what they have discovered to other situations. Since waves transfer energy, children may think to use wave knowledge to prevent earthquake damage by using different materials when building structures. Or they may think of using a machine that produces and measures waves–like x-rays, sonar, and MRI machines–to find out what things are made of that we can't see because of their location. If needed, you can prompt them with additional questions: *What have you learned about waves? How could that information be used in a different way to help people?*

How do you think the ray was able to detect a fish it could not see?

This question gets children wondering about something that happens in nature. They may guess that the fish is making a sound or moving. At this point, they most likely won't have the background knowledge to predict it involves bioelectric fields. If needed, you can prompt them with additional questions: *How do other animals find their prey? What senses might the stingray be using to find its prey?*

How would you design an investigation to test if sharks and rays hunt using bioelectric fields and not just sight and smell?

This question asks children to complete the same process as Adrianus. The variables sidebar will help lead children through a series of smaller steps in investigation design. You can guide their thinking by asking: *What question are you investigating? What are the variables in your investigation? What variable are you testing? What variables do you need to control? How are you going to control those variables?* Children may be able to articulate that they are seeking to figure out whether a shark hunts using bioelectric fields, and they are testing the bioelectric field variable. Children may share that they are controlling the variables of sight and smell. Their suggested methods should include some way to hide the fish from sight and contain its scent.

What variable would you test next to gather even more evidence that sharks and rays hunt by detecting weak bioelectric fields? How would you test that variable and control the others?

Once again, this question asks children to complete the same process as Adrianus. Children may think to test one of the other variables like sight or smell, or they may want to continue testing the bioelectric field by blocking it completely. You can guide their thinking by asking: *What question are you investigating now? What variable are you testing? What variables do you need to control? How are you going to control those variables?*

How could the knowledge that sharks and rays respond to bioelectric fields be used to help protect sharks? How could it help protect humans?

This question gives children the opportunity to apply what they have discovered to other situations. They may come up with engineering ideas that prevent sharks from getting caught in fishing nets or swimming into unsafe waters. Children may also think of masking a human's bioelectric field to prevent shark attacks. If needed, you can prompt them with additional questions: *What are some negative ways sharks and humans interact? How could your knowledge of bioelectric fields help prevent those interactions?*

How are tornadoes the same, and how are they different?

This question prompts children to look for patterns. They may share that all tornadoes have powerful, destructive winds, yet some tornadoes are more destructive than others. They may also share background knowledge about how tornadoes are formed or where they are most often located. If needed, you can prompt them with additional questions: *What do you already know about tornadoes? How would you describe a tornado? Why are tornadoes dangerous? How would you describe the destruction caused by a tornado? Would your description be the same for every tornado? Why or why not?*

Why would it be useful to categorize tornadoes? What characteristics would you use to determine the categories?

This question prompts children to consider the usefulness of the tornado scale they will soon discover and to think about the problems encountered by not having a scale. Children may share that wind speed and amount of destruction could be used to determine the categories, though they may have other ideas Ted didn't consider! If needed, you can prompt them with additional questions: *Why would it be helpful for people to understand the difference between tornados? How could that information be useful before a tornado strikes? How could it be useful after a tornado strikes? What are the characteristics of a tornado? (i.e., What makes a tornado a tornado?) How could those characteristics be turned into categories that would help scientists to sort tornadoes into groups?*

How would you name these two categories of data? Why?

This question asks children to complete the same process as Ted. Children may be able to look at the two piles of data and figure out the "main idea" of each pile: peak wind speed and amount of damage caused. If needed, you can prompt them with additional questions: *What do the pieces of data in each pile have in common? What name could you use to describe all the data in this pile? Do your category names help scientists to sort tornadoes by their most important characteristics? Why? If not, how could you change your category names to be more helpful to scientists?*

Look at the visual Ted developed. How did he represent both energy and matter in his Fujita scale? According to the scale, what is the relationship between energy and its effects on matter?

This question gives children the opportunity to apply their knowledge of energy and matter. They may share that Ted represented energy with the wind speed measurement and matter with the type of damage done. The speed of the wind is related to kinetic energy. The greater the kinetic energy of the wind, the more energy is transferred to matter (trees, houses, cars), resulting in more damage. If needed, you can prompt children with additional questions: *Where is a tornado's energy represented in the scale? Where is matter represented in the scale? What do you notice happens to the amount of damage as the wind speed increases? What does that tell you about how energy affects matter?* With these additional prompts, children may realize that the greater the amount of energy transferred, the greater its effects on matter.

[These investigations help grown-ups to further a child's understanding of energy. They could be printed in the back of the book or provided as a curriculum download.]

Hands-On Investigations to Explore the Science of Energy

Energy is central to the existence of life on Earth from a single-celled bacterium to the largest redwood tree. The more you understand about energy, the more you understand about how the world works, and the more amazing discoveries you can make!

You can explore energy with these hands-on investigations.

Energy Ideas

Unlike matter, energy moves in and out of Earth. Energy leaves Earth as infrared radiation going into space. Energy comes into Earth from sunlight and radioactive decay in Earth's interior. We mostly think about energy from the sun because it drives all of Earth's processes from food sources to ocean currents to the weather.

We access energy present in electrical and magnetic fields and can observe energy in action through motion, sound, light, and heat. When something happens, energy was transferred (moved) or transformed (changed)!

Investigation #1: Pound Playdough

Materials: playdough and a kitchen scale

1. Roll a palm-sized chunk of playdough into a ball.
2. Place the playdough on the scale and record the weight.
3. Set the ball on a table, and smash it with your fist.
4. What happened to the playdough? Why did it happen?
5. Weigh the playdough again. Is the weight the same?

What conclusions can you draw about energy from this investigation? How do energy transfers affect matter?

How this relates to energy: Energy can be transferred from place to place through motion. And energy is transferred between objects that interact, like a bat hitting a ball. In your experiment, the energy from your fist was transferred to the playdough, causing the dough to change shape. Even though the dough looked different, it still had the same mass. Energy transfers may affect how matter looks, but they don't change the amount of matter present.

Investigation #2: Create Waves

Materials: bowl, plastic wrap, rice or sprinkles, metal pan and spoon

1. Cover the top of the bowl with plastic wrap.
2. Scatter two teaspoons of rice or sprinkles on top of the wrap.
3. Place your face close to the bowl without touching it and hum.
4. What happened to the rice or sprinkles? Why did it happen?
5. Hold the metal pan close to the bowl without touching it and bang the pan with the spoon.
6. What happened to the rice or sprinkles? Why did it happen?

What conclusions can you draw about sound energy from this investigation?

How this relates to energy: Energy can be transferred from place to place through waves. Sound waves are a form of energy that travels through matter. We hear sounds because waves travel through air (matter) and into our ears. In your experiment, you could hear your voice humming and the spoon banging on the pan. You could also see the sound waves. They traveled through the plastic wrap (matter) and transferred energy to the rice or sprinkles. This transfer of energy caused the rice or sprinkles to move.

Investigation #3: Explore with Magnets

Materials: two magnets, iron or nickel object, plastic object, aluminum object

1. Hold the ends of two magnets close to one another. What happens?
2. Flip one of the magnets around and hold it close to the other magnet again. What happens?
3. Hold one of your magnets over a metal object made of iron or nickel without touching the object. What happens? Why did it happen?
4. Hold one of your magnets over a piece of plastic and an object made of aluminum? What happens? Why did it happen?

What conclusions can you draw about energy fields from this investigation? How do energy fields affect different objects?

How this relates to energy: Energy in magnetic fields can be transferred to objects that are magnetic or have ferromagnetic properties, causing them to move. This transfer of energy happens without the magnet touching the object. Not all metals are affected by magnets! Only certain metals like iron and nickel are affected by magnets or can be used to make magnets.

Investigation #4: Build a Circuit

Materials: two 4 inch lengths of insulated wire, tape, a battery, a small LED or flashlight bulb

1. Have an adult help you strip the insulation off both ends of the wires.
2. Tape one end of the exposed wire to the top of the battery.
3. Tape the other end of the exposed wire to one of the LED leads.
4. Tape one end of your second piece of wire to the other LED lead.
5. Touch the other end of your second piece of wire to the bottom of the battery.
6. What happens? Why does it happen?

What is the source of energy in your circuit? How could you prove that? What is the purpose of the light bulb in your circuit?

How this relates to energy: Energy can be transformed from one form to another. In your circuit, the electrical energy that is stored in your battery is transformed into light energy and heat energy by the light bulb. Both energy and matter cannot be used up. For example, when you burn gasoline in your car, digest food in your stomach, or burn wood in a fire, the matter has been converted into gasses (water and carbon dioxide), and the energy has been transferred to the surrounding environment as heat.

More About Energy

A common misconception is that food and caffeine are energy. Your hamburger and the caffeine in your soda are matter and potential energy. When you digest matter, you break the bonds of food molecules. Putting those atoms together in different ways to form new matter is what *releases* energy to be converted into other forms of energy such as heat to keep you warm or motion so you can run!

Energy Big Ideas: Energy flows through systems. It does not change the amount of matter in those systems. Energy can be transferred from place to place and can be transformed from one form to another.

Concepts of energy are developed over a lifetime of experience. Create energy waves, build circuits that convert electrical energy into light, heat, and motion, and explore with magnets. Keep in mind energy's big ideas as you observe and investigate. They will guide you as you make sense of our vast, fascinating world!

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Inge Lehmann

American Museum of Natural History. "Inge Lehmann: Discoverer of the Earth's Inner Core | AMNH." American Museum of Natural History, 2020, www.amnh.org/learn-teach/curriculum-collections/earth-inside-and-out/inge-lehmann-discoverer-of-the-earth-s-inner-core. https://www.amnh.org/learn-teach/curriculum-collections/earth-inside-and-out/inge-lehmann-discoverer-of-the-earth-s-inner-core. Accessed 1 Feb. 2023.

Bolt, Bruce A, and Erik Hjortenberg. "Memorial Essay." *Bulletin of the Seismological Society of America*, vol. 84, no. 1, 1 Feb. 1994, pp. 229–233, https://doi.org/10.1785/bssa0840010229.

Hjortenbergy, Erik. "Inge Lehmann's work materials and seismological epistolary archive." *Annals of Geophysics*, vol. 52, no. 5, Dec. 2009, pp. 679 – 698, https://www.researchgate.net/publication/50301979_Inge_Lehmann%27s_work_materials_and_seismological_epistolary_archive.

Kölbl-Ebert, Martina. "Inge Lehmann's Paper: P' (1936)." Episodes, vol. 24, no. 4, 1 Dec. 2001, pp. 262–267, https://doi.org/10.18814/epiiugs/2001/v24i4/007. Accessed 1 Feb. 2023.

Lehmann, Inge. "P ' " Publications du Bureau central séismologique international. Série A: Travaux scientifiques, vol. 14, 1936, pp. 87-115, https://courses.seas.harvard.edu/climate/eli/Courses/EPS281r/Sources/Inner-Core/Lehman-Inge-1936.pdf.

Mills, Allison. "March 29, 1936: Notes on Earth's Inner Core." *Earth Magazine*, January 30, 2015, https://www.earthmagazine.org/article/march-29-1936-notes-earths-inner-core.

"Scientist of the Day – Inge Lehmann." Linda Hall Library, 13 May 2019, https://www.lindahall.org/about/news/scientist-of-the-day/inge-lehmann.

Adrianus J. Kalmijin

Kalmijn, A.J. "The Electric Sense of Sharks and Rays." *Journal of Experimental Biology*, vol. 55, no. 2, 1 Oct. 1971, pp. 371-383, https://doi.org/10.1242/jeb.55.2.371.

Monroe, Robert. "Adrianus Kalmijn: 1933 – 2021." Scripps Institution of Oceanography, 16 Dec. 2021, https://scripps.ucsd.edu/news/adrianus-kalmijn-1933-2021.

Robbins, Gary. "Adrianus Kalmijn, biophysicist who discovered sharks have a 'sixth sense,' dies." *L.A. Times*, 4 Jan. 2022, sec. Obituaries, https://www.latimes.com/obituaries/story/2022-01-04/adrianus-kalmijn-ucsd-biologist-obituary.

Ted Fujita

Butler, Kirstin. "The Remarkable Mind of Mr. Tornado." *PBS American Experience*, 4 May 2020, https://www.pbs.org/wgbh/americanexperience/features/mr-tornado-remarkable-mind.

"Enhanced Fujita Scale" National Weather Service. https://www.weather.gov/tae/ef_scale. Accessed 2 Jan. 2023.

Fujita, Dr. Tetsuya. Fujita, Dr. Tetsuya Theodore "Ted", Papers, 1875-2003 and undated. Southwest Collection, Texas Tech University. https://hdl.handle.net/10605/298.

Fujita, Tetsuya Theodore. "Memoirs of Effort to Unlock the Mystery of Severe Storms during the 50 Years, 1942-1992," *Wind Research Laboratory, Department of Geophysical Sciences, University of Chicago.* Research Paper Number 239, 1994, swco-ir.tdl.org/items/d7813e90-b2eb-45bc-8fc6-398cd4493756. Accessed 3 Jan. 2023.

Henson, Bob. "How Ted Fujita Revolutionized Tornado Science and Made Flying Safer Despite Many Not Believing Him." *The Weather Channel*, 18 May 2020. https://weather.com/news/weather/news/2020-05-15-they-didnt-believe-him-how-ted-fujita-revolutionized-tornado-science

Lerner, Louise. "How one scientist reshaped what we know about tornadoes." *UChicago News*, 22 Oct. 2020. https://news.uchicago.edu/story/how-one-scientist-reshaped-what-we-know-about-tornadoes

"Mr. Tornado." *American Experience*, season 32, episode 8, PBS, 19 May 2020. https://www.pbs.org/video/chapter-1-mr-tornado/

AUTHOR'S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

- Patterns
- Cause and effect
- Stability and change
- Structure and function
- Energy and matter
- Systems and system models
- Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It's helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world's richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists' fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: THE ABYSS, ELEPHANTS, AND HAWK MOTHS
SOLVING SCIENCE MYSTERIES WITH STRUCTURE AND FUNCTION

By Emily Mae Starr

Are you holding this book with your feet? Do your ears chew your lunch? Does that sound silly? That's because you and every other organism on the planet has parts that are *structured* to perform a specific *function*.

Squeeze your hands open and shut. Your fingers are long and flexible, so you can grasp objects. Chomp your teeth. They are hard and jagged, so you can grind food.

The shape of your body parts and what they are made of determines what each is able to do for you!

Each of the scientists in this book observed structures in nature. They studied how different parts help plants and animals function, or do things, to survive. Come look at the world through their eyes. See how you can use the relationship between structure and function to solve science mysteries about the abyss, elephants, and hawk moths.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

THE ABYSS

Tucked tight in a small submersible, you stare out the window at the ocean's inky abyss. Black. Barren. Empty. Suddenly, a flash of light pops, and another, and another–winking lights, blinking lights, strobing lights…moving lights–a fantastical fireworks display beneath the waves. *What are those lights?*

THINK LIKE A SCIENTIST: What do you think is creating the light? Why do you think that?

[Sidebar: Structure and Function Big Idea: Functions (what something can do) are enabled by specific structures (an object's shape and materials it is made of).]

The Mystery of the Underwater Fireworks

Down…down…down Edith Widder sunk like a stone, disappearing into the darkness. 50 meters. 100 meters. 200 meters beneath the ocean's surface. She peered through the foggy visor of her atmospheric diving suit. The suit's headlamps illuminated floating particles of marine snow. These tiny bits of dead plants and animals drifted like dust in the empty expanse.

Tethered to a surface ship, Edith hung in the water, reached for the lights, and prepared to plunge into darkness. *Would she be able to see anything in these dark depths?* Edith cut the lights. *Flicker! Twinkle! Flash!* In the water beyond, a ceaseless light show erupted. Lights winked and blinked–some like small fireflies, others like rippling strings of Christmas lights. Blue! Indigo! A bioluminescent show for an underwater audience. Edith froze in shock. So. Many. Lights. *What creatures were creating this dazzling display and why?*

[Sidebar: Bioluminescent light is created by chemical reactions in the bodies of living things.]

THINK LIKE A SCIENTIST: How could you find out what is causing this flashing light show?

As a marine biologist, Edith knew that scientists learn about living creatures by observing them. But there were problems with studying creatures in the deep ocean. She could only explore in her diving suit for a few hours before running out of air. Submersibles had air for a few days, yet when she steered close to some creatures, they would zoom away. Undeterred, Edith worked out a solution with engineers. Together, they invented recording devices that could stay in the abyss and go completely unnoticed.

In 1983, Edith installed her new creations on the ocean floor. The recording devices produced hours and hours of video and light measurements for Edith to analyze. She used this data to identify organisms with bioluminescent structures, what causes them to emit light, and what happens after they light up.

[Sidebar: A marine biologist is a scientist that studies organisms in the ocean.]

THINK LIKE A SCIENTIST: According to the data, what are the bioluminescent structures allowing organisms to do?

[Illustration Note: On this page is a data table that lists a bioluminescent creature, what causes it to light up, and what happens after it lights up.]

Edith discovered black dragonfish that flash when attacked in the hopes of distracting a predator or drawing the attention of a larger organism to eat their attacker. *Chomp!*

She observed shrimp that communicate by gushing glowing chemicals into the water. *Squirt!*

And she marveled at stoplight loosejaw fish–one of the few deep ocean creatures that can see the color red. Because of this advantage, the fish hunt with red colored “flashlights” located beneath their eyes to sneak up on prey that can’t see red. *Gulp!*

Because of Edith’s work, we know that it is rare to find a creature in the abyss that doesn’t glow!

THINK LIKE A SCIENTIST: Why is it important to learn about organisms that live in the abyss? How could bioluminescence be helpful to humans?

Your first structure and function breakthrough! You dove into the data to shine a light on bioluminescent creatures in the deep.

[Sidebar: Structure and Function Spotlight: Bioluminescent structures allow deep ocean creatures to find food, evade predators, and reproduce.]

No time to rest. From the depths of the ocean to the sunny savanna, your next discovery awaits!

ELEPHANTS

Dirt floods the Jeep as you bump across the African savanna. You stop at a well-known watering hole, and almost immediately, a group of elephants arrive. The majestic matriarch leads the way, her herd fanning out along the shore. Suddenly, they freeze. Gray statues. Watching. Waiting. *Trumpet! Trumpet!* The frightened group bolts back into the brush. What is going on? You didn't hear or see anything to cause panic.

An hour later, as dusk creeps across the water, a pride of lions silently slinks into view. Ah ha! But it has been so long. *How did the elephants know the lions were coming?*

THINK LIKE A SCIENTIST: How could you figure out why the elephants froze and then knew to flee from predators so far away?

[Sidebar: Structure and Function Big Idea: The same function can be enabled by a variety of different structures.]

The Mystery of the Frozen Elephants

Caitlyn O'Connell tracked the snapped fence line and examined the devastation. Stalks stripped. Kernels scattered. Roots trampled. How was she going to keep the peace when the pesky pachyderms kept destroying farmers' crops? In search of a solution, Caitlyn spent days…weeks…months observing elephants. *How far did they roam? What made a tasty snack? How did they "talk"?*

THINK LIKE A SCIENTIST: Why is it important for Caitlyn to learn about elephants *before* offering a solution?

As a behavioral ecologist, Caitlyn studied how the elephants interacted–with each other, with other living things, and with their environment. As she watched and waited, wrote and recorded, she noticed something strange.

An entire herd of elephants would stop walking mid-stride, freezing in place as if instantly turned to stone. One second. Two seconds. A few would lift one foot off the ground, walk a few steps, and freeze again. Caitlyn heard nothing. Saw nothing. *What were they doing?*

Puzzled, Caitlyn thought back to her experience studying insects. Caitlyn observed insects communicating through vibrations. They froze in place when "listening" with their feet! *Could elephants also detect vibrations with their feet?*
[Sidebar: A behavioral ecologist is a scientist who studies how living things behave, or interact, with their environment and other living things.]

THINK LIKE A SCIENTIST: What investigation would you design to figure out if elephants can communicate with vibrations through the ground?

Caitlyn began by placing a common speaker capable of playing recorded audio on the ground. Next, she dug a hole, planted a different device, and covered it with dirt. Instead of playing audio, this machine transmitted vibrations through the ground.

As a herd of elephants gathered at the watering hole, Caitlyn began her investigation with the above ground speaker. She played a recorded elephant call that warned of lions in the area. Alarmed, the herd ran away in the opposite direction.

Later, when the herd returned, she played another elephant alert, but this time through the device buried in the ground. There were no above ground sound waves to hear. The message was transmitted as vibrations moving through the ground. The elephants froze, then moved into tighter family groups–ready to defend against an unseen predator. Vibrated message received! Caitlyn had discovered that elephants can "hear" with their feet!

THINK LIKE A SCIENTIST: Why is it important to understand what structures animals use to communicate? How could knowledge of elephant communication be helpful to humans?

Mystery solved. You discovered how elephants use structures in their feet to receive underground messages.

[Sidebar: Structure and Function Spotlight: Animals may hear with different structures and detect different vibrations than our human sense of hearing.]

From enormous elephants to mysterious moths, your next discovery awaits!

<u>HAWK MOTHS</u>

Croak! Chirp! Squawk! Your ears ring with the songs of the rainforest. A patch of white catches your attention. What an interesting flower–five long, thin petals arranged like a star with a thicker petal poking from the center. Is this flower sticking out its tongue at you?

You move closer, peering into the flower's center. A shiny liquid reflects back. Nectar! The sweet treat is pooled way down deep at the bottom of a long, thin tube. You know that flowers make nectar to attract pollinators–animals that carry pollen from one flower to another. *What pollinator is able to navigate such a long, narrow tube?*

THINK LIKE A SCIENTIST: How could you find out what organism is pollinating the star-shaped flower?

[Sidebar: Structure and Function Big Idea: The shape of an object and what it is made of (its structure) determines its functions.]

The Mystery of the Puzzling Pollinator

Alfred Russel Wallace circled the flower, examining it from every angle. Top. Bottom. Left. Right. Inside. Outside. This was the first time he laid eyes on the star orchid from Madagascar, and he was in disbelief. The delicate, ivory bloom had the longest nectar tube he had ever seen, stretching 11 inches from the base of the bloom to the grass-green stem.

As a naturalist, Alfred knew the purpose of nectar was to reward pollinators, but what creature could reach this nectar? It was at the bottom of such a long and narrow tube that an adventurous insect would crawl in and plummet to their death, drowning in a pool of sweet liquid. And even if it survived the fall, the tube was too narrow to fly back out. Since a flower cannot reproduce, or make seeds, unless it is pollinated, Alfred knew that some organism must be pollinating the orchid. Yet he had never seen a creature capable of it. *What would that pollinator look like?*

[Sidebar: A naturalist is a scientist who studies the relationships between organisms and their environment.]

THINK LIKE A SCIENTIST: What structure could allow a pollinator to sip the nectar? Are there clues in the structures of known pollinators?

In 1867, Alfred predicted that the pollinator must possess a very long proboscis, a straw-like feeding tube. He knew the hawk moth used a proboscis which it held coiled, unrolling it only when ready for a nip of nectar. Alfred thought the star orchid's pollinator must have a similar structure–just many times longer than he had ever seen.

Then, in 1903, scientists Karl Jordan and Lord Walter Rothschild caught sight of a new kind of hawk moth in Madagascar with the longest proboscis ever recorded. Maybe this was the orchid's pollinator! But they didn't witness the new hawk moth actually pollinating the star orchid, so the scientists couldn't be sure.

THINK LIKE A SCIENTIST: What would scientists need to do to prove which creature pollinates the star orchid?

Finally, in 1992, 125 years after Alfred Russel Wallace's prediction, entomologist Lutz Thilo Wasserthal traveled to Madagascar determined to capture the process on film. Since the moths are nocturnal, only active at night, Lutz set up special cameras with night vision and infrared lights. He collected several star orchids and placed them in a cage in front of the cameras. The bait was set! Next, he scoured the hills and was lucky to capture two hawk moths like Jordan and Rothschild had described. It turns out, they are very rare!

That night, Wasserthal released the hawk moths into the orchid aroma-filled cage. The insects fluttered and floated until. . .one of the moths hovered in front of an orchid, unfurled its proboscis and shoved it into the flower. One second…two seconds…four seconds…six seconds…the proboscis rolled up and the moth flew away, covered in seed producing pollen. Lutz had recorded proof! A hawk moth with the longest proboscis of any insect was the star orchid's pollinator, just as Alfred predicted.

[Sidebar: An entomologist is a scientist who studies insects.]

THINK LIKE A SCIENTIST: How did Alfred's knowledge of structure and function help him make an accurate prediction about the star orchid's pollinator? How can our knowledge of structure and function in living animals help us make predictions about extinct animals or newly discovered animals?

Another structure and function discovery! You uncovered how a flower's structure led to the correct prediction of a pollinator's structure.

[Sidebar: Structure and Function Spotlight: The shape of an animal's body parts allow it to perform specific functions.]

Congratulations, junior scientist! You made sense of our wondrous world using ideas about structure and function. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Edith Widder

Edith Widder never intended to research bioluminescence – it wasn't even an established field of study in 1984 – yet after her first dive in the atmospheric diving suit, Wasp, she was hooked! In order to make her groundbreaking discoveries, Edith had to invent new submersible instruments and deep sea observation equipment. Her HIDEX bathyphotometer, which measures bioluminescence in the ocean, is used by the U.S. Navy to help keep their submarines hidden from above. Her LoLAR deep-sea light meter measures sunlight and bioluminescence to help determine where animals are located throughout the deep ocean. Her Eye-in-the-Sea remotely operated camera system observes ocean organisms in their natural habitats. It has even spotted a new species of large squid more than six feet long. In 2005, Edith founded the Ocean Research & Conservation Association whose mission is to protect and restore ocean ecosystems.

Learn more: *The weird, wonderful world of bioluminescence* (TED)
https://www.ted.com/talks/edith_widder_the_weird_wonderful_world_of_bioluminescence?language=en

Ocean Exploration Careers: Meet Edith A. Widder (NOAA)
https://oceanexplorer.noaa.gov/edu/oceanage/04widder/welcome.html

Caitlyn O'Connell

Caitlyn O'Connell has been studying elephants in Africa for over thirty years. During that time, she experienced many close encounters with wildlife, including a lion almost falling through the roof of her underground observation room. Caitlyn has shared her research and experiences in numerous scientific papers, adult and children's books, and television productions, including *Elephant King*, an award winning Smithsonian documentary. She is even applying her knowledge of communication through vibrations to designing a new type of hearing aid for humans.

Learn more: *The Elephant Scientist* by Caityln O'Connell and Donna M. Jackson (Houghton Mifflin Children's Books, 2011)

Alfred Russel Wallace

Alfred Russel Wallace was not the first scientist to wonder about the creature that could pollinate the Madagascar star orchid. In 1862, fellow scientist Charles Darwin was sent one of the fragrant flowers. Upon examination, Darwin exclaimed, "Good heavens, what insect can suck it!" Dawin predicted the pollinator may be a moth. Five years later, Alfred Russel Wallace agreed with Darwin's prediction and furthered the idea by suggesting it was a hawk moth with a long proboscis, similar to a species found in Africa. Wallace wrote: "That such a moth exists in Madagascar may be safely predicted, and naturalists who visit that island should search for it with as much confidence as astronomers searched for the planet Neptune,—and they will be equally successful."
Alfred Russel Wallace traveled the world in search of plant and animal specimens for his own private collection and to sell to museums and nature enthusiasts. On his first trip abroad, thousands of specimens and field notes gathered during four years exploring the Amazon were lost at sea when his ship caught fire and sank. Undaunted, Wallace set sail for Indonesia, and over the course of eight

years, collected 125,660 specimens including 83,000 beetles and 5,000 organisms yet unknown to Western scientists.

Alfred came to believe that organisms best suited for survival would be most likely to pass their traits to offspring, resulting in more offspring with those desired traits. Today, we know this as natural selection. His revelation was around the same time as his more famous friend and colleague, Charles Darwin. Charles is the scientist most credited for the theory of evolution and natural selection. Alfred is best known for his description of the "Wallace line," an imaginary divide in Indonesia. According to Alfred, this line separates plants and animals into two groups–organisms from Asia are on one side of the line and organisms from Australia are on the other side.

Learn more: *Who Was Alfred Russel Wallace?* (London Natural History Museum)
https://www.nhm.ac.uk/discover/who-was-alfred-russel-wallace.html

POLLEN: Darwin's 130-Year Prediction (Moments in Science) by Darcy Pattison (Mims House, 2019)

Questioning Guide (For Grown-Ups)

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

What do you think is creating the light? Why do you think that?

This question gets children wondering about something that happens in nature. They may guess it is a manmade source like lights from other submersibles. Other children may guess it is living creatures. If needed, you can prompt them with additional questions: *What are sources of light on land? Which of those sources could be underwater?*

How could you find out what is causing this flashing light show?

This question asks children to complete the same process as Edith. Children may not think of a deep-sea recording device, yet they should articulate some of the challenges of observing organisms in the abyss and offer solutions that allow them to gather data. If needed, you can prompt them with additional questions: *How can you conduct an investigation so deep underwater? What questions are you trying to answer? What data will you record? What equipment will you need? What challenges will you need to overcome?*

According to the data, what are the bioluminescent structures allowing organisms to do?

This question gives children the opportunity to look for patterns in a data set. Children should notice that several effects are repeated in the table, and they may think to group the effects into categories such as: hunting, mating, and defense. If needed, you can prompt them with additional questions: *Are there patterns in the data? How are some of the data similar? What actions does bioluminescence help organisms do to survive?*

Why is it important to learn about organisms that live in the abyss? How could bioluminescence be helpful to humans?

The first question prompts children to consider why the work of scientists is important. Children may have background knowledge that allows them to share how humans use ideas from nature to improve our lives and that it is important to learn about Earth's biodiversity. The second question gives children the opportunity to apply what they have discovered to other situations. For example, a child may come up with engineering designs that use bioluminescence to reduce our energy consumption at night or to use as an alternative energy source during a blackout. If needed, you can prompt them with additional questions: *What could happen if we didn't know about organisms that live in the abyss? How could organisms in the abyss be helpful to humans? What are some ways organisms on land have been helpful to humans? In what situations would something that makes its own light be helpful?*

How could you figure out why the elephants froze and then knew to flee from predators so far away?

This question asks children to complete the same process as Caitlyn. Children should articulate that they are seeking to figure out how the elephants sensed a danger so far away, and they may share that they would set up recording devices to gather sensory inputs including sight, sound, and maybe even ground movement. If needed, you can prompt them with additional questions: *What question are you investigating? What data do you need to collect? What equipment do you need to record that information?*

Why is it important for Caitlyn to learn about elephants before offering a solution?

This question asks children to consider why scientists collect data. They may share that Caitlyn could offer a better solution if she understood more about elephants or that she might offer a bad solution if she didn't understand elephant behavior. If needed, you can prompt them with additional questions: *Why is it important to understand how an animal behaves before you interact with it? What might happen if Caitlyn offers a solution before she knows anything about elephants?*

What investigation would you design to figure out if elephants can communicate with vibrations through the ground?

Like the previous question, children are encouraged to complete the same process as Caitlyn. Some of their investigative methods may be similar to the previous question, and some may be different. Asking two similar questions in succession helps children to understand that once you draw conclusions from one experiment, you often design another experiment to further refine your conclusions. Children should articulate that they are seeking to figure out whether elephants can understand a message sent through ground vibrations. They should describe a method for sending ground vibrations and determining whether or not the elephants understand the message. If needed, you can prompt them with additional questions: *What question are you investigating? What data do you need to collect? What equipment do you need to record that information?*

Why is it important to understand what structures animals use to communicate? How could knowledge of elephant communication be helpful to humans?

The first question prompts children to consider why the work of scientists is important. Children may share that knowing about different animal structures helps us better understand animal behavior.

Children may realize that this knowledge can lead to better solutions to protect threatened animal populations. Children may make the connection that Caitlyn could use the information about elephant communication to create underground vibrations that would warn elephants to stay away from farmers' crops. Children may have background knowledge that allows them to share how humans use ideas from nature to improve our lives, which leads to the second question. It gives children the opportunity to apply what they have discovered to other situations. For example, a child may come up with an engineering design that uses vibrations to help people who cannot hear. If needed, you can prompt them with additional questions: *What problems do animals cause for humans that could be solved using knowledge of animal communication?*

How could you find out what organism is pollinating the star-shaped flower?

This question asks children to design a scientific investigation. Children should articulate that they are seeking to figure out how the star-shaped flower is pollinated and should describe some method of recording observations. If needed, you can prompt them with additional questions: *What question are you investigating? What data do you need to collect? What equipment do you need to record that information?*

What structure could allow a pollinator to sip the nectar? Are there clues in the structures of known pollinators?

This question gives children the opportunity to apply their knowledge of structure and function. They may share that the pollinator would need to have a structure that was very long to be able to reach the nectar at the bottom of the long tube. Children with prior knowledge of insects with a proboscis (a straw-like tongue) may suggest a very long proboscis as the required structure. If needed, you can prompt them with additional questions: *What pollinators do you already know? How do they eat nectar? What shape would a structure need to reach the nectar? Where have you seen a structure shaped like that before? How would that structure need to function to help the pollinator sip the nectar?*

What would scientists need to do to prove which creature pollinates the star orchid?

This question helps children to realize that evidence is required to prove predictions. It asks them to consider how they would gather that evidence. Children may think to observe the creature in action. Others may suggest photographing or recording the creature as it pollinates. If needed, you can prompt them with additional questions: *What evidence would scientists need to gather to prove to the world which creature pollinates the star orchid? How could they gather that evidence? What equipment would they need?*

How did Alfred's knowledge of structure and function help him make an accurate prediction about the star orchid's pollinator? How can our knowledge of structure and function in living animals help us make predictions about extinct animals or newly discovered animals?

This question gives children the opportunity to consider the usefulness of structure and function knowledge. They may share that Alfred's background knowledge of pollinators, their structures, and how flowers are pollinated helped him to make an accurate prediction. For the second question, children may share that the shape and material of a specific structure determines its functions. So, structures with similar shapes and materials most likely perform similar functions. For example, we know some dinosaurs ate plants because their broad, flat teeth were structured for grinding plant matter. We know other dinosaurs ate meat because their pointed teeth were perfect for ripping and tearing flesh. We can see similarly structured teeth in action in living animals and draw the conclusion that similar structures in extinct animals most likely performed similar functions. If needed, you can prompt them with additional questions: *What did Alfred already know about pollinators? Why was that information helpful when he made a prediction about the orchid's pollinator? How are the teeth of animals that eat meat different from animals that eat plants? Why are they different? How can that information help scientists predict what extinct animals ate?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Edith Widder

"Edith Widder: Oceanographer." *MacArthur Foundation*. 1 Sept. 2006, https://www.macfound.org/fellows/class-of-2006/edith-widder.

"Glowing life in an underwater world." *TED.com*, April 2010. https://www.ted.com/talks/edith_widder_glowing_life_in_an_underwater_world?language=en.

"How we found the giant squid." *YouTube*, uploaded by TED, 5 Mar. 2013. https://www.youtube.com/watch?v=rXkOPv3wVZw.

"Meet Edith A. Widder." *NOAA Ocean Exploration.* Accessed 4 Nov. 2022 https://oceanexplorer.noaa.gov/edu/oceanage/04widder/welcome.html.

Widder, Edith. *Below the Edge of Darkness: A Memoir of Exploring Light and Life in the Deep Sea*. Random House, 2021.

Widder, Edith. "Bioluminescence in the Ocean: Origins of Biological, Chemical, and Ecological Diversity." *Science*, vol. 328, no. 5979, 6 May 2010, pp. 704–708, https://doi.org/10.1126/science.1174269.

Widder, Edith A., et al. "Far Red Bioluminescence from Two Deep-Sea Fishes." *Science*, vol. 225, no. 4661, 3 Aug. 1984, pp. 512–514, https://doi.org/10.1126/science.225.4661.512.

Widder, Edith A., et al. "Marine Bioluminescence Spectra Measured With An Optical Multichannel Detection System." *The Biological Bulletin*, vol. 165, no. 3, Dec. 1983, pp. 791–810, https://doi.org/10.2307/1541479.

Caitlyn O'Connell

"007 Caitlin Elizabeth O'Connell-Rodwell The Secret Life of Elephants." *YouTube*, uploaded by lochhead, 4 Jan. 2019, https://www.youtube.com/watch?v=y7oDZOPS4Y4.

"Elephants are Human Too with Caitlin O'Connell." *YouTube*, uploaded by Skype a Scientist, 26 May 2020, https://www.youtube.com/watch?v=KJdFB1z-nYo&list=PLpHyOJsEgf97vCjxClHE-4tDl_xpsb75Z&index=2 .

"Meet the Woman Who Communicates with Elephants." *YouTube*, uploaded by Smithsonian

Channel, 19 Feb. 2013, https://www.youtube.com/watch?v=HdyPkqOEvU4.

O'Connell, Caitlin. *Caitlin E. O'Connell*. https://www.caitlineoconnell.com, Accessed 2 Nov. 2022.

O'Connell, Caitlin. *The Elephant Scientist*. Clarion Books, 2016.

O'Connell, Caitlin. *The Elephant's Secret Sense: The Hidden Life of the Wild Herds of Africa*. The University of Chicago Press, 2008.

"Studying Elephant Communication." *YouTube*, uploaded by HHMI Biointeractive, 16 Feb. 2017, https://www.youtube.com/watch?v=nII9yngRuac.

"The Family Structure of Elephants - Caitlin O'Connell-Rodwell." *YouTube*, uploaded by TED-Ed, 15 Apr. 2004, https://www.youtube.com/watch?v=VXHRtoH0kIQ&t=4s.

"The Secret Lives of Elephants: Caitlin O'Connell-Rodwell at TEDxStanford." *YouTube*, uploaded by TEDx Talks, 20 June 2013, https://www.youtube.com/watch?v=Yd0MRjq37uw.

Alfred Russel Wallace

Ashworth, Jr., William B. "Scientist of the Day - Alfred Russel Wallace." *Linda Hall Library*, 8 Jan. 2024. https://www.lindahall.org/about/news/scientist-of-the-day/alfred-russel-wallace-3/.

Askham, Beth. "Moth Predicted to Exist by Darwin and Wallace Becomes a New Species." *Www.nhm.ac.uk*, 30 Sept. 2021, www.nhm.ac.uk/discover/news/2021/september/moth-predicted-to-exist-by-darwin-and-wallace-becomes-a-new-species.html.

Beccaloni, G. W. "Wallace's moth and Darwin's orchid." 2017 June. DOI:10.13140/RG.2.2.35778.38087 Working paper.

"Island Adventurer: Alfred Russel Wallace and the Quest for the Origin of Species." *YouTube*, uploaded by John van Wyhe, 4 May 2016. https://www.youtube.com/watch?v=7hbdhl7lLV4.

Kritsky, Gene. "Darwin's Madagascan Hawk Moth Prediction." *American Entomologist*, vol. 37, no. 4, 1991, pp. 206–210, https://doi.org/10.1093/ae/37.4.206.

McNish, James. "Who Was Alfred Russel Wallace?" *Nhm.ac.uk*, 2018, www.nhm.ac.uk/discover/who-was-alfred-russel-wallace.html.

Miller, W. E. "Diversity and Evolution of Tongue Lengths in Hawkmoths (Sphingidae)." *Journal of the Lepidopterists' Society*, vol. 51, no. 1, 1997, pp. 9–31.

National Geographic. "Alfred Wallace." *Education.nationalgeographic.org*, 2023, education.nationalgeographic.org/resource/alfred-wallace.

Nechamen, Sarah. "The Intertwined Attractions of Plants, Moths, and People." *Arnold*

Arboretum, 13 Nov. 2021, arboretum.harvard.edu/stories/the-intertwined-attractions-of-plants-moths-and-people/#:~:text=%E2%80%9CGood%20Heavens%20what%20insect%20can.

Shersby, Megan. "Wallace's Sphinx Moth: The Long-Tongued Insect Predicted by Darwin Decades before It Was Discovered." *Livescience.com*, 28 Oct. 2023, www.livescience.com/animals/wallaces-sphinx-moth-the-long-tongued-insect-predicted-by-darwin-a-century-before-it-was-discovered.

"The Life of Alfred Russel Wallace." *YouTube*, uploaded by HHMI Biointeractive, 7 April 2014, https://www.youtube.com/watch?v=H8q3my7ujws.

Wasserthal, L. T. "The Pollinators of the Malagasy Star OrchidsAngraecum Sesquipedale, A. SororiumandA. Compactumand the Evolution of Extremely Long Spurs by Pollinator Shift." *Botanica Acta*, vol. 110, no. 5, Oct. 1997, pp. 343–359, https://doi.org/10.1111/j.1438-8677.1997.tb00650.

AUTHOR’S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

- Patterns
- Cause and effect
- Stability and change
- Structure and function
- Energy and matter
- Systems and system models
- Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It’s helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world’s richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists’ fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: CORN, THE UNIVERSE, AND FISH LIZARDS
SOLVING SCIENCE MYSTERIES WITH SCALE, PROPORTION, AND QUANTITY

By Emily Mae Starr

Hold a penny in your hand. Small, isn't it? Now imagine an ant scurrying over your palm.

Suddenly the penny doesn't seem as little. And if you peered through a microscope, a whole tiny world beyond our human eyesight would make that ant seem enormous.

The same happens when you think about the Earth. It is huge. . .until you compare it to the sun.

The sun is gigantic. . .until you think about the size of our solar system!

The same object can seem small or large depending on the measurement scale you use.

Each of the scientists in this book thought about scales of size, distance, and time. Come look at the world through their eyes. See how you can use big ideas about scale to solve science mysteries about corn, the universe, and fish lizards.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

CORN

You wander through a sea of colors in your grocery's produce section and throw a ripening banana in your cart. *Thunk!* You know that eating fruits and vegetables keeps you healthy. *So, how do people stay healthy if they can't buy fruits and vegetables where they live?*

THINK LIKE A SCIENTIST: How might a scientist solve the problem of malnutrition, when people have enough food to eat, but there aren't enough vitamins and minerals in that food to stay healthy?

[Sidebar: Scale Big Idea: Matter at a scale we can't see affect processes at a scale we can see.]

The Mystery of the Malnourishing Maize

Evangelina Villegas held the ear of maize up to the light, examining its rows of dented kernels. *How could this simple yellow vegetable be so helpful and so harmful at the same time*?

Evangelina knew that hundreds of millions of people survived on maize for breakfast, lunch, and dinner. She also knew that this diet made people very sick–especially children.

Maize provided calories to fill a hungry tummy, but it lacked the protein and essential nutrients to keep them healthy. In the 1960s and 70s, children eating a lot of maize were actually dying of starvation! Many people knew about this problem, yet they couldn't figure out how to deliver a variety of healthy foods to hundreds of millions of people. As a chemist, Villegas was determined to solve the problem in a different way.

THINK LIKE A SCIENTIST: How could a chemist use her knowledge to help millions of people receive more nutrition without changing the foods they eat?

[Sidebar: Corn and maize are different names for the same vegetable. In the United States, the word corn is typically used. Maize is the word used by scientists.]

[Sidebar: A chemist is a scientist that studies matter and its properties. In other words, they study what everything around us is made of and how those tiny atoms behave and interact.]

Evangeline wanted to make maize more nutritious. Other scientists had developed a variety that was slightly better, yet it still wasn't protein-packed or stuffed with nutrients. And it created other issues. The corn's softer kernel often rotted in the field or was eaten by insects. Plus, it tasted terrible!

THINK LIKE A SCIENTIST: Make a list of the criteria Evangeline's new maize needed to meet. Why was it important to meet *all* of the criteria?

[Sidebar: A criteria are standards to meet. In this case, the criteria are the characteristics the maize must possess–like a checklist of items describing the perfect ear of maize.]

Evangeline and her colleague Surinder K. Vasal, a cereal scientist, dove into the problem. Hunched over microscopes and pouring over printouts, Evangline analyzed kernel nutrition while Vasal cross-bred plants. Combine a plant with sweet tasting kernels and a plant with more protein. Cross the new breed with a harder kernel variety. One year….two years…five years…ten years!

[Sidebar: A cereal scientist studies grains that are a major source of food for humans and animals including wheat, millet, barley, oats, rye, rice and corn.]

Dedicated to a solution, the pair bred plants and analyzed up to 25,000 samples every year for over a decade. Finally, in the mid-1980s, success! A maize plant they called QPM (Quality Protein Maize) provided the nutrition people needed to stay healthy. It resisted rot and insects. Most importantly, it was delicious! Because of Evangelina and Vasal, millions of people were saved from malnutrition and starvation.

THINK LIKE A SCIENTIST: Why was the scale of the maize problem important to consider when designing a solution?

Your first scale breakthrough! You discovered how tiny food nutrients can be changed to improve the health of millions of people!
[Sidebar: Scale Spotlight: Changes on a small scale, like nutrients, can result in improvements on a large scale–human health.]

As the sun sets on green fields of maize, the moon rises in the cold reaches of space to illuminate your next discovery!

THE UNIVERSE

Flat on the grass, you stare at the seemingly endless pinpoints of light in the charcoal-colored sky. Tonight's blackout stopped the light pollution that always limits your stargazing. Like an old friend, the big dipper's seven stars shine. As you scan that section of space, you notice an oval-shaped smudge of light–as if someone had unsuccessfully tried to erase a star only to widen its borders and dull its color. You wonder, is that a different kind of star, a comet, or something else?

THINK LIKE A SCIENTIST: What tools could you use in today's world to figure out what the smudge of light is? How are those tools different from what scientists used 100 years ago?

[Sidebar: Scale Big Idea: Objects can seem large, until you compare them to something larger.]

The Mystery of the Blinking Star

Edwin Hubble peered through the eyepiece, his fingers numb from hours observing distant stars in freezing temperatures at the Mount Wilson Observatory in California. Unaware of his frosty breath and aching lungs, Edwin was deep in thought, unraveling a mystery. Tonight, as he peered through the most powerful telescope in the world, Edwin saw a blinking star–one he had never seen before. From deep inside the Andromeda nebula, a cloud of gas and dust, a pulsating star dimmed and brightened in a predictable pattern, as if sending a coded message just for him.

THINK LIKE A SCIENTIST: What questions would you have about a never seen before star?

As an astronomer, Edwin knew that every speck of light we could see existed within our own Milky Way galaxy. The discovery of a new star in our neighborhood of space was exciting–especially a pulsating star! Pulsating stars were like nature's yardstick. Their data could be used to calculate great distances in the vastness of space that otherwise could not be measured. *How far away was this new star?*

[Sidebar: An astronomer is a scientist who studies objects in outer space.]

Edwin observed his new discovery night after frigid night as tears froze his eyelashes to the telescope lens. *How bright was the star? How long did it take to dim and become bright again?* He recorded and calculated, double checked and triple checked. On December 30, 1924, cold and exhausted, Edwin completed his final computation, revealing an extraordinary discovery.
[Illustration Note: On this page, is a graphic titled Edwin's Calculations that shows the distance to the edge of our galaxy and the distance to the pulsating star in the Andromeda Nebula. This way children can see that the nebula is farther than the known distance to the edge of our galaxy.]

THINK LIKE A SCIENTIST: How did Hubble's calculations change our understanding of the scale of the universe?

The pulsating star was 800,000 light years away–eight times farther than the known edge of the Milky Way galaxy. This meant that Andromeda wasn't a nebula at all–it was another galaxy! Edwin Hubble had discovered a new star and identified a new galaxy!

Because of Edwin's discovery, scientists have gone on to identify billions of galaxies outside our own. Today, the scale of the observable universe stretches far beyond the reaches of our human understanding.

THINK LIKE A SCIENTIST: How could you help someone understand the scale of something as large as our universe?

Mystery solved. Using ideas about scale, you discovered that the universe beyond our galaxy is unbelievably gigantic.

[Sidebar: Scale Spotlight: Our galaxy seems large, until you compare it to the size of our universe.]

Time to tilt your gaze downward and dig in the dirt. Your next discovery awaits!

FISH LIZARDS

You flop to the ground and lean your back against a sturdy oak. *Whew!* As your muscles take a break from your morning hike, your gaze wanders to your right and falls on a pile of white leaves. Wait, no. Those aren't leaf shaped. And they look smooth and hard. What are those? You jump up and investigate. Woah! A pile of bones! *What animal was this?*

THINK LIKE A SCIENTIST: What could you learn about an animal by examining its bones?
[Sidebar: Scale Big Idea: The same event can seem different when compared on multiple timescales.]

The Mystery of the Missing Creatures

Twelve-year-old Mary Anning rushed home, her long dress soaked with sea spray and caked with mud. She had uncovered her largest curiosity yet–the fossilized skeleton of a creature nearly as big as a blue whale! In her mind, she pictured the menacing long snout and glaring eye socket she and her brother discovered months earlier poking from the crumbling cliffside. These ribs, tail, and flippers–flippers!–must belong to the same creature. It was a first-of-its kind find!

In 1811, in Mary's town of Lyme Regis, England, or anywhere for that matter, people believed that all of the plants and animals that had ever existed on Earth were still patrolling the planet. Yet, no one had spotted a creature like this gliding through the ocean.

THINK LIKE A SCIENTIST: Why do you think no one had seen a creature like Mary's fossil? What would it mean if the creature was no longer on Earth?

Returning with a group of workers, Mary dug and chiseled, carefully separating the hardened history from its resting place. Back home, Mary assembled the full skeleton, which was promptly purchased by a collector. The man donated it to a museum where scientists named the creature, *Ichthyosaur* (fish lizard), because of its lizard-like snout and fish-like habitat. People from around the world could now gaze on Mary's fossil with wonder: *Why hasn't anyone seen this creature in the ocean? Could animals become extinct? How old is the Earth?*

THINK LIKE A SCIENTIST: How do you think Mary's discovery changed the way scientists in 1811 thought about the stability of organisms on Earth?

For the rest of her life, Mary scoured the unstable cliffs near her home in a quest for curiosities. Because of her pioneering paleontology, our understanding of Earth's age and the stability of creatures living on it were forever changed.

[Sidebar: A paleontologist is a scientist who studies fossils.]

THINK LIKE A SCIENTIST: What can fossils help us understand about the time scale of life on Earth?

Another scale discovery! You uncovered how the fossil of an unusual animal led to understanding that Earth is much older than previously thought–so old that some animals had gone extinct.

[Sidebar: Scale Spotlight: The timescale of Earth is so long that some animals lived for millions of years before going extinct.]

Congratulations, junior scientist! You made sense of our wondrous world using ideas about scale. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Evangelina Villegas

Traditional maize lacks essential amino acids our bodies need to stay healthy, specifically lysine and tryptophan. Lysine helps our bodies absorb calcium and form the collagen needed in bones, skin, tendons, and cartilage. Tryptophan helps our bodies make melatonin which regulates sleep. It also helps make serotonin which regulates appetite, sleep, mood, and pain.

People usually get these essential nutrients from other foods, yet in some countries those other foods aren't available. This means millions of people, whose primary source of food was corn, were starving, even though their bellies were full. Although other scientists had worked on the maize malnutrition problem, the corn they developed had soft kernels that often rotted or were destroyed easily by insects. Plus, it tasted terrible, so people wouldn't grow it.

Evanglina Villegas's high-quality protein maize (QPM) contained twice as much lysine and tryptophan as traditional maize, and it tasted as good. Research shows that the weight and height of children who eat QPM increases 15% more than children who eat traditional maize. Evanglina's work didn't stop once the corn was produced. She continued to work tirelessly for decades to promote cultivation of the crop around the world.

In the year 2000, Evanglina was named Mexico's Woman of the Year and became the first woman to win the World Food Prize, an award dedicated to celebrating scientists whose work improves access to nutritious food around the globe. In her acceptance speech, she said, "What I would like to do with this prize is make the world more aware of what we have developed. Because for me, the greatest honor, as a Mexican, would be to see the fields of Mexico overflowing with QPM maize."

Learn more: 2000 Vasal and Villegas World Food Prize (World Food Prize)
https://www.worldfoodprize.org/en/laureates/20002009_laureates/2000_vasal__villegas/

Edwin Hubble

As a young boy, Edwin Hubble was captivated by the stars. When he received a hand-built telescope from his grandfather for his eighth birthday, his career as an astronomer began. Edwin's research paved the way for the discovery of billions of galaxies outside our own. Using modern technology, we now know that the Andromeda galaxy is actually 2.5 million light years away.

In other groundbreaking work, Edwin used data from distant stars to further enlarge our understanding of the vastness of the universe. He proved that our universe is growing larger, expanding outward from every point in space, and the farther away a galaxy is from Earth, the faster it is moving. This is known as Hubble's Law. This concept completely upended the current view at the time that the universe was static and unmoving, and caused Albert Einstein, one of the greatest scientific thinkers of all time, to declare that his belief in an unmoving universe was his "biggest blunder." The Hubble Sequence, a galaxy classification system developed by Edwin, is still used today, and Edwin's most well-known namesake, the Hubble Space Telescope, launched in 1990, continues to increase our knowledge of the ever more distant universe.

Learn more: *The Boy Whose Head Was Filled With Stars: A Life of Edwin Hubble* by Isabelle Marinov (Enchanted Lion Books, 2021)

Mary Anning

Mary Anning was born in 1799 in Lyme Regis, an area now called the Jurassic Coast and recognized as an UNESCO World Heritage Site, where fossil discoveries are still being made. She began hunting for fossils with her father at the age of five and made her first major discovery–the first ichthyosaurus–at the age of 12 with her brother Joseph. At first, people thought it was a crocodile, and like other unrecognized fossils had simply migrated to far-off lands. Yet her subsequent fascinating finds, including a pterosaur and the first plesiosaur, provided mounting evidence for the theory of extinction and an Earth much older than currently understood.

Though prominent scientists of that day consulted with Mary because of her vast fossil knowledge, she was rarely credited for her finds–primarily because of her gender. Until recently, she was all but forgotten in the history of paleontology despite helping to establish it as a field of scientific study.

Learn more: *Dinosaur Lady: The Daring Discoveries of Mary Anning, the First Paleontologist* by Linda Skeers (Sourcebooks Explore, 2020)

Questioning Guide for Grown-ups

The *Think Like a Scientist* questions do not have answers that are correct or incorrect. The questions are intentionally open-ended to encourage a variety of responses and lively discussions about important scientific concepts. The answers below are examples of the many ideas children may share.

How might a scientist solve the problem of malnutrition, when people have enough food to eat, but there aren't enough vitamins and minerals in that food to stay healthy?

This question gets children thinking about how science can be used to solve real world problems. At this point, most children will not have the background knowledge to suggest genetic modifications to food, so their ideas will be wide-ranging. If needed, you can prompt with additional questions: *How could scientists work with the human body, food, or food delivery methods to solve the problem?*

How could a chemist use her knowledge to help millions of people receive more nutrition without changing the foods they eat?

This question is narrower than the previous question, so it gets children thinking specifically about the relationship between chemistry and food nutrition. At this point, they may not have the background knowledge to suggest something as specific as gene editing or cross-breeding; however, they may be able to voice a solution that approximates those ideas by suggesting that the chemist could change something about the maize plant to make it more nutritious. If needed, you can prompt with additional questions: *What does a chemist do? How could a chemist work with food? How could a chemist change food to be more nutritious?*

Make a list of the criteria Evangelina's new maize needed to meet. Why was it important to meet all of the criteria?

This question gives children the opportunity to consider the role of criteria when developing a new product. Children should be able to use information in the text to list these criteria: tastes good, resists rot, resists insects, firm kernel, and increased nutrition. They may share that she needed to meet all of the criteria because not doing so would result in people not planting the maize. If needed, you can prompt with additional questions: *What problems with current maize varieties did Evangeline need to solve? Where in the text could you find those problems? What would happen if she didn't solve one or more of those problems?*

Why was the scale of the maize problem important to consider when designing a solution?

This question gives children the opportunity to consider why scale matters. Children may share that it is more difficult to feed millions of people than it is to feed hundreds of people. They may realize that scale needed to be considered when designing a solution because the solution needed to be able to meet the needs of millions of people. It couldn't work for just a few, or the problem would still exist. If needed, you can prompt with additional questions: *How is solving a problem for millions of people different from solving a problem for a few people? What would scientists need to do differently to solve a problem for millions of people instead of just a few?*

What tools could you use in today's world to figure out what the smudge of light is? How are those tools different from what scientists used 100 years ago?

This question prompts children to think about the relationship between technology advancements and scientific discoveries. They may share that more powerful telescopes mean we can make a more thorough investigation of space. Children may have background knowledge about new technologies and the discoveries they have enabled, or you could support them in conducting research to learn about the most recent technological achievements in space exploration. If needed, you can prompt with additional questions: *What tools do scientists use to look more closely at faraway objects? How have those tools changed over time? Where could you find information about the latest space exploration technologies?*

What questions would you have about a never seen before star?

This question gets children wondering about something in nature and encourages them to develop questions that could later be investigated. Children will share a wide variety of questions including but not limited to: What is the star made of? How big is the star? Why is the star blinking? Why didn't anyone notice the star before? How far away is the star? If needed, you can prompt with additional questions: *What characteristics of the star would you want to know more about? What do you think Edwin is wondering about the new star?*

How did Edwin's calculations change our understanding of the scale of the universe?

This question prompts children to draw conclusions using evidence presented in the text. The text says: "As an astronomer, Edwin knew that every speck of light we could see existed within our own Milky Way galaxy." and "The pulsating star was 800,000 light years away–eight times farther than the known edge of the Milky Way galaxy. This meant that Andromeda wasn't a nebula at all–it was another galaxy!" Children can use this information to conclude that the universe is much larger than we previously thought, and it contains galaxies in addition to our own. If needed, you can prompt with additional questions: *What does the text say people thought about the size of the universe before*

Edwin's discovery? What was Edwin's discovery? How does Edwin's discovery change previous ideas about the size of the universe?

How could you help someone understand the scale of something as large as our universe?

This question prompts children to consider how to explain or demonstrate a concept to others. Children may think of using analogies or scale models and could be supported in conducting research to construct their own accurate explanations. If needed, you can prompt with additional questions: *What could you create to show something that is too large for us to see? How could you describe something that is too large for us to see in a way that someone could understand?*

What could you learn about an animal by examining its bones?

This question prompts children to consider what information they can learn by examining evidence–in this case bones. Some children may think of basic information like the type of animal. Others may think about how the structure of the bones enabled specific functions. For example, sharp teeth are probably evidence that the animal ate meat. If needed, you can prompt with additional questions: *What can scientists learn about the animal by looking at how the bones fit together? What can scientists learn about the animal from the shape of the bones?*

Why do you think no one had seen a creature like Mary's fossil? What would it mean if the creature was no longer on Earth?

This question prompts children to draw conclusions using evidence presented in the text. The text says: "In 1811, in Mary's town of Lyme Regis, England, or anywhere for that matter, people believed that all of the plants and animals that had ever existed on Earth were still patrolling the planet. Yet, no one had ever seen a creature like this gliding through the ocean." Children may be able to make the connection that people realized that animals could go extinct because Mary had discovered the fossil of an animal that no longer existed. If needed, you can prompt with additional questions: *What could be some reasons no one had seen Mary's creature? Are there creatures we know about today that no one has ever seen? How do we know about them? What do scientists call creatures that are no longer living on Earth?*

How do you think Mary's discovery changed the way scientists in 1811 thought about the stability of organisms on Earth?

This question prompts children to consider how science changes based on new discoveries. Children may share that scientists realized that creatures could go extinct. They might go further and suggest that scientists might wonder what caused creatures to go extinct and how many creatures had gone extinct. If needed, you can prompt with additional questions: *According to the text, what did scientists believe about all of the organisms on Earth? How would the fossil of a creature they had never seen change that belief? What questions might scientists ask about extinction?*

What can fossils help us understand about the time scale of life on Earth?

This question prompts children to consider why the work of paleontology is important. Children may connect to the previous question and answer that fossils help us understand that Earth is older than we first thought. Some children may realize that fossils help us calculate Earth's age. If they have background knowledge about fossils, children might add that layers of rock in the ground contain fossils from different time periods in Earth's history. These layers help us construct a more accurate timeline from the formation of Earth to the present day. If needed, you can prompt with additional questions: *If scientists can figure out the age of fossils, how can that help us understand the age of our planet? How might finding different fossils in different rock layers help us figure out the age of our planet?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Evangelina Vallegas

"2000 Laureates: Evangelina Villegas and Surinder K. Vasal." *YouTube*, uploaded by World Food Prize Foundation, 29 April 2010, https://www.youtube.com/watch?v=Wnlac6qnSbs&t=3s.

"2000: Vasal & Villegas - the World Food Prize - Improving the Quality, Quantity and Availability of Food in the World." *Www.worldfoodprize.org*, www.worldfoodprize.org/en/laureates/20002009_laureates/2000_vasal__villegas/.

Bosques-Martínez, Marlia. "Women Who Revolutionized Agriculture and the World: Part 2." *Women in Ag Science*, 4 July 2020, www.womeninagscience.org/post/women-who-revolutionized-ag-2.

Cohen, John. "A Mexican-Bred Super Maize." *Science*, vol. 267, no. 5199, 10 Feb. 1995, pp. 825–825, https://doi.org/10.1126/science.267.5199.825.

Kenneth M. Quinn. "The World Food Prize Foundation Pays Tribute to 2000 Laureate Dr. Evangelina Villegas." *Worldfoodprize.org*, 26 Apr. 2017, www.worldfoodprize.org/index.cfm/87428/43030/the_world_food_prize_foundation_pays_tribute_to_2000_laureate_dr_evangelina_villegas.

Listman, Mike. "CIMMYT Renames Lab to Honor Evangelina Villegas, World Food Prize Laureate." *CIMMYT*, 7 June 2017, www.cimmyt.org/news/cimmyt-renames-lab-to-honor-evangelina-villegas-world-food-prize-laureate/.

Lynch, Christine. "Latinx Scientists You Should Have Learned about in School." *Vernier*, 9 Sept. 2021, www.vernier.com/blog/two-latinx-scientists-you-should-have-learned-about-in-school.

Ortega, Enrique I, et al. "Changes in Dry Matter and Protein Fractions During Kernel Development of Quality Protein Maize." *Cereal Chemistry*, vol. 68, no. 5, 1991, pp. 482-486. Available: https://www.cerealsgrains.org/publications/cc/backissues/1991/Documents/68_482.pdf

"SUPER WOMAN: Evangelina Villegas Developed Transformative Quality-Protein Maize." *CIMMYT*, 29 May 2015, www.cimmyt.org/news/super-woman-evangelina-villegas-developed-transformative-quality-protein-maize/.

"Zea mays L.: An Introduction to the History and Culture of Corn and Maize." *YouTube*, uploaded by National Agricultural Library, 31 August 2022, https://www.youtube.com/watch?v=bjtDM1n_Cq0&t=451s.

Vasal, S. K. "The Quality Protein Maize Story." *Food and Nutrition Bulletin*, vol. 21, no. 4, Jan. 2000, pp. 445–450, https://doi.org/10.1177/156482650002100420.

Edwin Hubble

Christianson, G E. *EDWIN HUBBLE : Mariner of the Nebulae*. University of Chicago Press, 1996.

"Edwin Hubble - A Short Biography." *YouTube*, uploaded by Deep Space TV, 30 June 2017, https://www.youtube.com/watch?v=6j-q4VN_7Hk.

European Space Agency. "Edwin Hubble: The Man Who Discovered the Cosmos." *Esa.int*, 2012, www.esa.int/About_Us/ESA_history/Edwin_Hubble_The_man_who_discovered_the_Cosmos.

King, Gilbert. "How Edwin Hubble Became the 20th Century's Greatest Astronomer." *Smithsonian*, Smithsonian.com, 20 May 2013, www.smithsonianmag.com/history/how-edwin-hubble-became-the-20th-centurys-greatest-astronomer-66148381/.

Mayall, N.U. "Edwin Powell Hubble 1889-1953: A Biographical Memoir." National Academy of Sciences, 1970. Available: https://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/hubble-edwin.pdf

Moore, Patrick. "Edwin Hubble, the Astronomer Who Discovered There Are Galaxies beyond the Milky Way." *Www.skyatnightmagazine.com*, 29 Mar. 2023, www.skyatnightmagazine.com/space-science/edwin-hubble.

NASA. "Biography of Edwin Powell Hubble (1889 - 1953)." *Nasa.gov*, 2012, asd.gsfc.nasa.gov/archive/hubble/overview/hubble_bio.html.

---. "Edwin Hubble - NASA Science." *Science.nasa.gov*, 2023, science.nasa.gov/people/edwin-hubble/.

PBS. "A Science Odyssey: People and Discoveries: Hubble Finds Proof That the Universe Is Expanding." *Pbs.org*, 2019, www.pbs.org/wgbh/aso/databank/entries/dp29hu.html.

Mary Anning

Buckland, W. "On the discovery of a new species of Pterodactyl in the Lias of Lyme Regis."

Transactions of the Geological Society of London, vol. s2-3, no. 1, Jan. 1829, pp. 217-222. Available at: https://www.lyellcollection.org/doi/abs/10.1144/transgslb.3.1.217

Currie, Adrian. "Mary Anning: How a Poor, Victorian Woman Became One of the World's Greatest Paleontologists." *The Conversation*, 2 Nov. 2018, theconversation.com/mary-anning-how-a-poor-victorian-woman-became-one-of-the-worlds-greatest-palaeontologists-105183.

Davis, Larry E. "Mary Anning of Lyme Regis: 19th Century Pioneer in British Paleontology." *Headwaters*, vol. 26, pp. 96-126. Available: https://digitalcommons.csbsju.edu/headwaters/vol26/iss1/14

Emling, Shelley. "Mary Anning: Fossil Hunter | National Center for Science Education." *Ncse.ngo*, June 2010, ncse.ngo/mary-anning-fossil-hunter.

---. *The Fossil Hunter*. St. Martin's Press, 13 Oct. 2009.

Eylott, Marie-Claire. "Mary Anning: The Unsung Hero of Fossil Discovery." *Nhm.ac.uk*, 2018, www.nhm.ac.uk/discover/mary-anning-unsung-hero.html.

Home, E. "Some Account of the Fossil Remains of an Animal Move Nearly Allied to Fishes than Any of the Other Classes of Animals." *Philosophical Transactions of the Royal Society of London*, vol. 104, 31 Dec. 1814, pp. 571–577. Available: https://wellcomecollection.org/works/aahagru2

"Mary Anning." *Museum of the Earth*, www.museumoftheearth.org/daring-to-dig/bio/anning.

Newman, Cathy. "The Forgotten Fossil Hunter Who Transformed Britain's Jurassic Coast." *History*, 29 Mar. 2021, www.nationalgeographic.com/history/article/mary-anning-forgotten-fossil-hunter-british-jurassic-coast.

O'Connor, Madeline. "Women in Science - Mary Anning." *The Oxford Scientist*, 19 Dec. 2018, oxsci.org/women-in-science-mary-anning/.

Torrens, Hugh. "Mary Anning (1799–1847) of Lyme; "the Greatest Fossilist the World Ever Knew." *The British Journal for the History of Science*, vol. 28, no. 3, Sept. 1995, pp. 257–284, https://doi.org/10.1017/s0007087400033161. Accessed 9 June 2023.

Zielinski, Sarah. "Mary Anning, an Amazing Fossil Hunter." *Smithsonian Magazine*, 5 Jan. 2010, www.smithsonianmag.com/science-nature/mary-anning-an-amazing-fossil-hunter-60691902.

AUTHOR’S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

• Patterns • Cause and effect • Stability and change

• Structure and function • Energy and matter • Systems and system models

• Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It’s helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world’s richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists’ fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: INSECTS, POISON, AND PLANETS
SOLVING SCIENCE MYSTERIES WITH SYSTEMS AND SYSTEM MODELS

By Emily Mae Starr

A forest. A bicycle. The Milky Way. An ant.

What do these very different things have in common?

They are all systems!

A system is a group of parts that make up a whole.

Plants, animals, soil, rocks, water, and air are parts of a forest ecosystem. Change one of those parts–remove the water–and the whole system changes.

That's because parts in a system work together. Gears, pedals, handlebars, and wheels work together to make a bicycle move.

Each of the scientists in this book observed what happens when one part of a system changes.
Come look at the world through their eyes. See how you can use big ideas about systems to solve science mysteries about insects, poison, and planets.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

INSECTS

You lie sprawled on the grass, bathed in the summer sun's warmth. Relaxed, eyelids drooping, you start to doze when. . . a tiny tap, tap, tap tickles your palm. What's that?! You jerk your hand and snap upright. A small white butterfly floats away. You've never seen a butterfly like that. *Where did it come from?*

THINK LIKE A SCIENTIST: How could you study butterflies around your home?
[Sidebar: Systems and System Models Big Idea: A system is a group of parts that make up a whole.]

The Mystery of the Insect Magic Trick – Now You See Me, Now You Don't

Maria Merian ducked behind a hedge and dashed into her home, carefully cradling this morning's find in her palm. Safe at home, she dropped the wiggly white worm into a glass jar. *Whew!* Now Maria could stop worrying about getting caught.

People in 1660 thought insects were evil creatures, emerging randomly out of mud or rotting meat. If neighbors knew she collected silk worms, they might think she was a witch. At thirteen, Maria was curious about the bugs, butterflies, and worms crawling and flitting around her backyard. *What do they* *eat? Where do they go when they disappear? And why do butterflies and moths arrive in her yard so suddenly?*

THINK LIKE A SCIENTIST: How could you record what you observe about insects around your home?

In secret, Maria observed her insect collection–snug in their glass jar homes. Her tiny treasures ate and grew, ate and grew until one day, the silk worms formed paper white cocoons. Always curious, she squeezed the peach-pit hard casings, holding them up to the light, examining every threaded detail. Watching. Waiting. Drawing. Painting. *What was happening to the worm inside?*

THINK LIKE A SCIENTIST: Why do Maria's paintings record more than just the insect?

Two weeks later…a cocoon moved! It wobbled and wiggled, rocked and rolled until finally…the cocoon cracked. Two feather-like antennae forced their way into the world attached to… a fuzzy white moth! Silk worms turned into moths! Maria Marian was the first person to illustrate the process of insect metamorphosis, when a creature changes from one form to another.

THINK LIKE A SCIENTIST: How could you share your findings with the world in 1660? What evidence could you present to support your claims?

Your first systems breakthrough! You uncovered the missing part of a silk worm's life cycle: metamorphosis.

[Sidebar: Systems and System Models Spotlight: Metamorphosis is one part of a moth's life cycle (a system.) Systems can be modeled through art.]

From the life of an insect to a hidden cause of death, your next discovery awaits!

POISON

A warm breeze ruffles your hair as your shoes crunch on the gravel trail. You've traveled this route many times before, yet this time is different. It's too quiet. No birds calling. No insects whirring. You spot a dead squirrel. Further ahead, a crow lies lifeless. *What happened here?* You reach the end of the path, arriving at your favorite pond. A terrible stench creeps into your nostrils. You glance right and spot the source–hundreds of dead, decaying fish clog the gaps between cattails and lily pads along the shore. *What could have caused these deaths?*

THINK LIKE A SCIENTIST: Why is a large number of dead creatures a cause for concern for an entire ecosystem?

[Sidebar: Systems and System Models Big Idea: Change one part of a system, and you affect the entire system.]

The Mystery of the Killer Chemicals

Clack! A dark dot–the final period–inked the end of Rachel Carson's book. Rachel sat back and sighed. For four years, she poured her knowledge and expertise into the pages of *Silent Spring*. Now it was time for the book to speak to the world.

Rachel Carson was a marine biologist, conservationist, and writer. In her job at the U.S. Bureau of Fisheries, she read scientific reports. Lots of reports. In the 1950s, over several years of report reading, Rachel saw a pattern emerge. A worrisome pattern. A deadly pattern.

[Sidebar: A marine biologist is a scientist who studies organisms in the sea. A conservationist is a scientist who advocates for the protection of the environment.]

THINK LIKE A SCIENTIST: What do these report titles have in common? Why do you think Rachel was concerned?

[Illustration Note: On screen are stacks of papers with titles showing that fish, birds and cattle are dying in areas linked to DDT spraying. These titles can be modified versions of the journal articles cited in Silent Spring.]

Report after report of dead birds, dead fish, dead cattle, and sick children worried Rachel. She suspected the widespread use of chemicals, such as DDT, was to blame. These human-made, insect-killing substances were sprayed seemingly everywhere. Chemicals misted from crop dusters floated over fields and wafted through windows into home kitchens. Yet were they safe?

Rachel knew she needed evidence. Lots of it. So instead of designing a single investigation to test DDT's potentially harmful effects, Rachel gathered the results of hundreds of researchers.
Her discovery? DDT was deadly–and not just to insects. It seeped into groundwater. It built up in the fat of animals. It passed through the food chain from one creature to another and ended up. . .in humans. Test after test in place after place–even places far from chemical spraying–recorded DDT. It was everywhere–including in milk fed to newborn babies.

THINK LIKE A SCIENTIST: Why is it important for scientists to share their discoveries? How do you think people reacted to Rachel's book sharing her discoveries?

Rachel's book, *Silent Spring*, showed how chemicals hurt organisms in every part of an ecosystem. Humans, too. They built up over time and caused diseases like cancer. And once chemicals entered an ecosystem, they couldn't be easily removed. DDT lasted decades.
People at powerful chemical companies argued that Rachel was causing alarm for no reason. They valued profits over people. Yet, Rachel had started an environmental movement too loud to be silenced. Her evidence even convinced the President of the United States, John F. Kennedy.
She spoke to Congress and worked tirelessly–even though she was very sick with cancer. The result? The United States government created the Environmental Protection Agency to protect "human health and the environment." And in 1972, after years of court battles, DDT was banned in the United States. Rachel Carson woke the world to Earth's closely connected ecosystem.

THINK LIKE A SCIENTIST: Why was it important for Rachel to gather data to support her claims? What information do you think committees should gather to help them make decisions about the safety of chemicals used today?

Mystery solved! Using systems thinking, you uncovered how spraying DDT caused harm to all life from insects to humans.

[Sidebar: Systems and System Models Spotlight: Adding chemicals to one part of an ecosystem affects the entire system.]

From Earth's ecosystems to space's solar systems, cast your eyes to the sky for your next science mystery!

PLANETS

Lying on a blanket, you gaze at the night sky. Pinpoints of light litter the velvety black background like a giant dot-to-dot puzzle. Some dots burn bright. Others twinkle. But all look nearly identical. *How do scientists know which are stars and which are planets when they are so impossibly far away?*

THINK LIKE A SCIENTIST: How could you study stars and planets if you are not able to visit them? How was studying objects in the night sky different in the past than it is today?
[Sidebar: Systems and System Models Big Idea: Systems can be modeled and those models used to predict future events.]

The Mystery of the Moving Sun

Galileo Galilei steadied the telescope–a device he built–and gazed through its eyepiece. Stars, planets, comets and moons begged for his attention. Yet tonight, like so many nights before, Galileo set his sights on Venus. He sketched the second planet from the sun, carefully recording size and shape, light and dark. There, in his detailed drawings, Venus revealed a cosmic secret. A world-changing secret. A dangerous secret.

THINK LIKE A SCIENTIST: What do you notice about Galileo's observations of Venus?

[Illustration Note: A drawing showing the progression of Venus's phases is shown. A date is noted beneath each drawing to indicate the passage of time.]

Most people in the early 1600s thought Earth was the center of our solar system–especially religious leaders. They believed since humans are children of God, and God created the universe, Earth must be at the center of his creation. Galileo's evidence proved them wrong.

THINK LIKE A SCIENTIST: Compare both solar system models. How does Galileo's evidence support the claim that the sun, not Earth, is the center of our solar system?

[Sidebar: A model shrinks things in real life down to a smaller scale. These models show our solar system shrunk to the size of this page.]

[Illustration Note: Two models are shown side by side. One shows Earth in the center with Venus and the sun revolving around it. The other shows the sun with Earth and Venus revolving around it. Phases are shown.]

Galileo observed Venus's phases–part of the planet's surface hidden in curved shadow, similar to the moon. His model showed that our neighbor's phases could only be observed from Earth if both planets revolved around the sun.

When Galileo wrote about his findings, church leaders worried that people would believe this respected astronomer, physicist, and engineer. They couldn't allow people to question the church's authority or doubt church teachings. So the Roman Catholic Church convicted Galileo of heresy–going against the church. They ordered him to remain at home for the rest of his life.

Yet ideas–especially those supported by science–are not so easily hidden. Soon, it was widely known and accepted that the sun, not Earth, is the center of our solar system.

THINK LIKE A SCIENTIST: Why are models an important and necessary tool for studying the solar system?

Another systems discovery! You discovered how a model of Venus revealed the sun at the center of our solar system.

[Sidebar: Systems and System Models Spotlight: Solar system models help us understand and predict the movements of planets.]

Congratulations, junior scientist! You made sense of our wondrous world using systems thinking. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Maria Merian

Though other scientists had documented the life cycle of moths and butterflies before Maria, most people at the time still believed insects spontaneously generated out of mud. Maria was the first to record insect life cycles beginning with eggs and discovered that some caterpillars rely on a single plant as their food source. The combination of Maria's unique position as a trained artist (taught by her step-father and his apprentices), her natural curiosity, and her keen observation, led her to record not only an organism's appearance, but what it ate, how it moved, and even how it interacted with its ecosystem.

During a two-year trip to Dutch Suriname, at a time when travel abroad was rare, let alone travel by a single woman, Maria documented many previously unknown plants and animals including leaf cutter ants and army ants. Her journey is believed to be the first extended travel by a woman for scientific purposes. Maria's paintings were featured in several self-published books and still today are sought after works of art.

Learn more: *Summer Birds: The Butterflies of Maria Merian* by Margarita Engle (Henry Holt and Co., 2010)

The Girl Who Drew Butterflies: How Maria Merian's Art Changed Science by Joyce Sidman (Clarion Books, 2018)

The Bug Girl: Maria Merian's Scientific Vision by Sarah Glenn Marsh (Albert Whitman & Company, 2019)

Rachel Carson

Rachel began her writing journey at age eight, resulting in her first published story at age ten in *St. Nicholas* magazine. Before *Silent Spring*, Rachel was known for her trilogy of books featuring the most thorough exploration of ocean ecosystems of its time. Rachel spoke out for the environment, telling all who would listen that humans could not control nature–we are simply one of its parts. Our survival depends on the health of Earth's entire system.

Rachel's research and advocacy led to the creation of the U.S. Environmental Protection Agency, whose mission is to "protect human health and the environment." Recognition of her work includes the U.S. National Book Award, induction into the National Women's Hall of Fame, and the Presidential Medal of Freedom, the highest civilian honor in the United States. A postage stamp and a statue in Massachusetts bear her likeness while numerous awards, buildings, schools, and even a bridge bear her name.

Learn more: *Spring After Spring: How Rachel Carson Inspired the Environmental Movement* by Stephanie Roth Sisson (Roaring Brook Press, 2018)

Rachel Carson and Her Book That Changed the World by Laurie Lawlor (Holiday House, 2014)

Galileo Galilei

Galileo is often called the father of physics and the father of astronomy for his significant contributions to science and mathematics. Galileo was seemingly equal parts inventor and scientist. His improvements on the telescope allowed him to build a device through which he could peer into space farther than anyone before. He is credited with discovering sun spots, was the first to see craters on the Moon, the first to view the rings of Saturn, and the first to realize Jupiter had four large moons–today called the Galilean moons in his honor.

On Earth, he devised investigations that led to new discoveries in motion and materials including why objects float or sink and what law governs acceleration. Although he observed Venus's phases in 1610, it wasn't until 1633, after Galileo published a book supporting the theory that Earth revolves around the sun, that the Roman Catholic Church convicted him of heresy and sentenced him to house arrest. In his seventies and in ill health, Galileo continued to experiment and publish his findings until his death in 1642. His legacy is not only in his discoveries but the methods he developed and mathematics he used to prove them.

Learn more: Starry Messenger: *Galileo Galilei* by Peter Sis (Square Fish, 2000)

Questioning Guide (For Grown-Ups)

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

How could you study butterflies around your home?

This question introduces children to the challenge of observing living organisms and asks them to wonder about a solution. Children may think of following the insect around or collecting it in a jar. They may also consider collecting eggs or caterpillars and observing them. If needed, you can prompt with additional questions: *How could you observe the butterfly for a long period of time? What would you need to keep it alive? What could you collect and observe in addition to the butterfly?*

How could you record what you observe about insects around your home?

This question introduces children to the idea of documenting observations. Children may suggest recording their observations with photographs and videos. Some may share non-electronic methods such as writing, drawing, and painting. If needed, you can prompt with additional questions: *How could you share your findings with someone not in your home? How could you share details about your observations? How could others see what you are seeing? How would you organize your findings?*

Why do Maria's paintings record more than just the insect?

This question gives children the opportunity to consider why recording more than one part of a system is valuable. Children may share that Maria's paintings also show plants each insect eats, which could help someone keep insects alive in captivity. They may also realize that her art shows how the insect is part of a larger ecosystem. In addition, children may notice that Maria documents all stages in an insect's life, not just the adult form, so people can learn about lifecycles from her work. If needed, you can prompt with additional questions: *What could someone learn from Maria's paintings? What system does Maria document? What parts of the system does she include? Why?*

How could you share your findings with the world in 1660? What evidence could you present to support your claims?

This question asks children to consider why producing evidence to support claims is important and why it was challenging to share observations in a world before electronics. Children may think of creating writings, drawings, and paintings to support their claims and publishing their work in a book. If needed, you can prompt with additional questions: *What materials could Maria use in 1660 to record her observations? In 1660, how did people learn about new ideas?*

Why is a large number of dead creatures a cause for concern for an entire ecosystem?

This question helps children realize that changing one part of a system affects the entire system. Children may worry that some animals will become extinct or that other animals might not have food to eat. If children have background knowledge of food webs, they may share that fewer predators means prey populations may grow too large, and those prey may decimate their food sources. Children may even realize that if the animals died of poisoning, eating poisoned animals may poison other creatures as well. If needed, you can prompt with additional questions: *If the animals died of poisoning, what will happen to animals that eat the poisoned creatures? How will a change in the number of prey affect the predators that eat the prey? How will a change in the numbers of prey affect the prey's food sources?*

What do these report titles have in common? Why do you think Rachel was concerned?

This question asks children to synthesize information from multiple sources to make an inference about Rachel's thoughts. Children may notice that the titles all talk about sickness or death in animal and human populations. They may think Rachel was concerned because people and wildlife were harmed. Children with background knowledge may realize that poisoning in one part of an ecosystem will impact the entire ecosystem. They may also examine the dates and infer that these events are happening frequently. If needed, you can prompt with additional questions: *What is happening in every report? How often is it happening? How could these events affect humans?*

Why is it important for scientists to share their discoveries? How do you think people reacted to Rachel's book sharing her discoveries?

This question asks children to consider why scientists publish their findings. Children may realize that sharing information helps people learn they need to make changes and that people can make good choices when they know proven facts. Children most likely will think people were happy to learn about Rachel's discoveries so they could make changes to keep ecosystems healthy. *How could reading about a scientific discovery help someone? How might they behave differently? Who might the information about DDT help? How might they respond? Why? Who might the information hurt? How might they respond? Why?*

Why was it important for Rachel to gather data to support her claims? What information do you think committees should gather to help them make decisions about the safety of chemicals still used today?

This question gives children the opportunity to consider why supporting claims with evidence is important. It also allows them to apply their knowledge to current events. Children may share that Rachel needed to provide evidence for people to believe her. In addition, she needed evidence to show why the issue was important–the chemicals were directly impacting humans. Children may think committees should gather information about a chemical's ingredients, testing, how it affects the environment, and how it affects humans. If needed, you can prompt with additional questions: *How would people have responded if Rachel didn't provide evidence? How do chemicals impact ecosystems, and how could you show those impacts to committees?*

How could you study stars and planets if you are not able to visit them? How was studying objects in the night sky different in the past than it is today?

This question introduces children to the problem of finding out about places we cannot visit and asks them to wonder about a solution. It also encourages them to consider how technology has helped to increase our space knowledge. Children may think of telescopes, satellites, rovers sent to other planets, and spacecraft sent to document objects in our solar system. They may realize that we could only make observations with our eyes until the first telescopes were invented. If needed, you can prompt with additional questions: *What tools do scientists use to observe objects in space? What tools can scientists send into space? How did scientists learn about space before modern technology like satellites and rovers?*

What do you notice about Galileo's observations of Venus?

This question gives children the opportunity to examine evidence. Children may notice the shading across the planet's surface follows a pattern. If they have studied the moon, they may recognize phases, similar to Earth's moon. They may comment that each shadow has a curved edge. If needed, you can prompt with additional questions: *Describe what you see. How do the drawings change from one to another? Do they follow a pattern? If so, what is the pattern? Does this remind you of anything you have learned about before?*

Compare both solar system models. How does Galileo's evidence support the claim that the sun, not Earth, is the center of our solar system?

This question asks students to combine two pieces of evidence–Galileo's drawing and the models–to determine which model is supported by his observations. Children may notice that the phases in his drawing match the phases in the heliocentric, or sun-centered, model. They may realize that the drawings are evidence to support Galileo's claim that the sun is the center of our solar system. If needed, you can prompt with additional questions: *What evidence did Galileo collect? How does that evidence compare to the two models? Which model does the evidence support, and why?*

Why are models an important and necessary tool for studying the solar system?

This question asks children to consider the usefulness of models. Children may share that models help us understand places we can't visit. They may also realize that models are helpful for learning about systems with many moving parts and understanding systems we can't directly observe because they are too large or too small. Children may also realize that models help us make predictions about future events. If needed, you can prompt with additional questions: *Why do we need models to understand the* *solar system? How do models help us to understand large systems with many parts? How do we know what Venus's phase will be several months from now?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Maria Merian

"Maria Sibylla Merian: Pioneering Artist of Flora and Fauna." *The British Museum*, www.britishmuseum.org/collection/animals/maria-sibylla-merian-pioneering-artist-flora-and-fauna.

Engle, Margarita. *Summer Birds : The Butterflies of Maria Merian*. New York, Henry Holt, 2010.

Etheridge, Kay. "Maria Sibylla Merian and the Metamorphosis of Natural History." *Endeavour*, vol. 35, no. 1, Mar. 2011, pp. 16–22, https://doi.org/10.1016/j.endeavour.2010.10.002. Accessed 12 Feb. 2024

Glann Marsh, Sarah. *The Bug Girl: Maria Merian's Scientific Vision*. Chicago, Illinois, Albert Whitman & Company, 2019.

Klein, Joanna. "A Pioneering Woman of Science Re-Emerges after 300 Years." *The New York Times*, 23 Jan. 2017, www.nytimes.com/2017/01/23/science/maria-sibylla-merian-metamorphosis-insectorum-surinamensium.html.

Lotzof, Kerry. "Maria Sibylla Merian: Metamorphosis Unmasked by Art and Science." *Www.nhm.ac.uk*, www.nhm.ac.uk/discover/maria-sibylla-merian-metamorphosis-art-and-science.html.

Pomeroy, Sarah B, and Jeyaraney Kathirithamby. *Maria Sibylla Merian Artist, Scientist, Adventurer*. Los Angeles, Calif. The J. Paul Getty Museum, 2018.

Sidman, Joyce. *The Girl Who Drew Butterflies*. HarperCollins, 20 Feb. 2018.

Wulf, Andrea. "Maria Sibylla Merian, the Woman Who Made Science Beautiful." *The Atlantic*, The Atlantic, 19 Jan. 2016, www.theatlantic.com/science/archive/2016/01/the-woman-who-made-science-beautiful/424620/.

Galileo Galilei

Boltz, C L. "Galileo Galilei." *New Scientist*, 7 Apr. 1983, www.newscientist.com/people/galileo-galilei/.

Br J Sports Med. "Galileo Galilei (1564-1642)." *British Journal of Sports Medicine*, vol. 40, no.

9, Sept. 2006, pp. 806–7, www.ncbi.nlm.nih.gov/pmc/articles/PMC2564400/.

Editors, Biography.com. “Galileo - Telescope, Quotes & Discoveries.” *Biography*, 30 Mar. 2021, www.biography.com/scientists/galileo.

“International Astronomical Union | IAU.” *Www.iau.org*, www.iau.org/public/images/detail/ann23043a/. Accessed 6 Mar. 2024.

Machamer, Peter, and David Marshall Miller. “Galileo Galilei.” *The Stanford Encyclopedia of Philosophy*, Summer 2021, plato.stanford.edu/archives/sum2021/entries/galileo/.

“The Phases of Venus, 1610-23 | Cabinet.” *Www.cabinet.ox.ac.uk*, www.cabinet.ox.ac.uk/phases-venus-1610-23.

Rachel Carson

Carson, Rachel. *Silent Spring*. London, Penguin Books, 27 Sept. 1962.

Ewald, Megan. “Rachel Carson: Biologist, Writer, Role Model | NOAA’s Office of Response & Restoration Blog.” *Blog.response.restoration.noaa.gov*, 9 Mar. 2019, blog.response.restoration.noaa.gov/rachel-carson-biologist-writer-role-model.

Ferrari, Michelle, director. *“American Experience: Rachel Carson's Silent Spring.”* PBS, 2023.

Lear, Linda J. *Rachel Carson:Witness for Nature*. Boston, Mariner Books, 2009.

Michals, Debra. "Rachel Carson." National Women's History Museum. National Women's History Museum, 2015.

Ryerson, Jade. “Rachel Carson (U.S. National Park Service).” *National Park Service*, www.nps.gov/people/rachel-carson.htm.

AUTHOR'S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

- Patterns
- Cause and effect
- Stability and change
- Structure and function
- Energy and matter
- Systems and system models
- Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It's helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world's richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists' fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: GHOSTLY CORAL, YELLOW FEVER, AND COCKROACHES
SOLVING SCIENCE MYSTERIES WITH CAUSE AND EFFECT

By Emily Mae Starr

Umph! You launch a heavy bowling ball.

Thunk! It races down the slick lane.

Crash! Ten pins clatter.

Strike!

Wow! Your first strike! *Why* did that happen?

Your strong and on-target throw *caused* an *effect*. The pins crashed.

How did it happen?

The mechanism, or science concept, behind your stunning strike is force and motion. The ball smashed into the first pins, transferring its energy, sending them flying. Those pins crashed and collided, transferring their energy to more pins, knocking them down.

Scientists observe effects–events that happen in our world and beyond.

Coral reefs are turning white.

People are getting sick.

Cockroaches can find hidden food.

Then, scientists conduct investigations to figure out the *why* and *how* of their causes.

Why do coral reefs turn white?

Why do people get sick?

How do cockroaches find food?

Each of the scientists in this book studied effects to figure out their causes. Come look at the world through their eyes. See how you can use the relationship between cause and effect to solve science mysteries about coral, disease, and cockroaches.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

GHOSTLY CORAL

Thush! You whoosh water out of your snorkel, take a deep breath, and dive. Catching a glimpse of colorful coral is your favorite part of snorkeling, but something is wrong with this reef. The coral looks pale and sickly. *What happened to the bright colorful coral?*

THINK LIKE A SCIENTIST: What do you think caused the colorful coral to turn bright white?

*[Sidebar: Cause and Effect Big Idea: Causes describe **why** things happen: Mechanisms (science concepts) describe **how** things happen.]*

The Mystery of the Ghostly Coral

Snip! Ove Hoegh-Guldberg clipped a tip, glued the coral to a microscope slide, and secured the specimen to his carefully constructed PVC pipe rack. He placed the completed rack in a small aquarium tank full of water. Ove sought to solve a mystery. Coral, in multiple locations around the world, was bleaching–turning bright white in the late 1980s.

[Sidebar: A specimen is one example of something–living or nonliving–that is used for scientific study.]

Coral is a living organism made of many tiny animals called polyps. Coral polyps cluster together to create huge reef structures. As a biologist, Ove knew these tiny polyps relied on even smaller organisms to survive.

Zooxanthellae [zo-UH-zan-thuh-lay], each just a single cell, live inside the polyps. These microscopic algae produce food through photosynthesis. The zooxanthellae share their food with the polyps, and the polyps provide the carbon dioxide and water the zooxanthellae need to make food. This is called a symbiotic relationship–the organisms work together to survive.

[Sidebar: A biologist is a scientist that studies living things.]

[Sidebar: Photosynthesis is how organisms (mostly plants) make food. They use energy from sunlight to combine water and carbon dioxide into sugar and oxygen.]

Coral looks bleached for two reasons: the zooxanthellae lose some of their color or the polyps expel, or kick out, the zooxanthellae. The first reason isn't as serious as the second.

Zooxanthellae can regain their color. But coral without any zooxanthellae at all? It dies. And dead coral affects the entire ocean ecosystem.

Ove wanted to find out what caused the zooxanthellae to exit the polyps. No one knew. *Could it be too much sunlight? Maybe too little salt in the water? Perhaps warmer water temperatures?*

THINK LIKE A SCIENTIST: How would you design an investigation to test if changes in sunlight, salt, or temperature cause coral bleaching?

[Sidebar: Variables are factors in an investigation that can change. You can think of them like different parts. The variables in your investigation are sunlight, salinity, and temperature. Scientists test one variable at a time. Which variable will you test first? How will you control the others?]

Ove collected healthy coral from a reef and cut it into smaller pieces. For his first experiment, Ove tested whether too much sunlight caused coral to kick out the zooxanthellae. He placed three aquarium tanks–a collection of coral submerged inside each–in three amounts of light. 25% full sunlight (the amount it would naturally receive beneath the waves). Full sunlight. And complete darkness. After ten days, the coral in full sunlight looked pale. The zooxanthellae lost some of their color yet were not expelled. Increased sunlight was not the cause of bleaching.

Next, Ove placed some specimens in seawater and others in water that was 5% less salty. The result? No change. Less salt in the water was not the cause of bleaching.

Finally, Ove submerged coral in aquariums set at different temperatures: 27˚C–the coral's natural habitat temperature–and three warmer temperatures, 30˚C, 32˚C and 34˚C. Seven hours later, he recorded these stunning results.

[Sidebar: The United States is one of very few countries that use the Fahrenheit scale to measure temperature. Since scientists from all over the world work together, the official temperature measurement scale for scientific work is Celsius.]

*[Illustration Note: Within the above sidebar is a table that shows the temperature conversions from ˚C to ˚F for the described study. 27˚*C = *81˚F, 30˚*C = *86˚F, 32˚*C = *90˚F,* 34˚C = *93˚F*]

THINK LIKE A SCIENTIST: What conclusion can you draw from Ove's results? Why can you draw that conclusion?

[Illustration note: Zooxanthellae expulsion rates from Ove's study will need to be translated into a simple graph that shows the number of organisms expelled on days 1, 4, and 7 for all four experimental water temperatures.]

Ove Hoegh-Guldberg discovered the main cause of coral bleaching–rising ocean temperatures. Further research led Ove to conclude that corals bleached if exposed to six weeks of temperatures just one degree warmer than their typical summer high. On average, water warmer than 29˚C results in mass bleaching, and if water remains warm–giving coral no time to recover–the coral dies.

Ove alerted authorities to the dangerous consequences of rising ocean temperatures–damage not only to coral reefs but to Earth's entire ecosystem.

THINK LIKE A SCIENTIST: Look at the graph below. What do you notice about global ocean temperatures? What does this data mean for the health of coral reefs?

[Illustration note: A graph similar to the one found here is included: https://climate.copernicus.eu/global-sea-surface-temperature-reaches-record-high]

Your first cause and effect breakthrough! You discovered how increased ocean temperatures cause coral bleaching.

[Sidebar: Cause and Effect Spotlight: Scientists observe effects in the natural world, like coral bleaching. They conduct investigations to find out why and how the effects are happening.]

No time to rest. From saving coral to saving people, your next discovery awaits!

YELLOW FEVER

Your brother sprints for the bathroom. Your Mom rolls over and moans. *Achoo!* Mucus drips from your sister's tiny nose. *How did you all get so sick?*

THINK LIKE A SCIENTIST: How do you think scientists figure out what makes people sick?

[Sidebar: Cause and Effect Big Idea: Understanding the cause of patterns allows us to make predictions and to develop solutions.]

The Mystery of the Deadly Disease

Carlos Finlay examined the tissue beneath his microscope. He stared at the patchy pink and white muscle. This sample came from a yellow fever victim, and it held a secret–one Carlos worked to discover.

Carlos was an epidemiologist. In his home country of Cuba, people were dying. Lots of people. In the late 1800s, more than 20,000 people died from yellow fever. For thirty years, the disease had ravaged his country causing constant fear. People couldn't prevent infection because no one knew how the disease spread. *Was it through coughing? Touching? Breathing?*

[Sidebar: An epidemiologist is a scientist who studies how diseases are spread.]

Carlos raced to help. Through his microscope, the first clue appeared. Somehow, blood from a sick person crept into the blood of a healthy person, causing illness. *But how?*

THINK LIKE A SCIENTIST: What do you think is causing blood from one person to make its way into another person? Why?

Carlos considered the facts. First, since so many people were sick, infection happened often. Second, people didn't know exactly when they got infected, yet blood was carried from one person's blood vessels to another.

Carlos wondered: How could blood be moved from inside one person to inside another without either knowing?

Of course! Carlos realized the terrifying transmitter had to be a vector–a living organism that spreads diseases. *But what?* He knew it had to be small enough to go unnoticed, yet still able to access blood inside someone's body.

[Sidebar: A vector is a living organism that transmits diseases from one person to another - gnats, bats, and cats are all potential vectors.]

THINK LIKE A SCIENTIST: What living organism do you think could be the vector? Why? Mosquitoes! To test his theory, Carlos carefully collected mosquitoes. He allowed them to bite people infected with yellow fever. Then he directed their piercing proboscises to healthy individuals.

Carlos was cautious and careful. The virus multiplied quickly, and there was no cure. He didn't want his experiments to cause someone's death. Carlos made sure the mosquitoes bit people who had just gotten sick. Without much time to multiply, the virus would be weak. He also insisted that healthy people receive just one bite. These measures protected patients from a dangerous dose of virus.

The result? Healthy people bitten by infected mosquitoes became sick with yellow fever. Carlos Finlay had discovered the cause of yellow fever's deadly spread!

THINK LIKE A SCIENTIST: How do you think Carlos's discovery helped people prevent yellow fever?

Mystery solved. You detected the vicious vector!

[Sidebar: Cause and Effect Spotlight: Knowing that mosquitoes caused the spread of yellow fever allowed people to develop life-saving solutions.]

It's time to buzz from one clever insect to another. Your next discovery awaits!

<u>COCKROACHES</u>

Something skitters across your desk in the dark. Was that a cockroach? You click on your lamp. Nothing there but your unfinished math homework. You'll report your bug sighting to the grown-ups in the morning. For now, you decide to work out these last three problems. *Argh!* Math is hard. Too bad that cockroach can't help! Which makes you wonder: *Can cockroaches learn, too?*
THINK LIKE A SCIENTIST: How do you think a scientist would figure out if cockroaches can learn?

[Sidebar: Cause and Effect Big Idea: Causes can be identified by testing variables.]

The Mystery of the Clever Cockroaches

Charles Henry Turner gently grasped the hind leg of a cockroach and placed it on the cool, flat copper maze. The cockroach scurried to the edge of the platform and leapt, plopping into the water placed below to prevent the cockroach from racing away. Charles retrieved the roach and set it back at the beginning of the maze. Once again, it dropped and plopped. Once again, Charles patiently rescued the roach, returning it to the maze.

This time the cockroach set off down the narrow path, antennae waving, claws gripping. Scuttle. Pause. Search. Turn Around. 37 minutes later, the cockroach rushed into its glass jar home placed behind a corner in the middle of the maze. Finish found!

After a 30 minute roach rest, Charles once again placed the cockroach at the beginning of the maze. 23 minutes later. Finish found!

THINK LIKE A SCIENTIST: What question do you think Charles Henry Turner is investigating?

Questions crept into Charles Henry Turner's mind, begging to be answered. Charles's current question: *Can cockroaches learn and remember?*

As a zoologist, Charles knew how to design investigations. He created a maze cockroaches needed to navigate to get home – a glass jar where they were caged and fed. Charles also knew how to control variables. *Was the cockroach spreading a scent on the maze to follow on repeat trips?* Clean the maze with alcohol between trials. *Was the cockroach making mistakes because it was tired?* Let the roach rest for 30 minutes between trials. *Was the roach who completed the maze just "smarter" than other roaches?* Test ten different roaches. Charles patiently completed trial after trial, carefully recording results.

[Sidebar: A zoologist is a scientist who studies animals.]

[Sidebar: Variables are factors in an investigation that can change. Charles controlled the variables of scent, fatigue (tiredness), and differences in individual cockroaches.]

THINK LIKE A SCIENTIST: What conclusion can Charles draw from these results? What evidence supports that conclusion?

[Illustration Note: A simplified version of Charles's results is shown that includes the number of trials and the amount of time taken to complete the maze for several different cockroaches.]
With nearly every trial, the more times a cockroach explored the maze, the quicker it found its way home. Some roaches even completed the challenge in one minute! With his carefully crafted investigations, Charles Henry Turner proved that cockroaches learn and remember through trial and error.

THINK LIKE A SCIENTIST: What do you wonder about cockroaches after learning about this investigation? How could you figure out the answers to those questions?

Another cause and effect discovery! You uncovered how repeating a maze over and over causes cockroaches to learn the perfect path home.

[Sidebar: Cause and Effect Spotlight: By controlling the variables of scent, tiredness, and individual differences, Charles was able to identify the cause of a cockroach's success navigating home. They can learn and remember!]

Congratulations, junior scientist! You made sense of our wondrous world using cause and effect relationships. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Ove Hoegh-Guldberg

Since his discovery that warming ocean temperatures are responsible for coral bleaching, Ove has worked to create awareness of the problem and its increasing severity as global warming is quickly raising the temperature of our oceans. In 1999, Ove published a paper warning that most coral reefs will not survive the next century. Many scientists didn't believe his prediction, though they provided little evidence to support their disbelief. In the decades since Ove's paper, an increasing number of coral bleaching events have lent further credibility to his dire prediction.

Ove was a leading author of the 2018 *Special Report on Global Warming of 1.5 °C*, a coordinated effort by scientists around the globe to sound the alarm about global warming. Ove helped to found the 50 Reefs Initiative to identify reefs with corals that were most likely to survive warmer temperatures so those corals can be used to re-populate reefs that will not survive. In 2024, ocean temperatures hit record levels and mass bleaching events were experienced around the globe. Two-thirds of the shallow water coral on the Great Barrier Reef turned bright white.

Learn more: *Ove Hoegh-Guldberg received death threats for his work. He kept fighting anyway* (Youtube)
https://www.youtube.com/watch?v=hqYcVMej7zU

Why Is No-One Talking About the Black Summer of Our Oceans? (Climate Council.org)
https://www.climatecouncil.org.au/why-is-no-one-talking-about-the-black-summer-of-our-oceans/

Carlos Finlay

Convincing fellow scientists of Carlos's mosquito vector hypothesis was not easy. Even after conducting 102 experiments to prove his theory, it still took over twenty years for his discovery to gain acceptance. Because of Carlos's discovery, a mosquito elimination campaign, combined with other public health measures, reduced yellow fever deaths in Havana, Cuba from 462 people between 1890 and 1900 to 12 people in 1901. Eventually the disease disappeared completely from the island. Today, mosquitos continue to transmit illnesses, including yellow fever, that result in nearly one million deaths across the globe every year.

The Carlos J. Finlay Prize for Microbiology is awarded each year to a scientist for their work in microbiology, the study of tiny organisms such as viruses and bacteria. In addition, Carlos has several buildings named after him–including an elementary school in Florida–and the name Finlay was given to an exoplanet located 112.5 light years from Earth.

Learn more: *The Great Fever: Carlos Finlay* (PBS)
https://www.pbs.org/wgbh/americanexperience/features/fever-carlos-finlay/

Charles Henry Turner

In addition to cockroaches, Charles conducted investigations with bees, ants, crustaceans, moths, pigeons, spiders, wasps, and even plants. Charles was the first to prove that insects can hear and distinguish pitch and that honey bees can see colors and patterns.

His work was different from his peers because he applied concepts such as learning and memory to animals that most scientists believed were only capable of responding to the world around them reflexively–an automatic reaction without a thought process. Some of the groundbreaking techniques he developed to measure insect learning are still in use today.

What made Charles Henry Turner's discoveries even more remarkable was that he conducted his investigations, not in a University lab, but in Sumner High School in St. Louis, Missouri, where he taught science for fourteen years.

Learn More: *Buzzing With Questions: The Inquisitive Mind of Charles Henry Turner* by Janice N. Harrington (Calkins Creek, 2019).

<u>Questioning Guide (For Grown-Ups)</u>

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

What do you think caused the colorful coral to turn bright white?

This question gets children wondering about something in nature. They may guess animals or humans are harming the coral. They may also suggest environmental factors such as strong waves or sunlight. At this point, they most likely won't have the background knowledge to predict it involves ocean temperatures and single-celled algae. If needed, you can prompt them with additional questions: *Do you think the bright white coral is healthy? Why or why not? What does coral need to survive? What could prevent coral from getting what it needs?*

How would you design an investigation to test if changes in sunlight, salt in the water, or temperature cause coral bleaching?

This question asks children to complete the same process as Ove. The variable sidebar will help lead children through a series of small steps in the investigation design. You can guide their thinking by asking: *What question are you investigating? What are the variables in your investigation? What variable are you testing? What variables do you need to control? How are you going to control those variables?* Children may be able to articulate that they are seeking to figure out what is causing the coral bleaching, and they will test the variables of sunlight, salinity, and temperature. Their suggested methods should include some way to test one variable at a time while controlling the other two variables.

What conclusion can you draw from Ove's results? Why can you draw that conclusion?

This question gives children the opportunity to analyze and interpret data. Children may notice that the higher the temperature, the more zooxanthellae are expelled from the coral until the temperature is so high, the coral dies. Children may be able to conclude that high ocean temperatures are most likely causing coral bleaching, and they can draw that conclusion because they controlled the other two variables of sunlight and salinity. If needed, you can prompt them with additional questions: *According to the graph, what happens to the number of zooxanthellae expelled from the coral as the temperature rises? How does this information help you to predict the cause of coral bleaching? Why can you* *predict coral bleaching is caused by rising ocean temperatures and not less salt in the water or more sunlight?*

Look at the graph below. What do you notice about global ocean temperatures? What does this data mean for the health of coral reefs?

This question gives children the opportunity to analyze and interpret data and apply what they have learned. Children may notice that global ocean temperatures are rising. They may realize that temperatures are predicted to climb half a degree higher than average, and they may recall that the text says mass bleaching happens at one degree higher than average. Children may draw the conclusion that there are going to be more mass bleaching events and more coral will die in the near future. If needed, you can prompt them with additional questions: *According to the graph, what has happened to oceans in the last few years? What is predicted to happen in the next few years? What did the text say happens to coral when ocean temperatures rise? How can you combine information in the text with the data in this graph to make a prediction about the future health of coral reefs?*

How do you think scientists figure out what makes people sick?

This question asks children to place themselves in the shoes of scientists and to think about the processes used to answer scientific questions. Children may think of tests that are run at a doctor's office or interviewing people to learn about their symptoms. Children with background knowledge may mention the scientific process or testing variables. If needed, you can prompt them with additional questions: *When you are sick, where do you go? How do doctors figure out what is making you sick? How might scientists use some of the same processes as doctors?*

What do you think is causing blood from one person to make its way into another person? Why?

This question asks children to make a prediction based on limited information. Children may suggest that two people have cuts and their blood somehow mixes. Children with background knowledge may suggest blood transfusions. At this point, they most likely will not consider an animal vector, like a rat, bat, mosquito or flea. If needed, you can prompt them with additional questions: *How does blood get out of a person's body? How could that same blood get into another person's body?*

What living organism do you think could be the vector? Why?

This question asks children to use collected information to make a prediction. Children may suggest that the vector may be an insect. Children with background knowledge may be able to predict it is a mosquito. If needed, you can prompt them with additional questions: *What types of organisms are so small they often go unnoticed? What small organisms bite humans in order to access their blood?*

How do you think Carlo's discovery helped people prevent yellow fever?

This question allows children to apply what they have learned to solve a problem. Children may suggest that once people knew mosquitos were the vector, they probably worked to reduce mosquito populations and to help people avoid mosquito bites. Other children may suggest that scientists developed a vaccine. Children with background knowledge may suggest repellant sprays, netting over beds, and eliminating standing water from the environment. If needed, you can prompt them with additional questions: *How did people get infected with yellow fever? What could people do to avoid getting infected?*

How do you think a scientist would figure out if cockroaches can learn?

This question asks children to place themselves in the shoes of scientists and to think about the processes they use to answer questions. Children may think of observing cockroaches in their natural environment. Children with background knowledge may think of designing an investigation to test cockroaches. If needed, you can prompt them with additional questions: *What is important to cockroaches, and what can they physically do? What could a scientist teach a cockroach? How could a scientist teach a cockroach? How could a scientist test to see if a cockroach had learned something?*

What question do you think Charles Henry Turner is investigating?

This question asks children to think about the reason scientists conduct investigations: to answer a research question. At this point, children may think of a general question such as: *Can a cockroach complete a maze?* Some children may suggest that he is testing to see if a cockroach can learn a maze. If needed, you can prompt them with additional questions: *What is Charles requiring the cockroach to do? What question could he answer by having the cockroach complete the same maze multiple times?*

What conclusion can Charles draw from these results? What evidence supports that conclusion?

This question gives children the opportunity to analyze and interpret data. Children may notice that the cockroach usually completes the maze more quickly with each attempt. They may realize that this evidence supports the conclusion that cockroaches can learn a path home and remember it. If needed, you can prompt them with additional questions: *What do you notice about the amount of time it takes a cockroach to complete the maze? What does this data tell you about a cockroach's abilities? How does this data support the conclusion that cockroaches can learn?*

What do you wonder about cockroaches after learning about this investigation? How could you figure out the answers to those questions?

This question helps children to consider how answers to questions can lead to more questions. In addition, it emphasizes that there are always more questions to investigate. Children may wonder how long cockroaches can remember the path home. They may question if the age of the cockroach affects its abilities or if other insects can complete a similar maze. Children may describe an investigation they could conduct to answer their question(s) or they may suggest conducting Internet research. If needed, you can prompt them with additional questions: *What other variables could you test? What behaviors of cockroaches would you like to understand? How would a scientist answer your question? What investigation would they design?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Carlos Finlay

Chaves-Carballo, Enrique. “Carlos Finlay and Yellow Fever: Triumph Over Adversity.” *Military Medicine*, vol. 170, Oct. 2005, pp. 881-885.

Bell, Danna. “Discovering Carlos Finlay.” The Science Teacher, vol. 89, no. 2, Nov./Dec. 2021. Available: https://www.nsta.org/science-teacher/science-teacher-novemberdecember-2021/discovering-carlos-finlay.

Faerstein, Eduardo, and Warren Winkelstein. “Carlos Juan Finlay.” *Epidemiology*, vol. 21, no. 1, Jan. 2010, p. 158, https://doi.org/10.1097/ede.0b013e3181c308e0.

Finlay, Carlos J. “The Mosquito Hypothetically Considered as the Transmitting Agent of Yellow Fever.” *MEDICC Review*, vol. 14, no. 1, 1 Jan. 2012, pp. 56–59, https://doi.org/10.1590/s1555-79602012000100011.

PBS. “Carlos Finlay (1833-1915) | American Experience | PBS.” *Www.pbs.org*, www.pbs.org/wgbh/americanexperience/features/fever-carlos-finlay/.

Ove Hoegh-Guldberg

Hoegh-Guldberg, Ove. “Climate Change, Coral Bleaching and the Future of the World’s Coral Reefs.” *Marine and Freshwater Research*, vol. 50, no. 8, 1999, p. 839, www.publish.csiro.au/MF/MF99078, https://doi.org/10.1071/mf99078.

Hoegh-Guldberg, Ove, et al. “Coral reefs in peril in a record-breaking year.” *Science*, no. 382, 7 Dec. 2023, vol. 382 no. 6676 pp.1238-1240. DOI:10.1126/science.adk4532

Hoegh-Guldberg, Ove and G. Jason Smith. “The effect of sudden changes in temperature, light and salinity on the population density and export of zooxanthellae from the reef corals Stylophora pistillata Esper and Seriatopora hystrix Dana.” *Journal of Experimental Marine Biology and Ecology*, 1989, vol. 129, no. 3, pp. 279-303, https://doi.org/10.1016/0022-0981(89)90109-3.

Hughes, Dr. Ove Hoegh-Guldberg, Simon Bradshaw, Lesley. “Why Is No-One Talking about the Black Summer of Our Oceans?” *Climate Council*, 9 Apr. 2024, www.climatecouncil.org.au/why-is-no-one-talking-about-the-black-summer-of-our-oceans/. Accessed 25 Apr. 2024.

"Ove Hoegh-Guldberg - Coral reefs: from climate victims to survivors." *YouTube*, uploaded by Frontiers, 16 Dec. 2022, https://www.youtube.com/watch?v=lN6WPrLK6Gs.

"Ove Hoegh-Guldberg received death threats for his work. He kept fighting anyway." *YouTube*, uploaded by Guardian Australia, 24 Nov. 2023, https://www.youtube.com/watch?v=hqYcVMej7zU.

"Professor Ove Hoegh-Guldberg - UQ Researchers." *Uq.edu.au*, 2013, researchers.uq.edu.au/researcher/839.

Readfearn, Graham. "The Scientist Who Was Branded Alarmist for Exposing the Fate of Coral Reefs." *The Guardian*, 24 Nov. 2023www.theguardian.com/australia-news/2023/nov/25/prof-ove-hoegh-guldberg-scientist-great-barrier-reef-coral-bleaching-causes-effects-climate-change-crisis-ocean-heating-warming.

Charles Henry Turner

Abramson, Charles I. "A Study in Inspiration: Charles Henry Turner (1867–1923) and the Investigation of Insect Behavior." *Annual Review of Entomology*, vol. 54, no. 1, Jan. 2009, pp. 343–359, https://doi.org/10.1146/annurev.ento.54.110807.090502.

"Charles Henry Turner's Study of Bees." *YouTube*, uploaded by nine PBS, 11 Oct. 2021, *YouTube*, uploaded by Frontiers, 16 Dec. 2022, *YouTube*, uploaded by Frontiers, 16 Dec. 2022, https://www.youtube.com/watch?v=YmoW09Qby4o.

Giurfa, Martin, et al. "Charles Henry Turner and the Cognitive Behavior of Bees." *Apidologie*, vol. 52, no. 3, 8 Apr. 2021, pp. 684–695, https://doi.org/10.1007/s13592-021-00855-9.

Katsnelson, Alla. "This Pioneering Black Zoologist's Insights Were a Century ahead of Their Time." *Smithsonian Magazine*, 9 Aug. 2023, www.smithsonianmag.com/science-nature/this-pioneering-black-zoologists-insights-into-animal-behavior-were-a-century-ahead-of-their-time-180982658/.

Lack, Caleb. "CHT - Biography." *Okstate.edu*, 2019, psychology.okstate.edu/museum/turner/turnerbio.html.

Mickens, Ronald, and Charmayne Patterson. "Dr Charles Henry Turner: A Pioneer in Animal Cognition and Intelligence." *Georgia Journal of Science*, vol. 79, no. 1, 6 Apr. 2021, digitalcommons.gaacademy.org/gjs/vol79/iss1/6/. Accessed 28 Feb. 2024.

Turner, Charles Henry. "BEHAVIOR of the COMMON ROACH (PERIPLANETA ORIENTALIS L.) on an OPEN MAZE." *The Biological Bulletin*, vol. 25, no. 6, Nov. 1913, pp. 348–365, https://doi.org/10.1086/bblv25n6p348. Accessed 28 Feb. 2024.

AUTHOR’S NOTE (For Grown-Ups)

Research shows that the best way to raise scientists is to help children see themselves *as* scientists. They must be given opportunities to do the same work that scientists do.

This book series was created to help children *think like scientists* by mastering the crosscutting concepts. The crosscutting concepts (CCCs) are tools scientists use to understand the natural world. There are seven crosscutting concepts:

- Patterns
- Cause and effect
- Stability and change
- Structure and function
- Energy and matter
- Systems and system models
- Scale, proportion, and quantity

All scientists share this common language, and children can become fluent in it.

It’s helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world’s richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists’ fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: HIDE AND SEEK MONARCHS, DANCING BEES, AND TALKING TREES
SOLVING SCIENCE MYSTERIES WITH PATTERNS

By Emily Mae Starr

Did you gobble down your breakfast this morning? Yesterday morning? Every morning this week? That's a pattern!

Squeeze your eyes shut and imagine a tree. Did you see shiny green leaves, breaches reaching for the sky, and a thick sturdy trunk? That's a pattern!

A pattern is something that repeats and has a cause. You eat breakfast every morning because you are hungry. Your body needs energy.

A tree always has leaves, branches, and a trunk because that is how tree cells grow. These parts make a tree . . . a tree.

Patterns are everywhere–in the shake of an earthquake, the flight of a butterfly, and the movement of a bee.

Each of the scientists in this book noticed patterns in nature. Come look at the world through their eyes. See how you can use patterns to solve science mysteries about monarchs, bees, and trees.

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

<u>HIDE AND SEEK MONARCHS</u>

You sit at the top of the slide, ready to zoom when a snowflake lands on your cheek. Isn't October too early for snow? Suddenly, an orange and black wing flits by your face. You jump back. Strange! You've never seen a monarch in the snow before. *Why don't you see monarchs in winter? Where do they go?*

THINK LIKE A SCIENTIST: How could you figure out where this monarch goes for the winter without using a computer or cell phone?

[Sidebar: Patterns Big Idea: Patterns that repeat help scientists make predictions.]

The Mystery of the Migrating Monarchs

Fred Urquhart carefully secured sticky tag #354 and released the captive creature. Floating on a fall breeze, the numbers looked out of place on the monarch's delicate wing. The butterfly was now part of a mystery–one Fred had been working to solve for nearly fifty years.

Fred was a zoologist. As a child, he noticed that monarch butterflies disappeared from Canada every fall and reappeared in the spring. *Where did they go in winter?* He asked a professor and was surprised by his answer. No one knew!

[Sidebar: A zoologist is a scientist who studies animals.]

Fred decided to solve this mystery. He started by tagging butterflies. When people found them, they would write to him, so he could track where each monarch traveled. Easy, right? Wrong. Painted tags? Confusing. Ink tags? Washed away. Lick-and-stick tags? Fell off. Few butterflies were found and reported. Ten years of tagging. Ten years of failure.

Then, in 1945, Fred married Norah Patterson. Together, they developed a better tag–one that folded over the edge of the wing and could hold more information. But there was still one problem. Fred and Norah couldn't possibly tag enough butterflies on their own.

THINK LIKE A SCIENTIST: How could Fred and Norah find help for their investigation? (Remember: This is before computers, the Internet, and cell phones!)

Norah wrote articles in magazines and newspapers asking people to help. She mailed tags and directions to citizen scientist volunteers in Canada and the United States. Finally, letters and packages trickled in – inside were tags, butterfly wings, and sometimes even a live butterfly! Years and years of data formed a pattern on Fred and Norah's monarch map.

[Sidebar: A citizen scientist is a person who collects or analyzes data to help scientists with their investigations.]

THINK LIKE A SCIENTIST: What pattern(s) do you see in the map data?

[Illustration Note: A map showing string lines beginning at monarch tagging locations in Canada and the northern United States and ending where they were collected. All strings lead from the North, South through Texas.]

The butterflies flitted and fluttered South! Fred and Norah took to the road, following the migrating monarchs through Texas and into Mexico. Could they find the spot where the monarchs spent the winter? No! But they did find more people excited to help.

Finally, 1975, after nearly 50 years of searching and wondering, tagging and writing, the Urquarts received a phone call from Mexico. Guided by locals, a pair of citizen scientists, Catalina Aguado and Ken Brugger, made an amazing find in the mountains of Mexico. At this tiny dot on the map, trees were blanketed with millions of monarchs! Monarch mystery solved–hidden home revealed at last.

THINK LIKE A SCIENTIST: Why is knowing the monarch migration pattern useful? How might the information inspire additional research?

Your first patterns breakthrough! You tracked the flight of millions of monarchs to discover their winter home.

[Sidebar: Patterns Spotlight: Scientists can predict monarch behavior based on their previous migrations.]

From a butterfly blanket to a honeybee hive, your next discovery awaits!

DANCING BEES

You inch closer to the table-top hive. *Bzzzzz!* A flurry of activity. The bees deposit nectar, feed larvae, and protect the queen. Suddenly, a buzz near your ear. A bee dives into the hive. Fellow bees gather – circling the new arrival. It begins to wiggle and waggle, circle and sway. *What is this bee doing?*

THINK LIKE A SCIENTIST: Why do you think this bee is moving so strangely?

[Sidebar: Patterns Big Idea: Patterns help scientists connect observations to explanations.]

The Mystery of the Dancing Bee

Karl Von Frisch dabbed a dot of paint on a fuzzy honeybee. It zipped back into the glass-front hive, joining bees spotted with red, green, and blue. Karl kept close–watching, waiting for a colorful creature to take flight.

As an ethologist, Karl was fascinated by bees–and one bit of behavior in particular. Over and over, Karl saw honeybees slurp a serving of nectar, buzz back to the hive, and appear to. . .dance. *Why did they waggle like that? What did the movements mean?*

[Sidebar: An ethologist is a scientist who studies animal behavior.]

THINK LIKE A SCIENTIST: How could you figure out what the bee's movements mean?

Finally, a marked bee emerged. Karl was ready. He followed as it zipped through the meadow and landed on the nearest bowl of sugary syrup Karl had placed there earlier. The bee sipped. It slurped. Then it zoomed. Karl tracked the industrious insect back to the hive and peered through the glass. Bees were already circling the new arrival.

The performance began. Circle. Circle. Circle. Round and round the bee danced while Karl recorded every movement in his notebook. Over and over, Karl followed the dotted bees. From hive to sugar bowl from sugar bowl to hive. While the bees circled and waggled, Karl observed and recorded.

THINK LIKE A SCIENTIST: What patterns do you see in the data?
[Illustration Note: The illustration shows a diagram of the round dance and waggle dance with location and distance data to flowers beneath each diagram in the table. The table contains information from several bees.]

Through careful study, Karl discovered that bees communicate the location of a food source through movement. Bees perform a "round dance"–turning left, then right in tight circles if sweet nectar is nearby. If farther away, bees perform a "waggle dance." A series of figure eight movements communicate both direction and distance to the sweet treat.

[Illustration Note: A more detailed diagram of the waggle dance is labeled to explain how the angle of the line the bees dance along shows the flowers in relation to the sun.]

THINK LIKE A SCIENTIST: Why is knowing the behavior patterns of bees useful? How might the information inspire additional research?

Mystery solved. You discovered how bees communicate through dance.

[Sidebar: Patterns Spotlight: Observation led to the explanation that bees report the direction and distance to nectar with a specific pattern of movement.]

From dancing bees to talking trees, nature calls out for your next discovery!

TALKING TREES

Sunlight fills your face as you step out of the cool, damp forest. Tree stumps litter the landscape. You already knew about clear-cuts, where loggers took every tree, but the sight is still shocking. Your gaze falls on a tiny seedling, then another, and another. A wave of tiny trees spread across the ground – scrawny sticks compared to the sturdy stumps. At least the forest was planted to grow back – *but would it?* You bend to inspect a seedling and notice yellowing needles, a spindly stem. Now that you look closely, most of the seedlings seem…sick.

THINK LIKE A SCIENTIST: What do you think is causing the unhealthy seedlings?

[Sidebar: Patterns Big Idea: Patterns help scientists identify relationships.]

The Mystery of the Talking Trees

Suzanne Simard crumbled the cool, musty-scented soil over the seedling's roots. The baby fir joined a birch and a cedar–a trio of twigs. Similar groups dotted the football-field sized area of scattered stumps – rough tombstones of trees taken by logging companies. Suzanne brought life back to clear-cut areas of forest, and today, she planted with purpose–an investigation had begun.
Suzanne knew the Canadian government supported replanting clear-cuts–but only in a specific way. First, the ground must be cleared of other trees and plants that could take light, water, and nutrients away from new seedlings. And second, the new plantings must be trees useful to loggers: spruces, pines, and firs.

In the 1980s, as a forest ecologist in British Columbia, Suzanne had visited these government-approved plots. Neat rows of thin pine branches. Brown earth stripped of every green thing. In this stark environment, Suzanne unearthed a mystery: the newly planted trees were dying.
Yet, yards away, just inside the shade of towering firs and spicy-scented birches, seedlings in the old-growth forest thrived. These tiny trees had less sunlight and more competition for water and nutrients, yet were healthier than the clear-cut plantings. *What was causing this pattern?*

[Sidebar: A forest ecologist is a scientist that studies the plants, animals, and patterns in a forest ecosystem.]

THINK LIKE A SCIENTIST: Why do you think the seedlings in the forest are thriving while the clear-cut plantings are dying? What makes you think that?

Suzanne suspected trees needed one another to survive. She imagined an underground network connecting root to root carrying nutrients from old to young, birch to fir, strong to struggling. *But was this helpful hidden highway real?*

Suzanne designed an investigation to find out. First, she planted trees in groups of three in a clear-cut area. In some of the groups, she covered the firs with cloth. Without full sunlight, it would be difficult to photosynthesize (make food). *Would a birch pass nutrients underground to save a starving fir?*

[Sidebar: Photosynthesis is how organisms (mostly plants) make food. They use energy from sunlight to combine water and carbon dioxide to create sugar and oxygen.]

[Illustration Note: A diagram shows three groups of three trees – labeled fir, birch, and cedar. In two of the groups the firs are covered with a material to block out the light – one group is labeled with "No Shade" one labeled with "50% Shade" and one labeled with "95% Shade." There is a note with the cedar tree: The cedar is a control tree. It has a different underground communication system than the birches and firs. Since it isn't involved in the experiment, it is used to detect any unexpected effects.]

A month later, the shaded firs were struggling to survive, yet still alive. *Were the birches helping their neighbors?* To find out, Suzanne secured air tight bags around the firs and birches. She injected carbon dioxide, an invisible gas that plants need to make food, into each bag. The gas had been specially tagged with a radioactive isotope. Radioactive isotopes are elements that send out radiation, invisible energy waves, that Suzanne could detect with a special device.

When the bagged trees took in the carbon dioxide, they also took in the radioactive isotopes that were connected to the gas. When the trees used the tagged carbon dioxide, Suzanne could track where the carbon traveled. Half of the trees breathed in one type of isotope, and half breathed in a second type. *Would the carbon in the bagged birches show up in the struggling firs? Did the firs share any carbon with the birches?*

THINK LIKE A SCIENTIST: Is there a pattern in Suzanne's results? If so, what is the pattern? How do you know it is a pattern?

[Illustration Note: A diagram shows the movement of tagged carbon from birch to fir and fir to birch. Both types of isotopes could be shown in different colors. More carbon is given by the birches and is in proportion to the amount needed as determined by the amount of sunlight received.]

Suzanne sat in disbelief. Not only did birch help fir, the more distressed the fir, the more birch helped. And, surprise! Fir sent resources back to birch. Suzanne had discovered that trees communicate and cooperate through an underground "wood-wide-web!"

THINK LIKE A SCIENTIST: How do Suzanne's findings help explain why the seedlings in the clear-cut were struggling? How could Suzanne's findings be used to improve tree planting projects?

Another patterns discovery! You uncovered how patterns in tree growth led to understanding forest underground networks.

[Sidebar: Patterns Spotlight: Patterns in the growth of seedlings helped scientists identify the relationships between trees in a forest.]

Congratulations, junior scientist! You made sense of our wondrous world using patterns. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Fred Urquhart

The fact that Fred and Norah's research was conducted before the Internet makes their determination even more inspiring. They enlisted help from more than 4,000 citizen scientists through the hard work of getting thousands of articles printed in magazines and newspapers. When the trail of tagging data led to Mexico, the couple visited the country. They were fortunate to connect with Catalina Aguado and Ken Brugger who vowed to continue the search in Mexico. Locals helped Catalina and Ken to locate the monarchs' winter home in 1975. One year later, Fred and Norah visited Cerro Pelon to see firsthand the fantastical display.

Fred went on to discover that butterflies only fly during the day. Identifying this pattern led other scientists to conduct research which showed that butterflies are able to navigate South using an internal "sun clock" that keeps track of the time of day and the position of the sun in the sky.

Learn More: *The Mystery of the Monarchs* by Barb Rosenstock (Knopf Books for Young Readers, 2022)

Monarch Watch Tagging Program (Monarch Watch.org)
https://monarchwatch.org/tagging

Karl von Frisch

In 1973, Karl was awarded the Nobel Prize for Physiology or Medicine for his bee behavioral research. In addition to decoding bee communication, Karl discovered that bees use the Sun as a compass and can remember patterns of polarized light, combined with landmarks, to use this method of orientation even when the Sun is not visible in the sky. Karl also demonstrated that bees can be trained to tell the difference between various tastes and smells. This led to the discovery that while bees' sense of smell is similar to humans, their sense of taste is not as developed.

Learn More: *Bee Dance* by Rick Chrustowski (Henry Holt and Company, 2015)

Honey Bee Dance Language (University of California, Riverside)
https://www.youtube.com/watch?v=1lhVBNQ-Ik8

Suzanne Simard

Suzanne Simard has been studying communities of trees for more than forty years. In addition to her discovery that trees share resources, Suzanne and her students discovered how trees pass resources through fungi in the soil, protect one another from disease and harmful insects, and even share their last nutrients with the next generation when they die.

Mother trees are Suzanne's most well-known discovery. She found that these centuries-old forest elders nurture seedlings and saplings–even passing more resources to their own offspring–and are an essential part of a healthy ecosystem.

In addition to her autobiographical book: *Finding the Mother Tree: Discovering the Wisdom of the Forest*, Suzanne has given three TED talks, and contributed to two documentaries. She is currently a professor in the Department of Forest and Conservation Sciences at the University of British Columbia.

Learn More: *The networked beauty of forests* (TED-Ed) https://ed.ted.com/lessons/the-networked-beauty-of-forests-suzanne-simard

Questioning Guide (For Grown-Ups)

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

How could you figure out where this monarch goes for the winter?

This question introduces children to the challenge of observing living organisms and asks them to wonder about a solution. Children may think of following the insect in person. Some with background knowledge may think of tagging the insects, but most will not. If needed, you can prompt with additional questions: *How could you keep track of a butterfly across a wide distance over a long period of time? Whose help would you need? How would you let them know you need help? How could you be sure you were tracking the same butterfly? What technology could you use?*

How could Fred and Norah get help with their investigation? (Remember: This is before computers, the Internet, and cell phones!)

This question introduces children to the concept of citizen scientists, people who collect or analyze data to help with investigations conducted by trained scientists. It also helps children to realize that it was a lot of hard work for Fred and Norah to find volunteers willing to help. Children may think of asking other scientists and even other people in general for help. When thinking about how to contact volunteers, it may be challenging for children to think of communication methods that don't involve electronics. They may think of writing letters, but they may not have the background knowledge to think of putting an ad in newspapers and magazines. If needed, you can prompt with additional questions: *Who could Fred and Norah ask to help? How could they contact them? How did people communicate with one another and get news and information in the 1950s?*

What pattern(s) do you see in the map data?

This question helps children to use the crosscutting concept of patterns. Children should be able to identify the pattern that the monarchs are flying south and ending up in Mexico. If needed, you can prompt with additional questions: *What do all of the lines on the map have in common? How do you know that monarchs migrating south for the winter is a pattern?*

Why is knowing the pattern of monarch migration useful? How might the information inspire additional research?

These questions ask students to apply what they have learned to new situations and to practice asking new questions based on current discoveries. The question emphasizes that answering one question leads to even more questions, so there are always new questions to investigate! Children may realize that knowing the pattern can help people protect monarchs as they migrate south and as they winter in the mountains in Mexico. If needed, you can prompt with additional questions: *How can knowing* *when and where monarchs migrate be used to help protect them? What questions do you still have about the monarch's migration process?*

Why do you think this bee is moving so strangely?

This question gets children wondering about something that happens in nature. Without background knowledge, children will just be making a guess. If needed, you can prompt with additional questions: *What clues in the story could you use to help you make a prediction? What do you know about bees that could help you make a guess?*

How could you figure out what the bee's movements mean?

This question puts children in the role of a scientist. Some children may suggest observing the bees and others may suggest recording what they are seeing. Children may think to design an investigation– either by making the suggestion in general or by describing a specific procedure. If needed, you can prompt with additional questions: *How do scientists figure out why something is happening in nature? What actions could you take?*

What patterns do you see in the data?

This question helps children to use the crosscutting concept of patterns. Children may notice that bees perform a circle dance if the nectar is close to the hive and a waggle dance if it is far away. They may realize that the number of waggles indicates the distance to the food source. If needed, you can prompt with additional questions: *What is the relationship between the dance and the distance to the food source?*

Why is knowing the behavior patterns of bees useful? How might the information inspire additional research?

These questions ask students to apply what they have learned to new situations and to practice asking new questions based on current discoveries. The question emphasizes that answering one question leads to even more questions, so there are always new questions to investigate! Children may realize that knowing the pattern can help people better understand bees and to design plans to protect them. If needed, you can prompt with additional questions: *How can knowing how bees communicate be used to help protect them? What questions do you still have about how bees work together and communicate?*

What do you think could be causing the unhealthy seedlings?

This question gets children wondering about something that happens in nature. At this point, they will most likely guess that the plant isn't getting something they know it needs to survive, like water, nutrients, or sunlight. Some may guess that it has some sort of disease or is being attacked by insects. At this point, they most likely won't have the background knowledge to wonder if it is because the trees are disconnected from a nurturing ecosystem. If needed, you can prompt with additional questions: *What do trees need to survive that the seedlings might not be getting?*

Why do you think the seedlings in the forest are thriving while the clear-cut plantings are dying? What makes you think that?

This question asks students to make an educated guess about the cause of a pattern. Some students might infer that the difference between the two groups is the presence of older, more mature trees. Other students may point out the difference in the amount of sunlight the seedlings receive. Students should support their claims with evidence from the text. They may share that the seedlings in the clear cut are all new fir trees and that there are no other plants in the area while the seedlings in the forest are surrounded by plant life. They may also use the sunlight and shade descriptions as evidence. If needed, you can prompt with additional questions: *Compare the two groups of seedlings. What is the same? What is different? Which of the differences do you think is causing the seedlings to thrive or die?*

Is there a pattern in Suzanne's results? If so, what is the pattern? How do you know it is a pattern?

This question helps children to use the crosscutting concept of patterns. Children may notice that fir and birch exchange resources and that birch shares more with fir. They may also notice that the more sunlight fir receives, the fewer resources birch sends. If needed, you can prompt with additional questions: *What is the same about all of the diagrams? What is different? What do you notice is happening over and over again?*

How do Suzanne's findings help explain why the seedlings in the clear-cut were struggling? How could Suzanne's findings be used to improve tree planting projects?

This question asks children to draw conclusions and apply what they have learned to new situations. Children may realize that the trees in the clear-cut were struggling because the ground was stripped of all other plant life. There was no connection to other trees, such as birches, that could pass resources to the firs. Children may mention that new trees should be planted in groups so they can share resources with one another. If needed, you can prompt with additional questions: *According to Suzanne's research, what helped firs survive? Why didn't the seedlings in the clear-cut have that help? How could you provide that help when planting new trees?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Fred Urquhart

Davis, Donald A. "Fred Urquhart (1912-2002)." *Entomological Society of Canada*. https://esc-sec.ca/wp/wp-content/uploads/2017/02/Obit_Urquhart_Fred.pdf Accessed 5 Aug. 2022.

Scott, Alec. "Where Do You Go, My Lovelies?" *University of Toronto Magazine*, August 24, 2015.

Slee, Mike (dir.). *Flight of the Butterflies*. DVD. Los Angeles: Shout! Factory, 2016.

Urquhart, F. A. "A Proposed Method for Marking Migrant Butterflies." *The Canadian Entomologist*, vol. 73, no. 2, 1941, pp. 21-22.

Urquhart, F. A. "Monarch Migration Studies (An Autobiographical Account)." *News of the Lepidopterists' Society*, 4 July/Aug. 1978, pp. 3-4.

Urquhart, F. A. "Monarch Butterflies Found at Last: The Monarch's Winter Home." *National Geographic*, August 1976, no. 150, pp. 161-73.

Urquhart, Fred A., and N.R. Urquhart. "Autumnal migration routes of the eastern population of the monarch butterfly (*Danaus p. plexippus* L.; Danaidae; Lepidoptera) in North America to the overwintering site in the Neovolcanic Plateau of Mexico." *Canadian Journal of Zoology*. vol. 56, no. 8, 1978, pp. 1759-1764. https://doi.org/10.1139/z78-240

Urquhart, Fred A., and Norah Urquhart. "Insect Migration Studies Newsletter to Research Associates." 1964-1995. https://monarchwatch.org/read/articles/index.htm Accessed 5 Aug. 2022

Urquhart, Fred A., and N.R. Urquhart. "The Overwintering Site Of The Eastern Population Of The Monarch Butterfly (*Danaus p. plexippus*; Danaidae) In Southern Mexico." *Journal of the Lepidopterists' Society*, vol. 30, no. 3, 1976, pp. 153-158. Available: https://images.peabody.yale.edu/lepsoc/jls/1970s/1976/1976-30(3)153-Urquhart.pdf

Karl von Frisch

Couvillon, M. J. “The Dance Legacy of Karl von Frisch.” *Insectes Sociaux*, vol. 59, no. 3, 10 Feb. 2012, pp. 297–306, https://doi.org/10.1007/s00040-012-0224-z.

Edrich, Wolfgang. “Honey Bees Can Perform Accurately Directed Waggle Dances Based Solely on Information from a Homeward Trip.” *Journal of Comparative Physiology A*, vol. 201, no. 10, 18 July 2015, pp. 1003–1010, https://doi.org/10.1007/s00359-015-1030-7.

Hu, Zongwen, et al. “Decoding the Dance Parameters of Eastern Honeybee, Apis Cerana.” *Apidologie*, vol. 54, no. 1, 31 Jan. 2023, https://doi.org/10.1007/s13592-023-00990-5. Accessed 12 Aug. 2022.

Karl von Frisch. *Dance Language and Orientation of Bees*. Harvard University Press, 2014.

Karl von Frisch – Facts. NobelPrize.org. Nobel Prize Outreach AB 2024. Thu. 25 Apr 2024. https://www.nobelprize.org/prizes/medicine/1973/frisch/facts/

Rooum, Donald. “Karl von Frisch and the “Spot Codes” for Marking Insects.” *Bee World*, vol. 70, no. 3, Jan. 1989, pp. 120–126, https://doi.org/10.1080/0005772x.1989.11099002. Accessed 12 Aug. 2022.

“The Dancing Bees: Karl von Frisch and the Discovery of the Honeybee Language.” *YouTube*, uploaded by Linda Hall Library, 10 July 2023, https://www.youtube.com/watch?v=7Yw6uYn9j0U

Thorpe, W.H. “Karl von Frisch, 20 November 1886 - 12 June 1982.” *Biographical Memoirs of Fellows of the Royal Society*, vol. 29, Nov. 1983, pp. 197–200, https://doi.org/10.1098/rsbm.1983.0008.

von Frisch, K., and M. Lindauer. “The “Language” and Orientation of the Honey Bee.” *Annual Review of Entomology*, vol. 1, no. 1, Jan. 1956, pp. 45–58, https://doi.org/10.1146/annurev.en.01.010156.000401.

von Frisch, Karl. “Dialects in the Language of the Bees.” *Scientific American*, vol. 207, no. 2, Aug. 1962, pp. 78–89, https://doi.org/10.1038/scientificamerican0862-78. Accessed 12 Aug. 2022.

Suzanne Simard

Beiler, K. J., et al. “Mapping the Wood-Wide Web: Mycorrhizal Networks Link Multiple Douglas-Fir Cohorts.” *New Phytologist*, vol. 185, 2010, pp. 543–553.

“How Trees Talk to Each Other - Suzanne Simard.” *YouTube*, uploaded by TED, 30 Aug. 2016, https://www.youtube.com/watch?v=Un2yBgIAxYs.

Simard, S. W. “Conversations in the Forest: The Roots of Nature's Equanimity.” *SGI Quarterly*, vol. 79, 2015, pp. 8–9.

---. “Mycorrhizal networks facilitate tree communication, learning and memory.” *Memory and Learning in Plants.* edited by F. Baluska, M. Gagliano, and G. Witzany, Springer, 2018, pp. 191-213.

Simard, S. W., et al. “Mycorrhizal Networks: Mechanisms, Ecology and Modelling.” *Fungal Biology Reviews*, vol. 26, no. 1, Elsevier BV, Apr. 2012, pp. 39–60, https://doi.org10.1016/j.fbr.2012.01.001.

Simard, S.W., et al. “Net transfer of carbon between tree species with shared ectomycorrhizal fungi.” Nature, no. 388, 1997, pp. 579-582.

Simard, Suzanne. *Finding the Mother Tree*. New York, Alfred A. Knopf, 2021.

Song, Y. Y., et al. “Defoliation of Interior Douglas-Fir Elicits Carbon Transfer and Defense Signaling to Ponderosa Pine Neighbors through Ectomycorrhizal Networks.” *Nature,* vol. 5, 2015, https://doi.org10.1038/srep08495.

Teste, F.P., et al. “Access to mycorrhizal networks and tree roots: importance for seedling survival & resource transfer.” Ecology, no. 90, 2009, pp. 2808-2822.

“The secret language of trees - Camille Defrenne and Suzanne Simard.” *YouTube*, uploaded by TED-Ed, 1 July 2019, https://www.youtube.com/watch?v=V4m9SefyRjg.

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The crosscutting concepts provide a framework for curiosity. When you teach children to use the CCCs, they think more deeply about what they are observing. They are able to organize their thoughts and communicate their ideas clearly. And they can experience the world’s richness during a lifetime of exploration, whether they become scientists or not.

Sparking an early interest in science is the key to a rich relationship with the world around us. So go on, invite the children in your life to join you in making sense of these curious scientists’ fascinating finds. Discovery awaits!

THINK LIKE A SCIENTIST: ASTEROIDS, COLOR-CHANGING MOTHS, AND GREEN DESERTS
SOLVING SCIENCE MYSTERIES WITH STABILITY AND CHANGE

By Emily Mae Starr

Look in the mirror. Can you see your face changing? *No!*

But, look in the mirror ten years from now, and you will have changed. The changes are just too slow for you to notice from day to day.

Not all changes are slow. An asteroid hitting the earth is a quick change. You would notice!
Other changes are too small for us to see–like bacteria growing on leftovers that should have been put in the fridge. *Yuck!*

Each of the scientists in this book noticed changes in the world that led to ground breaking discoveries. Come look at the world through their eyes. See how you can use big ideas about stability and change to solve science mysteries about asteroids, moths, and deserts!

Grab your favorite notebook, sharpen your pencil, and get ready to think like a scientist!

ASTEROIDS

Roooooaaaarrrr!!! A T-rex pounds across the screen chasing a screaming actor. That's not right! You know dinosaurs were not on Earth with humans. But, the thought makes you wonder: *Why did dinosaurs become extinct?*

THINK LIKE A SCIENTIST: Where would you look for evidence to figure out why dinosaurs went extinct millions of years ago?

[Sidebar: Stability and Change Big Idea: Some earth events happen slowly while others happen quickly.]

The Mystery of the Dead Dinos

Walter Alvarez puzzled over photographs–rock samples magnified thousands of times. Fossilized forams were locked in the rock. The teeny tiny invertebrates hinted at an ancient mystery. One sample held forams as big as one millimeter–the size of a grain of sand–quite large for a foram. The other sample showed forams a fraction of the size–nearly invisible without a microscope–and fewer in number. *Why were the samples so different?*

As a geologist, Walter had extracted the rock from two different layers, one closer to Earth's surface than the other. The rock layers were separated by a thin, gray stripe of clay–called the K-Pg boundary. This dingy colored layer, found in rocks around the globe, had mysteriously blanketed the entire world at the same time–65 million years ago. The forams below the clay layer–huge and plentiful. The forams above–puny and sparse. *Did the clay have something to do with the difference?*

[Sidebar: A geologist is a scientist who studies rocks.]

[Sidebar: The boundary is called K-Pg because it marks the end of the Cretaceous time period (K because Kreide is the German word for the Cretaceous) and the beginning of the Paleogene time period (Pg).]

In the mid-1970s, Walter heard another scientist talk about the K-Pg boundary. Not only did forams change at the boundary, so did fossils everywhere on Earth. More than 75% of animals appeared to go extinct at the clay layer–including the most famous disappearance of all–the dinosaurs!

THINK LIKE A SCIENTIST: What conclusion could you draw from the fossil evidence that 75% of animals appear below the clay layer but not above it? Why do you think that?

Convinced of clues in the clay, Walter asked his physicist father, Luis, for help. *Was the clay deposited slowly or quickly? How was it spread around the world?* Luis thought analyzing elements in the clay held the answers–specifically, the element iridium.

[Sidebar: A physicist is a scientist who studies the interactions of matter and energy.]

Iridium is a hard, silver-colored metal. Hardly any occurs naturally in Earth's crust, yet rocks everywhere contain some iridium. That's because iridium falls to Earth in meteorite dust–a constant light sprinkling we don't even notice. Yet, rocks remember.

If Luis could find out how much iridium was in the clay, he could determine how quickly the layer was deposited.

Luis calculated. *How much iridium normally drifts through the atmosphere every year?*

Luis tested. *How much iridium is in the clay?*

Impossible!

Luis shared his results with a colleague. He suggested they do the test again. It couldn't be right!

Luis tested again.

His results were even more astounding.

[Illustration Note: On this page is a graphic that shows the amount of iridium expected versus the amount found.
Expected Iridium Amount If Clay Deposited Slowly: .1 ppb
Expected Iridium Amount If Clay Deposited Quickly: 0 ppb (None at all.)
Actual Iridium Amount in Clay: 9 ppb
Note: ppb equals parts per billion. It is a tiny amount. To help you visualize, think about a billion marbles in a huge container. One of those marbles is one part per billion. Now, think about cutting one

marble into ten parts, one of those small pieces of a whole marble equals .1 part per billion. This is the amount of iridium they expected if the clay deposited slowly. Instead, they found nine parts per billion – nine whole marbles!]

THINK LIKE A SCIENTIST: What do you notice about the amount of iridium found in the clay layer? How do you think that amount of iridium could be quickly deposited all over Earth?

Iridium was 90 times greater than expected in the K-Pg boundary! The layer of clay was so thin, there was no way it had deposited slowly enough to collect that much iridium sifting slowly from space. This meant something quick and catastrophic wiped out three-fourths of life on Earth. *But what?*

Walter, Luis, and a team of colleagues brainstormed and calculated, discussed and tested. In 1980, they finally shared their conclusion: a massive asteroid hit the earth 65 million years ago. The impact sent a gigantic cloud of rock and dust into the atmosphere that blanketed the entire globe. This sun-blocking plume prevented photosynthesis, cooled the planet, and caused the extinction of more than 75% of plants and animals–including the dinosaurs. After many years, the rock and dust settled into the iridium-rich layer of clay, covering the bones of the last dinosaurs to walk Earth. Walter and Luis had discovered the catastrophic change that doomed the dinosaurs.

[Sidebar: Photosynthesis is how organisms (mostly plants) make food. They use energy from sunlight to combine water and carbon dioxide into sugar and oxygen. All life on Earth depends on food from plants.]

THINK LIKE A SCIENTIST: Although most scientists agree with Luis and Walter's claim, some think dinosaurs went extinct for other reasons. What additional evidence would you search for to support the asteroid extinction theory?

Your first stability and change breakthrough! You dug into the rock record to discover an asteroid impact that wiped the dinosaurs off the planet.

[Sidebar: Stability and Change Spotlight: While many events on Earth happen slowly, the asteroid that killed three-fourths of life on earth was a quick catastrophe.]

No time to rest. From disappearing dinosaurs to multi-colored moths, your next discovery awaits!

<u>COLOR-CHANGING MOTHS</u>

Gasp! That hill hike was brutal! You reach to rest on the trunk of a sturdy oak and quickly yank your hand away. Statue-still, as if painted on the rough bark is a charcoal-colored moth. You lean in and the moth flees. . . along with four more moths. These black and white speckled surprises were nearly invisible against the lichen-covered wood. The moths looked like the same type, so you wonder: *Why are they different colors?*

THINK LIKE A SCIENTIST: Why might the same type of moth be different colors?

[Sidebar: Stability and Change Big Idea: Changes in one system cause changes in other systems.]

The Moth Mystery

Henry Bernard Davis Kettlewell picked his way through the overgrown forest in the English countryside. Dodging bushes and ducking limbs, he worked his way to the base of an oak. Henry set his last trap–topped with a moth-attracting light and a funnel to direct the curious insects into the bucket base.

The trap was part of Henry's plan to solve a moth mystery. As a lepidopterist, Henry knew that the same peppered moth species was found in different colors in different areas.
Near cities, charcoal colored dominated. In the country, black and white speckled flourished.
Why did the same moth appear in two different colors in two different areas? No one knew.

[Sidebar: A lepidopterist is a scientist who studies butterflies and moths.]

Other scientists guessed that predator birds ate some moths but not others. Henry wasn't sure birds preferred a moth meal. So, he designed an investigation to find out.

In 1955, he set his tricky traps in two areas–a polluted forest next to a city and an unpolluted forest in the country. Once collected, he counted the moths, noted their colors, and marked the underside of their wings with paint.

Properly prepared, Henry returned to the polluted forest near the city and released the marked moths. Since peppered moths are only active at night, they quickly settled, still as stone on the dark oak bark blackened by the city's sooty pollution. Henry settled in to watch. Over hours of observation, he saw predator birds swoop and snatch. They snacked and gulped. *Birds do eat moths!*

Henry repeated the process in the unpolluted forest in the country. Once again, the moths settled. But this time, their host bark was not blacked by soot. It was lighter in color and spotted with lichens. Once again, the birds feasted while Henry watched and recorded.

THINK LIKE A SCIENTIST: What do you notice about the two photographs below? Which color of moth do you think the birds ate the most in the polluted forest? In the unpolluted forest? Why?

[Sidebar: Lichens look like plants, but they are not. Lichens are two organisms, usually fungi and algae, growing together in low leafy-looking structures on walls, rocks and trees.]

[Illustration note: On the page are two photographs. One shows both colors of moth on a sooty tree while the other shows both on a lighter barked tree.]

A week later, Henry once again crept through both forests and set traps. *How many painted participants were left in each location?*

THINK LIKE A SCIENTIST: What do you notice and wonder about Henry's data?

[Illustration note: On the page is a chart showing a simplified version of Henry's data from his research study:

Percentage of Painted Moths Recaptured

	Polluted Woods	*Unpolluted Woods*
Light Wings	*13%*	*12.5%*
Dark Wings	*27.5%*	*7%*

Henry's data showed that birds in polluted forests ate more speckled, freckled moths. The light colored moths were unable to hide against a black background–a sooty canvas that gave the charcoal moths the perfect camouflage. In unpolluted rural forests, the charcoal moths stood out as black bird bullseyes against the lighter oak bark.

[Sidebar: Camouflage is the ability to blend into your surroundings, so you are not as easily seen.]

More charcoal survivors in polluted forests meant more charcoal offspring. The opposite was true in the country forests where more light-colored moths lived to create the next generation. Over time, the changing city had changed the forest and the moths.

Henry's experiments are one of the best pieces of evidence proving the theory of natural selection–how populations of organisms change over time. Those with the most effective survival traits, like better camouflage, live to have offspring. Members of the species without those traits are eaten before they have a chance to reproduce.

THINK LIKE A SCIENTIST: What do you think would happen if the urban forest became less polluted? Why?

Mystery solved. You discovered how peppered moths changed color over time because of their changing environment.

[Sidebar: Stability and Change Spotlight: An increase in the amount of pollution in forests changed the color of peppered moths over time from speckled to charcoal.]

From the colors of moths to the colors of a desert, your next discovery awaits!

GREEN DESERTS

You wave to your house one last time as your packed SUV pulls down the street. Your family is trading soggy Seattle for sunny San Diego. Moving is tough, but you brought a bit of home to soften the blow–an orchid from your front yard. You'll place the plant on the windowsill in your new bedroom, making sure it gets enough sunlight and water. You can keep one plant alive indoors, but you've heard San Diego has little rain. *How are you going to keep plants alive in your new yard?*

THINK LIKE A SCIENTIST: How might plants that thrive in San Diego be different from plants that grow well in Seattle? Why?

[Sidebar: Stability and Change Big Idea: Changes in nature can have human causes.]

The Mystery of the Green Desert

Katherine Olivia Sessions stood statue-still gazing over City Park in San Diego. In 1883, this dry, dusty, scrubby ground was not a proper park. Kate thought a park should be filled with life–trees stretching skyward, bushes spreading wide, and flowers providing pops of color. The people of San Diego thought this was impossible. They knew their warm, dry climate turned green things brown. Kate didn't listen. Where passersby saw a lifeless landscape, Kate saw possibility.

As a botanist, Kate knew that all plants need sunshine, rain, and nutrients–yet some plants require less than others. *But which plants were right for San Diego?*

THINK LIKE A SCIENTIST: How could you conduct research to find plants that could grow in San Diego's climate if you didn't have a phone or computer to help you?

[Sidebar: A botanist is a scientist who studies plants.]

Kate wrote to gardeners across the country. *What plants need little water? Which thrive the sizzling summer sun?* Kate traveled to Mexico and trekked through the desert–seeking, searching, *hunting* the perfect plants.

She filled her new San Diego nursery with boojum trees shaped like upside down carrots and dragon trees with leaves like bursting fireworks. They joined purple flowered jacaranda trees and fragrant eucalyptus that Kate helped residents plant to beautify their yards and streets.

Kate even made a deal with city leaders–if she could use a patch of land in City Park for her nursery, she would plant one hundred trees in the park every year and give the city three hundred more to plant anywhere they chose.

While the park slowly and steadily became greener, Kate slowly and steadily realized the job of planting trees was too large for one person. Her vision of a green, lush landscape needed help. Lots of help.

THINK LIKE A SCIENTIST: As a scientist, how might you find help to accomplish a large goal like planting millions of trees and plants in a park?

In 1909, help arrived in the form of a fair. City leaders planned to host the Panama-California Exposition in 1915. The location? City Park. Not wanting visitors to bake in the sweltering sun, city leaders realized the park needed more trees. Millions more. *Who could accomplish such a feat?* Kate of course!

Kate collected friends, rallied residents, and cheered volunteers. They hauled and sweat, dug and planted. And when the fair opened, visitors strolled beneath leafy canopies and along sidewalks lined with beautiful bougainvillea. *Who knew San Diego could support such bountiful plant life?* Kate did. She knew from the moment she glimpsed the park–renamed Balboa Park–where trees planted by Katherine Olivia Sessions still flourish.

THINK LIKE A SCIENTIST: How could ideas from Kate's story help you improve an area in your community?

Another stability and change discovery! You uncovered how planting the right kinds of trees can change a landscape from brown and barren to green and growing.

[Sidebar: Stability and Change Spotlight: Natural landscapes can be changed over time by humans planting vegetation suited for a specific climate.]

Congratulations, junior scientist! You made sense of our wondrous world using ideas about stability and change. What puzzling mysteries will you think like a scientist to solve next?

BACK MATTER

Walter Alvarez

Walter and Luis's theory that an asteroid killed the dinosaurs along with three-fourths of life on Earth rocked the world. Many geologists resisted the idea because they believed in uniformitarianism, the idea that the way things happen today is also how they happened in the past. They believed events only happen gradually, like a species slowly dying out over thousands of years. An asteroid impact would have killed life on earth very quickly. This theory of a sudden catastrophic event didn't fit with many geologists' view of the world.

But Walter and Luis believed in their theory. Along with other scientists, they searched for more evidence. They discovered shocked quartz–rock that had been damaged by a sudden shock wave traveling through the rock - the kind of wave created by an asteroid impact. They found ripples in rocks and ocean sediments deposited far inland–evidence of a huge tsunami wave. A wave that could have been triggered by an asteroid plunging into the ocean.

In 1991, eleven years after Walter and Luis published their theory, a group of scientists found the most convincing evidence–the Chicxulub (Chicks-uh-lub) crater. Buried deep in the Yucatan Peninsula in Mexico, this 150 kilometer wide crater is so large it would take you an hour and a half to drive across it in a car–if you could. Because the asteroid hit both land and ocean, clues in the rock record were confusing–part of the reason the crater remained hidden for so long.

Walter has won several awards including the Penrose medal from the Geological Society of America. He is the originator of the idea of Big History–the "attempt to understand, in a unified and interdisciplinary way, the history of the Cosmos, Earth, Life and Humanity." His Big History idea led to the founding of the International Big History Association.

Learn more: *The Day the Dinosaurs Died* (PBS - Nova Video, 2017)

Walter Alvarez (John Simon Guggenheim Memorial Foundation)
https://www.gf.org/fellows/walter-alvarez/

Henry Bernard Davis Kettlewell

Henry's experiments showed not only how natural selection occurs but also how pollution has dramatic effects on surrounding environments. The phenomenon of organisms that live near sources of pollution becoming darker over time is known as: industrial melanism.

Henry examined peppered moth research conducted before the industrial revolution and found that charcoal colored peppered moths were almost non-existent. He also found that the number of dark colored moths increased as pollution in an environment increased. Since Henry's experiments in the 1950s, environmental laws in England and the United States have resulted in cleaner air and lighter colored surfaces. In the United States, the moth population has responded by going from nearly 100% charcoal-colored in Pennsylvania and Michigan in 1959 to only 6% in 2001.

Learn more: *Moth: An Evolution Story* by Isabel Thomas (Bloomsbury Children's Books, 2019)

Dr. Kettlewell (Ask a Biologist)
https://askabiologist.asu.edu/peppered-moths-game/kettlewell.html

Peppered Moth natural selection experiments (University of Oxford)
https://learningzone.oumnh.ox.ac.uk/peppered-moth-natural-selection-experiments

Katherine Olivia Sessions

Katherine Olivia Sessions was a pioneering biologist during a time when women were not encouraged, and sometimes not even allowed, to earn scientific degrees. When Kate moved to San Diego for a teaching job, she took with her a lifelong love of plants and a degree in natural science from the University of California, Berkeley. This background allowed her to see potential that no one else saw in the almost barren City Park (later renamed Balboa Park).

Kate shared gardening advice in newspaper and magazine articles to help everyone become successful gardeners. She was honored with many awards including the Meyer Medal, awarded for successfully introducing foreign plants into the United States. She was the first woman to receive the medal. Kate is credited with turning San Diego into the lush, green place it is today where some trees she planted over one hundred years ago are still thriving. Balboa Park is enjoyed by fourteen million visitors each year, who walk past a statue of Kate at the entrance to the green oasis in the desert she created.

Learn More: *The Tree Lady* by H. Joseph Hopkins (Beach Lane Books, 2013)

Questioning Guide (For Grown-Ups)

The *Think Like a Scientist* questions do not have correct or incorrect answers. The questions are intentionally open-ended to encourage a variety of responses and lively scientific discussions. The answers below are examples of the many ideas children may share.

Where would you look for evidence to figure out why dinosaurs went extinct millions of years ago? This question puts children in the role of a scientist and helps them realize the importance of gathering evidence. Children may initially share sources such as the Internet and books. Children with background knowledge may suggest examining rocks and fossils. If needed, you can prompt with additional questions: *Where in nature could you look for evidence? What type of evidence would last millions of years?*

What conclusion could you draw from the fossil evidence that 75% of animals appear below the clay layer but not above it? Why do you think that?

This question gives children the opportunity to draw an evidence-based conclusion. Children may share that the fossil evidence shows that some animals went extinct. Others may share that the Earth changed in some way or that something terrible happened. If needed, you can prompt with additional questions: *What do fossils tell us? Why would fossils of some animals stop showing up in the rock record? What do you think may have happened on Earth that caused 75% of animals to stop showing up in fossils?*

What do you notice about the amount of iridium found in the clay layer? How do you think that amount of iridium could be quickly deposited all over Earth?

This question gives children the opportunity to analyze data. Children may be able to recognize that the amount of iridium found in the clay layer is much greater than expected. Children may be able to use the text clue that iridium comes from space to predict that something large from space–like a comet, meteor, or asteroid crashed into Earth. If needed, you can prompt with additional questions: *How does the amount of iridium found compare to the amount they expected to find? Where does the text say iridium on Earth comes from? How do you think such a large amount of iridium could be brought to Earth from space?*

Although most scientists agree with Luis and Walter's claim, some think dinosaurs went extinct for other reasons. What additional evidence would you search for to support the asteroid extinction theory?

This question puts children in the role of a scientist and helps them realize the importance of gathering evidence. Children may share that they would search for more clues in the rock record or that they would want to find where the asteroid hit Earth. If needed, you can prompt with additional questions: *What additional evidence of an asteroid impact would be in the rock record? How do you think an asteroid impact would affect Earth? What evidence would those effects leave in the rock record?*
Why might the same type of moth be different colors?

This question gets children wondering about something that happens in nature. Children's predictions will be wide ranging. Some may guess camouflage is involved. Others may say it is because all animals come in a variety of colors. At this point, they most likely won't have the background knowledge to predict it involves pollution or natural selection. If needed, you can prompt with additional questions: *Why are animals certain colors and not others? How does an animal's color help it to survive? How might a moth's survival be related to its coloring?*

What do you notice about the two photographs below? Which color of moth do you think the birds ate the most in the polluted forest? In the unpolluted forest? Why?

This question gives children practice observing nature and drawing conclusions. Children should notice that the charcoal moth blends in more easily in one photo than the other; however, they may not yet know it is called camouflage. Children will most likely predict that birds ate more speckled moths in the polluted forest and charcoal moths in the unpolluted forest because the moths were not well camouflaged. If needed, you can prompt with additional questions: *Which moth can you most easily see in each photograph? Why? Do you think birds ate more of the well-hidden moths or the moths they could more easily see? Why?*

What do you notice and wonder about Henry's data?

This question gives children the opportunity to analyze data, draw conclusions, and develop questions for further investigation. Children may notice that there were more light-colored moths collected in the unpolluted forest and more dark colored moths collected in the polluted forest. Children may relate back to the previous photographs and wonder if it is because of a difference in camouflage–though they may not yet use that vocabulary. If needed, you can prompt with additional questions: *What do you notice when you compare the number of charcoal moths collected in the polluted forest to the* *number collected in the unpolluted forest? What do you wonder about that difference? What questions would you ask Henry about his data? What questions would you investigate next?*

What do you think would happen if the urban forest became less polluted? Why? How long do you think it would take to see a change in the peppered moth population? What information would help you to make an accurate prediction?

This question asks children to make a prediction based on a pattern of change. Children should be able to predict that the moth population would become more speckled. They should use evidence from the text to support their prediction, specifically that birds will begin eating more charcoal moths because they no longer have soot covered trees to camouflage their dark bodies. Some children may share that they would want to know how long it took the moth population to change from light to dark in the first place or that they would need to know how quickly the tree bark lightened. Some children may also want to know how quickly the moths reproduce. If needed, you can prompt with additional questions: *What would the trees look like if the urban forest became less polluted? How would a change in the color of the trees affect the color of the moths? What information in the text could help you with your prediction? How could knowing how quickly the forest becomes lighter help you to make your prediction?*

How might plants that thrive in San Diego be different from plants that grow well in Seattle? Why?

This question asks children to combine their prior knowledge with information from the text to draw a conclusion. Children may identify that the text says Seattle was rainy and San Diego is dry. They can combine this information with prior knowledge that plants need water to draw the conclusion that plants needing a lot of water will do well in Seattle while plants needing little water will thrive in San Diego. If needed, you can prompt with additional questions: *What do plants need to survive? How is the weather in San Diego different from the weather in Seattle? How might those weather differences affect what can grow in each location?*

How could you conduct research to find plants that could grow in San Diego's climate if you didn't have a phone or computer to help you?

This question asks children to consider research methods that do not involve electronics. It may be challenging for children to think of communication methods that do not involve the Internet. They may think of writing letters, but they may not have the background knowledge to think of putting an ad in newspapers and magazines. Some children may think of traveling to other locations with a similar climate. If needed, you can prompt with additional questions: *How did people communicate with one another and get news and information in the early 1900s? If you knew of another location with a climate similar to San Diego, how could you find out what plants grow well there?*

As a scientist, how might you find help to accomplish a large goal like planting millions of trees and plants in a park?

This question introduces children to the concept of community volunteers. It also helps children to realize that it was a lot of hard work for Kate to find volunteers willing to help. Children may think of asking friends, family, and people in the community for help. When thinking about how to contact volunteers, it may be challenging for children to think of communication methods that don't involve electronics. They may think of writing letters, but they may not have the background knowledge to think of putting an ad in newspapers and magazines. If needed, you can prompt with additional questions: *Who could Kate ask to help? How could she contact them? How did people communicate with one another and get news and information in the early 1900s?*

How could ideas from Kate's story help you improve an area in your community?

This question asks children to apply what they have learned to a new situation that directly impacts their community. Children's ideas will be wide ranging and should focus on using information from the text, such as planting trees, asking volunteers for help, or conducting research on what types of plants will grow well in their area. If needed, you can prompt with additional questions: *How could Kate's ideas about planting trees and gathering community volunteers be used to help our community?*

Bibliography

Crosscutting Concepts

Next Generation Science Standards. National Academies Press, 2013, https://doi.org10.17226/18290.

Nordine, Jeffrey. and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning.* NSTA Press, National Science Teaching Association, 2021.

Walter and Luis Alvarez

Alvarez, L. W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." *Science*, vol. 208, no. 4448, 6 June 1980, pp. 1095–1108, https://doi.org/10.1126/science.208.4448.1095.

Alvarez, Walter. *T. Rex and the Crater of Doom*. Princeton, Princeton University Press, 2015.

Chiarenza, Alfio Alessandro, et al. "Asteroid Impact, Not Volcanism, Caused the End-Cretaceous Dinosaur Extinction." *Proceedings of the National Academy of Sciences*, vol. 117, no. 29, 29 June 2020, pp. 17084–17093, https://doi.org/10.1073/pnas.2006087117.

Durand-Manterola, Hector, and Guadalupe Cordero-Tercero. *Assessments of the Energy, Mass and Size of the Chicxulub Impactor*. 19 Mar. 2014.

Senel, Cem Berk, et al. "Chicxulub Impact Winter Sustained by Fine Silicate Dust." *Nature Geoscience*, vol. 16, no. 11, Nov. 2023, pp. 1033–1040, https://doi.org/10.1038/s41561-023-01290-4.

Henry Bernard Davis Kettlewell

Cook, L. M., et al. "Selective Bird Predation on the Peppered Moth: The Last Experiment of Michael Majerus." *Biology Letters*, vol. 8, no. 4, 8 Feb. 2012, pp. 609–612, https://doi.org/10.1098/rsbl.2011.1136.

de Roode, Jaap. "The Moths of War." *NewScientist*, 8 Dec. 2007, pp. 42–45, biology.emory.edu/research/deRoode/PDFs/De%20Roode%202007%20-%20peppered%20moth.pdf.

Grant, B. S. "Recent History of Melanism in American Peppered Moths." *Journal of Heredity*, vol. 93, no. 2, 1 Mar. 2002, pp. 86–90, https://doi.org/10.1093/jhered/93.2.86.

Hagen, Joel B. "H.B.D. Kettlewell and the case of the peppered moths." *In Doing Biology*, edited by J.B. Hagen, D. Allchin and F. Singer, Harper Collins, 1996, pp. 1-10.

---. "Kettlewell and the peppered moths reconsidered." *BioScene*, vol. 19, no. 3, 1993, pp. 3-9.

---. “Retelling Experiments: H.B.D. Kettlewell’s Studies of Industrial Melanism in Peppered Moths.” *Biology & Philosophy*, vol. 14, no. 1, Jan. 1999, pp. 39–54, https://doi.org/10.1023/a:1006576518561.

Kettlewell, H. B. D. “Darwin’s Missing Evidence.” *Scientific American*, vol. 200, no. 3, Mar. 1959, pp. 48–53.

---. “Darwin’s Missing Evidence: Changes in Moths Observed.” *Scientific American*, 20 Feb. 2009, www.scientificamerican.com/article/darwins-missing-evidence/.

---. “Further Selection Experiments on Industrial Melanism in the Lepidoptera.” *Heredity*, vol. 10, no. 3, Dec. 1956, pp. 287–301, https://doi.org/10.1038/hdy.1956.28.

---. “Selection Experiments on Industrial Melanism in the Lepidoptera.” *Heredity*, vol. 9, no. 3, Dec. 1955, pp. 323–342, https://doi.org/10.1038/hdy.1955.36.

Majerus, M.E.N. “Industrial Melanism in the Peppered Moth, *Biston betularia*: An Excellent Teaching Example of Darwinian Evolution in Action.” *Evo Edu Outreach*, no. 2, 2009, pp. 63–74. https://doi.org/10.1007/s12052-008-0107-y

Rudge, David W. “The Beauty of Kettlewell's Classic Experimental Demonstration of Natural Selection.” *BioScience*, vol. 55, no. 4, April 2005, pp. 369–375, https://doi.org/10.1641/0006-3568(2005)055[0369:TBOKCE]2.0.CO;2

Rutowski, Ronald, and Sean Hannam. “Peppered Moth - Natural Selection - Ask a Biologist.” *Asu.edu*, 4 Aug. 2015, askabiologist.asu.edu/peppered-moth.

Katherine Olivia Sessions

“About.” *Balboa Park*, balboapark.org/about-balboa-park.

Dykens, Margi. “Kate Sessions: A Legendary San Diego Icon.” *The Nat*, www.sdnhm.org/blog/blog_details/kate-sessions-a-legendary-san-diego-icon/99.

“Balboa Park - The Jewel of San Diego.” *YouTube*, uploaded by San Diego, 13 Jan. 2015, https://www.youtube.com/watch?v=IeIqaNR5Zs4.

Carter, Nancy Carol. “WHEN DR. FAIRCHILD VISITED MISS SESSIONS: SAN DIEGO 1919.” *The Journal of San Diego History*, vol. 50, no. 3, 2004, pp. 74-89.

“Kate Sessions.” *Women’s Hall of Fame*, www.sandiegowomenshalloffame.com/inductee/kate-sessions.

“Kate Sessions 1857-1940.” *San Diego History Center*, sandiegohistory.org/archives/biographysubject/sessions/.

“Nancy Carol Carter: Kate Sessions’ World Wide Web of Horticulture.” *YouTube*, uploaded by San Diego Horticultural Society, 16 Aug. 2020, https://www.youtube.com/watch?v=P8f6QsVaG5g

“November 8 – Kate Sessions, Mother of Balboa Park, Born (1857) – Today in Conservation.” *Today in Conservation: Day by Day in Conservation History*, todayinconservation.com/2022/03/november-8-kate-sessions-mother-of-balboa-park-born-1857/. Accessed 16 Apr. 2024.

“San Diego History Center |.” *San Diego History Center*, collections.sandiegohistory.org/asset/52150. Accessed 16 Apr. 2024.

“TWO MEYER MEDALS AWARDED DURING 1939: Kate Sessions and David Fairchild Cited for Plant Introduction Achievements,” *Journal of Heredity*, vol. 30, no. 12, Dec 1939., pp. 531–536, https://doi.org/10.1093/oxfordjournals.jhered.a10465

Encouraging Students to "Think Like a Scientist" Through Picture Books Designed to Support Research-Based Science Education

By Emily Starr

Think Like a Scientist is a STEM series of nonfiction picture books that invite 7-11 year olds to delight in the thrill of scientific discovery. Intriguing questions pull readers into the shoes of diverse scientists to form hypotheses, design investigations, and examine evidence. Conceptualized as part adult handbook for science discussions and part children's role model for real life science, the series is designed to cultivate an early love of science in every child.

When my son, Logan, graduated from preschool, he participated in a diploma ceremony. As each five-year-old walked across the stage, the teacher announced the child's adult career aspirations. Among a group of future police officers, firefighters, princesses, and ballerinas, Logan's choice stood out. He wanted to be a paleontologist. This stark contrast was a turning point for me. I already knew Logan possessed a profound advantage when it came to STEM. We had been reading nonfiction picture books, conducting STEM experiments, and exploring the world around us for years. For me, the career-sharing ceremony served to shine a spotlight on Logan's head start, and because of my research, I knew this gap would likely grow larger.

Between 2015 and 2022, I was the principal investigator for five federally funded Small Business Innovation Research Grants. I investigated how young children learn science and developed two award-winning products that help elementary educators be better science teachers. As part of that work, I became well-versed in elementary science content and pedagogy. I discovered that by eighth grade nearly 50% of students could care less about science–no thank you, not interested, won't change their minds. The greatest flood of talent is leaking from the STEM pipeline in elementary school and no one is addressing this problem–or even talking about it.

It was my experience with Logan coupled with my research knowledge that sparked the idea for this series in 2022. As I read nearly 600 STEM-themed nonfiction picture books for a work-related project, I noticed a gap in the market. I couldn't find picture books that helped students to actively take on the role of a scientist, and there certainly weren't any books that incorporated the crosscutting concepts (one of three dimensions, or parts, of the Next Generation Science Standards.) I envisioned a series that could help create awareness of the need for early science education and that could provide busy parents and teachers a resource to help their children develop a love of science. I imagined Logan's classmates reading the *Think Like a Scientist* series and discovering diverse STEM careers, gobbling up fascinating facts, and engaging in rich discussions about the world around us.

Most of all, I wanted children to be able to see themselves doing the same work as scientists. According to The National Academies *Brilliance Report*, in order to pursue and persist in STEM careers, children must see themselves *as* scientists–engaging in tasks that adults perform in the field (61). This is one of the key differentiators of the series. Strategic questions throughout each book encourage children to engage in scientific thinking just like real-world scientists.

As a former fourth grade teacher and current provider of science curriculum materials and professional development to elementary educators, I always intended classroom educators to be the target market for this picture book series. In 2013, the Next Generation Science Standards (NGSS) were released.

Adopted by 20 states and the District of Columbia (with an additional 24 states adopting standards based on the NGSS), these new standards are written in the form of student performance expectations and integrate three dimensions of learning–Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts.[1]

This is a significant change from previous science standards that were statements of knowledge. Advice from the National Research Council provides one of the clearest ways to think about the shift in instructional practices an elementary teacher must make to meet the NGSS. The organization asserts that educators must help students move from "learning about" science to "figuring it out" (McNeill, et at. 13). This change in mindset has impacted the best practices recommended to teachers on the use of picture books as instructional tools in their classrooms.

No longer are teachers to read a nonfiction picture book about plants, such as Gail Gibbons's *From Seed to Plant*, and have their students complete a worksheet to solidify and demonstrate their understanding of the parts of a plant. Nor should a picture book reading be followed by a "canned" investigation with predefined steps a teacher has provided so students can find out if plants need light to grow. By reading a nonfiction picture book at the beginning of a lesson, teachers are "front-loading" the content. They are telling students information that, according to the NGSS as well as the constructivist theory of learning, students should be discovering on their own.

Instead of telling students how to discover this information through a teacher directed investigation, teachers should be leading students through a series of questioning experiences to help the students plan and conduct their own investigations. Planning and conducting investigations is one of the science and engineering practices in the NGSS. These are the practices scientists use in the real world; therefore, they are the practices we want our students doing in our classrooms.

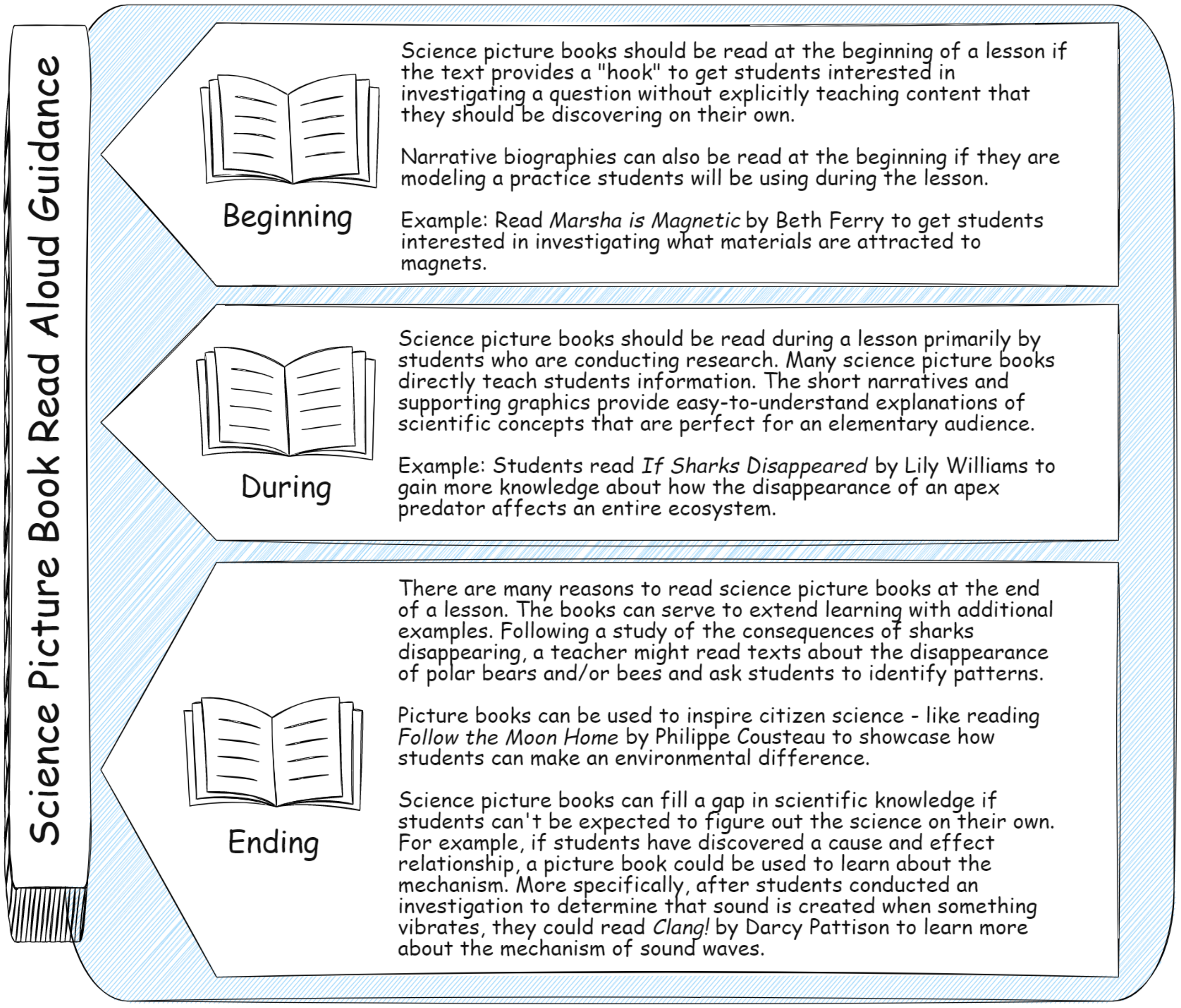
This change in best practices for science instruction has caused teachers, myself included, to think about how picture books should be used *strategically* in the structure of a lesson to support the pedagogical shift. It was this consideration that led me to develop guidelines for the use of picture books in elementary science classrooms that I shared in presentations in 2022 and 2023 at the National Science Teaching Association Conference, Iowa Reading Association Conference, and STEM Con and Beyond virtual conference. Figure 1 summarizes the guidelines I presented.

The main takeaway for teachers is that students should be constructing their own knowledge of science through investigations, not learning content ideas in isolation (in this case through picture books). Research shows that even though a student might understand a concept when taught this way, they will still struggle to apply it to new situations.[2] My pedagogical guidelines (Figure 1) help teachers to apply best practices in science education to their picture book integration strategies by moving from using picture books to "tell and show" to using texts to "inspire and motivate."

[1] See The Next Generation Science Standards.

[2] See Brown et al.; Krajcik and Shin; Duschel, et al.; and Sawyer.

FIGURE 1



An Examination of Currently Published Nonfiction Picture Books

Elementary (and middle and high school!) teachers have more nonfiction science picture books available to them than ever before. This is not only a function of the amount of publishing time that has passed but also a result of conscious changes in nonfiction picture book publishing.

In *5 Kinds of Nonfiction: Enriching Reading and Writing Instruction with Children's Books*, Melissa Stewart and Marlene Correia organize children's nonfiction into five categories:

Traditional Nonfiction – These are the "all about" books one might typically first think of as nonfiction picture books. In fact, until the late 1980s, they were the only type of nonfiction picture books available. With an expository writing style and descriptive text structure, these books give an overview of a particular topic such as *Owls* by Gail Gibbons or *Tornadoes* by Seymour Simon.

Browsable Nonfiction – Appearing in the late 1980s, these heavily illustrated books contain short blocks of text written in an expository writing style and descriptive text structure. Readers can browse specific “chunks” of information or read the entire text. One of the most well-known examples may be the yearly *Guinness Book of World Records.* Other titles include *Knowledge Encyclopedia Dinosaur!: Over 60 Prehistoric Creatures as You've Never Seen Them Before* from DK Smithsonian and *National Geographic Kids Why?: Over 1,111 Answers to Everything.*

Narrative Nonfiction – Available since the mid-1990s, this is the writing style used for most biographies, books that describe processes, and books about scientific discoveries. These texts mirror fiction with their story-like structure that includes characters, dialogue, and a narrative arc. The narrative writing style is often organized in a chronological sequence which, in the case of biographies, helps readers get an overall sense of a person and their important achievements. Examples include: *The Girl Who Built an Ocean: An Artist, an Argonaut, and the True Story of the World's First Aquarium* by Jess Keating or *Eclipse: How the 1919 Solar Eclipse Proved Einstein’s Theory of General Relativity* by Darcy Pattison.

Expository Literature – In the mid-2000s, the children’s picture book market responded to a slump in sales–the result of the Internet’s growth and the plethora of factual information suddenly at students’ fingertips–by publishing this new category of texts. Unlike traditional nonfiction which presents straightforward facts about a singular topic, expository literature presents information in creative ways–a unique text structure, a lyrical voice, and/or interesting language devices. They are often about specialized ideas such as STEM concepts and are further separated from traditional nonfiction by their innate artistic value. Examples include Melissa Stewart’s *Feathers: Not Just for Flying* and Steve Jenkins and Robin Page’s *The Animal Toolkit: How Animals Use Tools.*

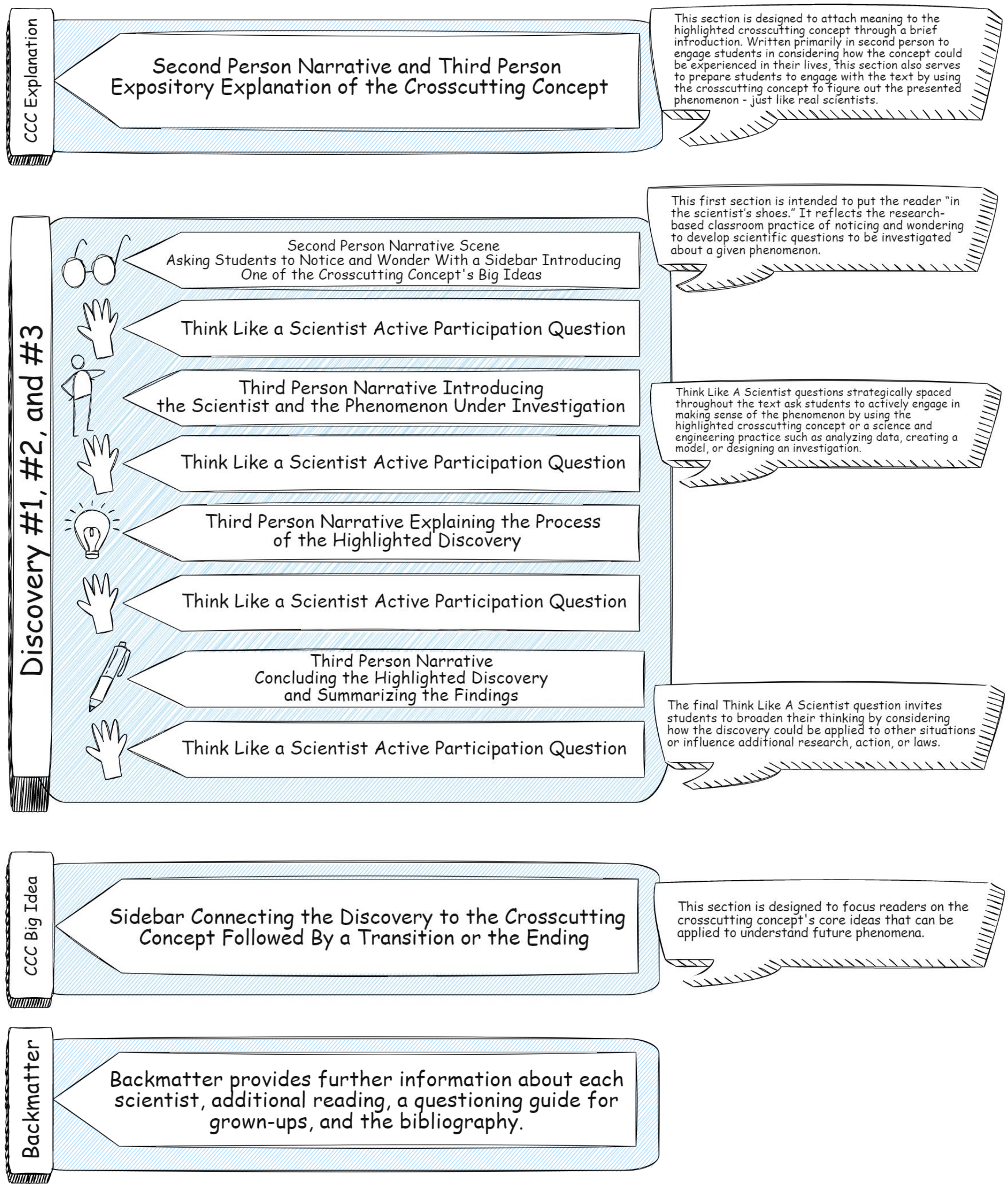
Active Nonfiction – In the market since the 1980s, these books have seen a revival in recent years as makerspaces and STEM classes have begun popping up in elementary schools across the country. These titles are “highly interactive and/or teach skills that readers can use to engage in an activity” (Stewart and Correia). Field guides, craft books, cookbooks, experiments and the like make information clear and accessible for active participation. Examples include: *The 101 Coolest Simple Science Experiments (Awesome Things to Do With Your Parents, Babysitters and Other Adults)* by Holly Homer, Rachel Miller, and Jamie Harrington and *The Delish Kids (Super-Awesome, Crazy-Fun, Best-Ever) Cookbook: 100+ Amazing Recipes* by Joanna Saltz.

Others who study and advocate for nonfiction children’s literature have also created classification systems–like from *Uncommon Corps* shared on Melissa Stewart’s blog. In the *Uncommon Corps’s* taxonomy, Inquiry, Interpretation, Action, and Disciplinary thinking are sub-categories of Stewart’s Expository Literature or Narrative Nonfiction. These more granular divisions take into account the topic of the text rather than just the text structures and features included in Stewart’s classifications.

Classifying my *Think Like a Scientist* series was a useful endeavor as I began the process of line editing because it helped to clarify the juxtaposition of different writing styles and points of view in the texts. The structure I used for every book in the series is diagrammed in Figure 2.

In her book, Stewart devotes an entire chapter to “blended nonfiction,” which is composed of the characteristics of two or more of the five categories. Since research shows that 25% of elementary students prefer narratives, 42% gravitate toward expository writing, and 33% enjoy both (Stewart and Correia 27), blended nonfiction texts encourage the literacy skills of all students by combining a preferred style with a style they may not gravitate toward naturally.

FIGURE 2



The *Think Like a Scientist* series is a member of this blended nonfiction group with its mixture of narrative nonfiction and expository literature.

Identifying a Gap in the Science Picture Book Market

In 2014, my work with my education publishing company, StarrMatica, changed to focus solely on helping teachers to implement the Next Generation Science Standards. As a result of this shift, I conducted a significant amount of research into elementary science instruction–both current practices and the research-based pedagogical vision the NGSS promoted. This research informed my writing of five successful National Institute of Food and Agriculture funded Small Business Innovation Research Grants which resulted in my development of two new products:

1) *StarrMatica Texts: Science Your Way*, a collection of Lexile-leveled science informational articles aligned to every K-5 NGSS performance expectation.
2) *The Virtual Science Coach*, an online teacher professional development platform comprised of "bite-sized" coaching videos, podcasts, and activities that take 20 minutes or less and focus on the most high-impact teaching strategies shown to raise student achievement in science.

During my grant research, I was deeply affected by a study which showed that by eighth grade, almost half of students no longer have an interest in science or do not believe it is relevant to their education and future (Murphy). Therefore, targeting students' interests and motivation *before the eighth grade* can significantly facilitate their career intentions and persistence in STEM fields.[3] In fact, research shows that sparking students' interest in science in elementary school *more effectively* creates eventual STEM career paths than encouraging high school students to take more advanced courses (Maltese and Tai 681).

The research was clear. Young children need quality elementary science instruction. It plays a critical role in keeping STEM career opportunities open to all students. Yet, research also showed that elementary science instruction–at the time of my research, a full five years after the new standards were released–was (and still is) haphazard, ineffective, and often non-existent. According to The Nation's Report Card, a survey conducted as part of the 2019 National Assessment of Educational Progress (NAEP) science assessment found that "30% of grade 4 students had teachers who reported students' participation in scientific inquiry-related activities never to once or twice a year, and these students scored lower on average in 2019 than those whose teachers reported that students participated more frequently" (National Center for Education Statistics). Additionally, only 31% of elementary teachers reported feeling very well prepared to teach science, a significant decrease from 39% in 2012. When focusing on content knowledge, only 24% felt prepared to teach life science and 20% to teach earth science. This lack of self-efficacy (along with other factors, such as an outsized emphasis on reading and math instruction because of educators' focus on standardized test scores) has led to insufficient science instructional time–an average of 20 minutes a day nationwide (Horizon 17).

I knew that in order to truly improve science teaching, educators needed: 1) a year of intensive science professional development training that allowed them to deepen their science content knowledge and to learn high impact teaching strategies shown to raise student achievement and 2) daily classroom instructional time to implement high-quality research-based science lessons. Because of the current high-stakes testing climate and an unrelenting focus on reading and math exacerbated by pandemic pressures, in most school districts, a focus on improving science instruction simply wasn't realistic.

It was this realization that led me to a year-long study of nonfiction science picture books. If a full-scale overhaul of science practices within school districts wasn't possible, picture books could provide a "first step" to making an impact on science instruction. Helping teachers to use science picture books

[3] See Maltese and Tai; PCAST; Tai, Liu, Maltese, & Fan.

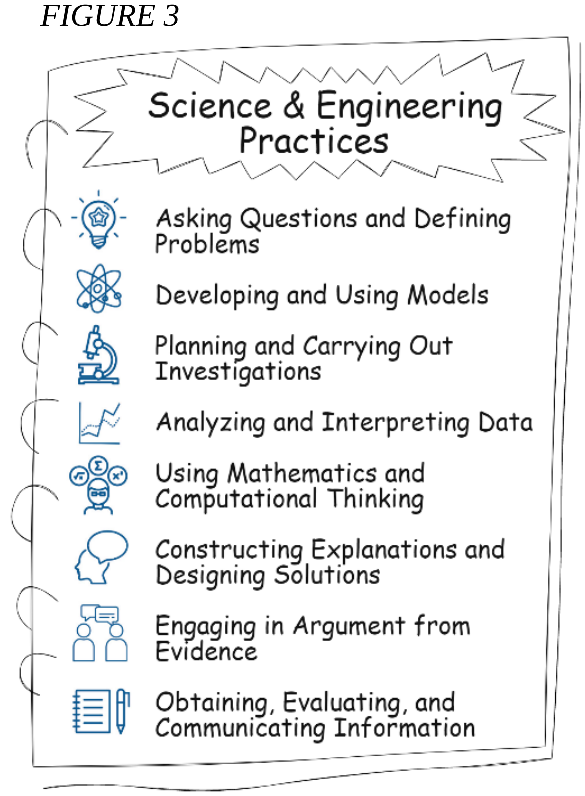
in authentic ways could infuse more scientific thinking into their daily routines without adding another element to their already packed schedules. Furthermore, science picture books could provide, in a medium already familiar to and used by teachers, initial scaffolding to help teachers begin to shift towards NGSS supported teaching practices.

I spent most of 2022 scouring the web–including NSTA's list of outstanding science trade books, picture book award lists, blogs, YouTube read alouds, and even Pinterest "best of" pins–to create the most comprehensive list of nonfiction science picture books known to the education community. I checked out nearly every science picture book I uncovered–more than 700–from my local library using their inter-library loan system. Those I couldn't physically access through the library, I often found featured in YouTube read aloud videos, or on occasion, I purchased the book to add to my personal collection.

I focused on narrative nonfiction and expository nonfiction because it is those groups of texts that teachers would be most likely to use as a read aloud. I chose not to explore traditional nonfiction, although they are also "read aloud friendly," because of the volume of titles and breadth of topics. In addition, their straightforward, expository text is better structured for individual student research rather than an engaging listening experience.

In addition, reading traditional nonfiction at the beginning of a lesson is counter-productive to the shift teachers should be making to helping students locate information and figure out science concepts on their own. Within the narrative nonfiction category, I attempted to access all of the currently published picture book biographies which, as Stewart suggested, are written in a narrative style. The expository nonfiction category contained both expository and blended titles. A list of the picture books I examined is included in Appendix A.

FIGURE 3

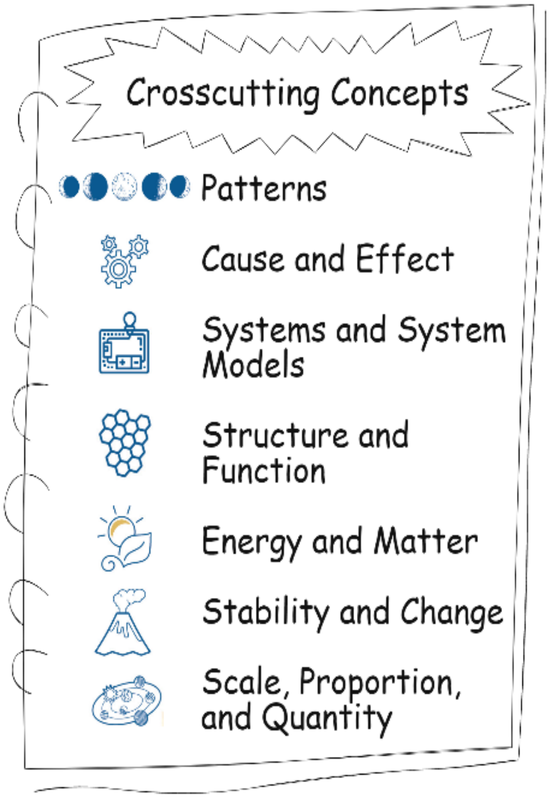


Utilizing these texts, I developed a series of curriculum resources and professional development classes for elementary educators. In one class, I focused on the science and engineering practices – one of the three dimensions of the NGSS. The science and engineering practices (Figure 3) are the practices that real life scientists and engineers do, so they are the practices we should have our students doing.

During this class, I showed teachers how the science and engineering practices could be modeled by real life scientists and engineers featured in picture book biographies. For example, *On a Beam of Light* by Jennifer Berne emphasizes the central role asking "the right" questions played in Albert Einstein's life. *Gregor Mendel: The Friar Who Grew Peas* by Cheryl Bardoe provides specific details about how Mendel planned and carried out investigations.

In another class, I showed teachers how to help students examine scientific concepts in expository literature using the crosscutting concepts–another of the three dimensions of the NGSS. The crosscutting concepts (CCC) (Figure 4) are one of the tools scientists use to understand the natural world, to describe their work, and to understand the work of

FIGURE 4



their peers. It is helpful to think about the CCCs as lenses, like magnifying glasses that children can hold up to see how the world works. When they find an ant hill, they can peer through different lenses to think: *How do the ants work together as a system? What energy and matter are flowing in and out of the hill? Is the ant hill stable or changing? How does the body structure of an ant allow it to build a home in the ground?*

In this class, I teach how students can use the lenses of systems and system models, cause and effect, and stability and change to explain the events described in Susannah Buhrman-Deever's *If You Take Away the Otter* (Figure 6). *The Sun, The Wind, and The Rain* by Lisa Peters, which compares and contrasts the wind and water erosion of a mountain and a sandcastle, is a rich text for exploring nearly all the crosscutting concepts (Figure 5).

Additionally, I created a curriculum resource that aligns each picture book to a K-5 Next Generation Science Standard performance expectation and can be used by educators to create a collection of nonfiction picture books to support their exploration of scientific concepts at a specific grade level.

FIGURE 5

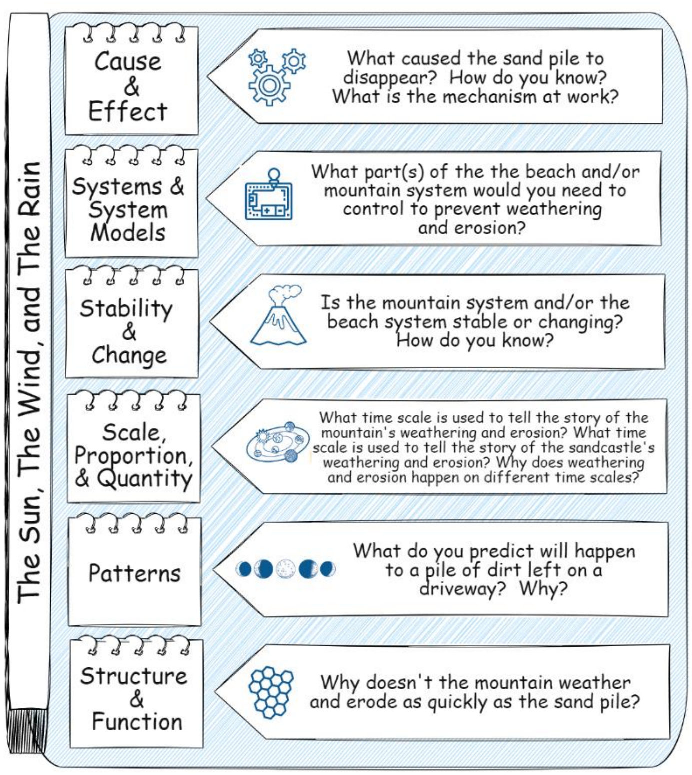
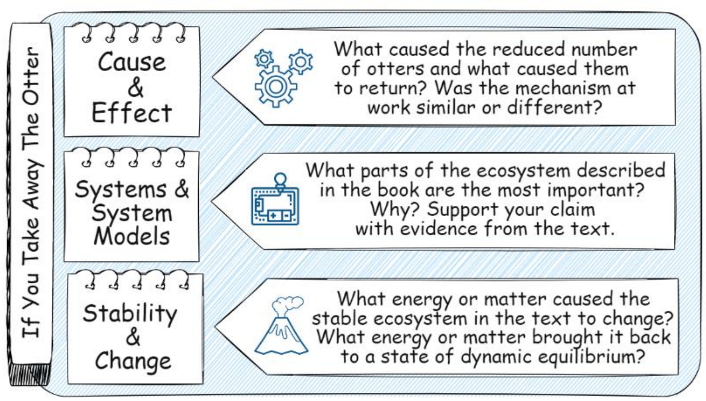


FIGURE 6



It was after this intensive research and during my picture book curriculum and professional learning development that I identified a gap in the science picture book market. There were no picture books that focused on–or even mentioned–the crosscutting concepts. As a former classroom educator, I knew that texts focused on the crosscutting concepts would be pedagogically useful, yet I also believed they could serve to expand the canon of nonfiction picture book literature. I envisioned a type of blended nonfiction that showcased how the crosscutting concepts are used by real life scientists and encouraged students to use the concepts to "think like scientists" in order to make sense of scientific phenomena.

Instead of focusing on the scientists, like a narrative nonfiction biography, the texts would focus on the scientists' discoveries. I imagined a similar purpose as the *Scientists in the Field* series from Houghton Mifflin Harcourt, which focus on specific scientific discoveries with chronologically organized expository writing and photographic evidence. Yet, at 50 – 80 nonfiction pages, these books are not appropriate for a read aloud and are too textually dense to be easily accessible for an elementary-aged audience.

In addition to focusing on scientific discoveries, I wanted the books to highlight how a crosscutting concept was used by scientists in the real world–not as an abstract concept, but as a tool to assist in understanding scientific phenomena. Not only would these texts show students how *scientists* use the concepts, but by incorporating elements of active nonfiction, the texts would also be structured to invite *students* to use the crosscutting concepts to "make discoveries" alongside the experts.

Determining Pedagogical Criteria

As I began to conceptualize a series of crosscutting concept focused picture books, I made a list of pedagogical criteria that, as an educator and an advocate for research-based science instruction, I wanted the texts to fulfill:

1) To support what the research shows are best practices in science education.
2) To provide a literature resource for time-crunched elementary educators of all levels of science knowledge and experience.
3) To capitalize on the known benefits of picture book read alouds for students of all ages.

What follows is a brief explanation of how each criterion was fulfilled in the *Think Like a Scientist* picture book series.

Supporting Best Practices in Science Education

The *Think Like a Scientist* series supports best practices in three distinct ways: presenting an anchoring phenomenon, engaging students in sensemaking, and providing experiences where the crosscutting concepts are useful.

Current best practices promoted by the creators of the NGSS state that high quality science instruction should begin with the presentation of a phenomenon that anchors all of the subsequent learning experiences. According to literature distributed on the official NGSS website, "Anchoring learning in explaining phenomena supports student agency for wanting to build science and engineering knowledge. Students are able to identify an answer to 'why do I need to learn this?' before they even know what the "this" is… Explaining phenomena and designing solutions to problems allow students to build general science ideas in the context of their application to understanding phenomena in the real world, leading to deeper and more transferable knowledge" (Using Phenomena in NGSS-Designed Lessons and Units 1). For example, at the beginning of a unit exploring what plants need to grow, students might be presented with an ear of corn that has sprouted (phenomenon) and be asked to first notice and then wonder about what has happened to the corn. This initial session will be followed by a series of lessons carefully sequenced by the teacher into a "storyline" in which students are making observations and designing investigations to answer their self-developed questions about plants.

Similarly, each scientific discovery in the *Think Like a Scientist* series is prefaced with a narrative that presents a phenomenon for students to wonder about. In the Energy collection, before learning about Caitlyn O'Connell's discovery that elephants can "hear" through their feet, readers are transported to Africa where they observe a herd of elephants that is walking, pausing, and moving in specific ways. *Why are they behaving so strangely?* Before reading about Adrianus J. Kalmijn's discovery that sharks and rays hunt primarily by sensing weak electric fields emitted by their prey, students are asked to imagine a scuba diving adventure where they observe a manta ray "slurping" a fish out of a sandy bottom–a fish that was completely hidden from view. *How did the ray know the fish was there?*

Whenever possible, the phenomenon the featured scientist observed is described; however, if the phenomenon under study couldn't be easily understood by an elementary audience without prior context or if the phenomenon didn't lend itself to a compelling introductory narrative, a more engaging experience was substituted and the phenomenon under study was introduced later in the text. This was the case for Inge Lehman's discovery of Earth's solid core. Opening with a discussion of how P waves and S waves move through the Earth would be confusing to students who lack basic background knowledge about waves. Instead, readers are asked to imagine peering into a deep excavated hole and wonder: *How far could the excavator keep digging? What would it uncover?* Only after reading an inset that provides a basic explanation of waves are students invited to analyze a simplified model that illustrates the phenomenon Lehman observed.

The initial narratives also mirror the now pervasive and effective instructional protocol of "noticing and wondering" about phenomena (Brown and Bybee 23).[4] Each section begins with a phenomenon followed by a wondering question.

Another pillar of science best practices supported by recent research is engaging students in sensemaking. Sensemaking refers to "the conceptual process in which a learner actively engages with the natural or designed world; wonders about it; and develops, tests, and refines ideas with peers and the teacher. . . Sense-making is about actively trying to figure out how the world works and exploring how to create or alter things to achieve design goals." (Schwarz et al. 6) This is one of the most significant shifts for educators used to presenting science content to students in the typical "find out" model. In the "figure out" model, students engage in making sense of phenomena using the science and engineering practices and crosscutting concepts.

Using our previous example of a unit on what plants need to grow, in the old model, teachers (or a text) would tell students that plants need sunlight and water to grow. A more hands-on approach would have students conducting a teacher developed and directed experiment that provided sunlight and water to some plants but not to others. In neither of these examples are students making sense of a phenomenon. A research-based approach to the plants unit would have students observe the sprouted corn and other seeds growing. Students would notice that leaves are growing toward light and roots are growing toward a water source. Students would describe the pattern they have discovered and develop initial theories about why it is occurring. Next, students would design investigations to gather evidence that could be used to support a claim about what plants need to grow.

Rather than explaining each discovery, in the *Think Like a Scientist* series, readers are shown charts, diagrams, graphs, or models and asked questions that encourage them to "make sense" of the observed

[4] See also Fukawa-Connelly, Klein, Silverman, & Shumar; Hogan & Alejandre; Shumar & Klein.

phenomenon. In the Energy collection, readers analyze a simplified diagram that shows where P waves and S waves should have registered after a large earthquake compared to where they actually registered and are asked: *What do you notice in these models created from seismograph data?* In the same collection, readers need to be given the background knowledge that fish give off weak electric fields and that scientists thought sharks could sense these fields. So instead of asking readers to make wild conjectures about the initial phenomenon, they are given the requisite prior knowledge and told that Adrianus Kalmijn thought sharks used these electric fields to hunt prey. Then, readers are asked to engage in the science and engineering practice of planning and carrying out investigations: *How would you design an investigation to test if sharks and rays hunt using bioelectric fields and not just sight and smell?*

In the book *Crosscutting Concepts: Strengthening Science and Engineering Learning,* Helen Quinn shares that we need to start by giving students experiences where a crosscutting concept lens is useful before we talk about it in the abstract as a tool that can be used to understand unfamiliar phenomena in the future. She further shares that, "a tool is not useful if it is unfamiliar, so students must develop familiarity with these tools and need to be guided to use them in multiple contexts" (xii).

The design of the Think Like a Scientist series is based on this concept of having students use the crosscutting concepts as lenses to make sense of phenomena just like real life scientists. Though the texts mention the featured concept in the introduction, the purpose of the text is not for students to understand the intricacies of a crosscutting concept or to memorize its definition as an abstract idea. Each text is intended to provide teachers with three opportunities for students to use the same crosscutting concept as a lens to make sense of phenomena that led to consequential scientific discoveries.

Providing a Science-Focused Literature Resource for Elementary Educators

As discussed earlier, though elementary science instruction is critical to the development of STEM career paths, elementary teachers typically have an extremely limited amount of time for science instruction. One solution to this dilemma is to show teachers how to integrate science and literacy so more time for scientific thinking can be found within a block of time designated for reading instruction. As a picture book series, the *Think Like a Scientist* texts can be used as read alouds to encourage scientific thinking in a short amount of time. The texts could even be segmented into three distinct parts (one for each discovery) to accommodate even shorter periods of available time.

While elementary educators are most likely comfortable using picture book read alouds as instructional tools for exploring reading comprehension topics such as main idea, figurative language, and nonfiction text features, they may be less well-versed in how to use picture books to engage students in scientific discussions. By presenting phenomena, asking students to notice and wonder, and promoting active sensemaking, *the texts* scaffold research-based instructional techniques for all educators, no matter their level of science instruction experience. Furthermore, through the embedded "Think Like a Scientist" questions, teachers are able to use the texts as catalysts for rich peer-to-peer scientific discussions around phenomena during literacy instruction without additional advance lesson planning.

In addition to classroom applications, the series uniquely offers busy parents, mostly untrained in instructional strategies, specific guidance for building the scientific thinking capabilities of their children while sharing in the joy of learning about fascinating discoveries.

Capitalizing on the Known Benefits of Picture Book Read Alouds

The picture book structure along with embedded questions and graphics that encourage scientific thinking and discussion help teachers to capitalize on several known read-aloud benefits. First of all, research has shown "the positive effect of reading aloud on student engagement, thinking, and reading achievement" (Layne ix). Having questions explicitly written within the text that are an integral part of the read aloud experience helps teachers to promote student engagement and to provide opportunities for students to voice their sensemaking processes. In addition, for students new to the science and engineering practices and/or the crosscutting concepts, the read aloud format provides the opportunity for teachers to model their scientific thinking through the "think-aloud" research-based technique more commonly used to model reading comprehension strategies (Wilhelm).

This list of pedagogical criteria informed the text structure of the series which is detailed in the following section.

Determining A Text Structure: Scientists, Discoveries, and Crosscutting Concepts

The jumping off point for my thinking about the content and structure of the *Think Like a Scientist* picture books, was conceptualizing a series of texts with each text highlighting one of the seven crosscutting concepts. A text specifically teaching each concept seemed dry and didactic and antithetical to the purpose of the concepts as tools to understand phenomena versus abstract concepts to master. I wanted to show these concepts in action–to help students see them not just as constructs to learn but to understand how to put them into practice. And what better way to help students see how the crosscutting concepts could be useful than to show them being used by real life scientists. After all, one of the purposes of the NGSS is to get students "doing" scientific practices and examining the world using the crosscutting concepts just like real scientists.

Yet, just focusing on one scientist in each book felt like a missed opportunity. Research shows that the stereotype of a typical scientist–a white male often in a lab coat–is learned and grows stronger from later elementary into high school (Miller et al. 1950-1952). The series was an opportunity to introduce students to a diverse group of scientists engaging in a wide variety of STEM careers.

Also playing a role in my text structure thoughts was the nature of the crosscutting concepts–they cut across disciplines. They are lenses for viewing the world that create a common language for earth scientists, physical scientists, life scientists and even social scientists. In fact, concepts like cause and effect are embedded in studies of English Language Arts and history while patterns are critical to understanding mathematics and geography. Though I had made the decision to focus the texts on scientific concepts, I wanted each text to show how the identified crosscutting concepts could be used in multiple scientific disciplines.

It was these two desires–to introduce students to a diverse group of scientists and to show how those scientists used the same crosscutting concept in different disciplines–that led to the decision to feature three scientists in each book. Instead of focusing on the scientists' lives, like typical narrative picture book biographies (which would also be impossible in a 32-page picture book), I instead chose to focus on one of their major discoveries and how the crosscutting concept being featured either informed or could be used to understand their specific scientific achievement. For example, in the Scale, Proportion, and Quantity collection, students are asked to consider why scale was important for Evangelina Vallegas to think about when seeking to solve the problem of maize that was devoid of essential nutrients (quantity). They are asked to consider how Edwin Hubble's discovery of a galaxy outside our own drastically changed our understanding of the scale of the universe (distance scale).

And they are invited to consider how fossils, like those discovered by Mary Anning, help us to understand the timeline of life on Earth (time scale).

Choosing which scientists to feature in picture book texts is a heavy responsibility and a form of censorship through who is not chosen for inclusion in the texts. Encouraged by the publishing industry's acknowledgement of the need to represent more diverse voices in picture books, these were the criteria I used for determining the scientists currently included in the series:

a) The scientist's discovery must be able to be easily explained to an elementary audience given their limited scientific knowledge and must allow students to apply a specific crosscutting concept lens to understand the phenomenon. For example, with in-depth instruction on genetics, concepts of energy and matter at the particle level, the mechanics of photosynthesis, and cellular structures not entering the curriculum until middle school, this eliminated many modern-day scientists in the fields of energy and genetics from inclusion.
b) The three scientists in any given text (and across the entire series) must represent a diverse group of individuals along the lines of race, gender, country of origin, age at the time of the discovery and/or time period in which the discovery was made.
c) The discoveries must be interesting to and appropriate for an elementary audience. For example, while Ernest Just's groundbreaking cellular work could be explained to an elementary audience, their lack of cellular background knowledge and innate interest in how a cell divides were prohibitive of his inclusion in the series. (However, there is a picture book biography, *The Vast Wonder of the World: Biologist Ernest Everett Just* by Mélina Mangal, that students can read to learn more about Just and his discoveries. The text is accessible to a young audience because of its focus on the scientist's life and achievements as a whole rather than on a single discovery.)
d) While all scientists are real people with complicated personal lives, the scientists selected needed to be widely accepted as role models in their fields and free from controversies that would be considered unacceptable by an overwhelming majority, such as participation in the Nazi party or unethical genetic research.

Detailed Description of the Series

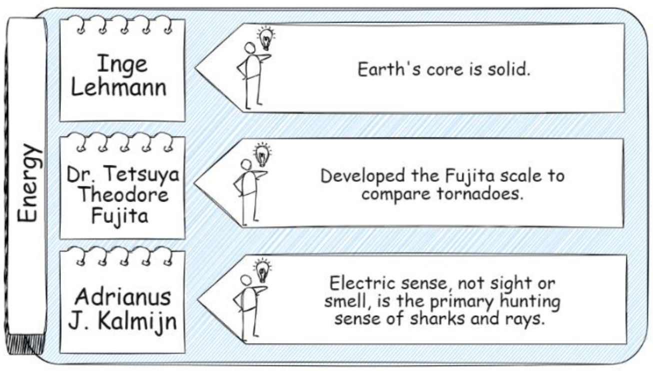
Find a killer asteroid, train cockroaches, and spy on talking trees in *Think Like a Scientist* a STEM series of nonfiction picture books that invite 7-11 year olds to delight in the thrill of scientific discovery. Intriguing questions pull readers into the shoes of diverse scientists to examine evidence and design investigations. Each book highlights three revolutionary scientists whose stories coalesce around a crosscutting concept, such as energy.

The series high-interest topics and engaging narration are intended to entertain and inform younger readers while open-ended questions, side bars, and graphic elements are designed to invite older readers to interact with the text. In addition, the books act as a close-at hand, trusted guide for adults to help spark rich science discussions with children. The layered elements, intriguing scientists, and high-interest topics provide multiple entry points for readers of different ages, abilities, and interests.

At its core, THINK LIKE A SCIENTIST is a series designed to help children discover that they can "do" science just like real life scientists. The books introduce diverse STEM careers and scientists, scaffold scientific thought and discussions for both children and adults, reveal the process behind interesting discoveries, and enrich a child's understanding of the world.

Backmatter includes additional information about each featured scientist with links to further reading. A questioning guide for grown-ups provides teachers, parents, and caregivers with guidance for each embedded question including: the question's purpose, typical answers a child may give, and how to guide a child's thinking with additional questions. The final section of backmatter details hands-on investigations a child can conduct to develop further understanding of the book's featured crosscutting concept.

Book 1: THINK LIKE A SCIENTIST: EARTHQUAKES, SHARKS, AND TORNADOES! SOLVING SCIENCE MYSTERIES WITH ENERGY

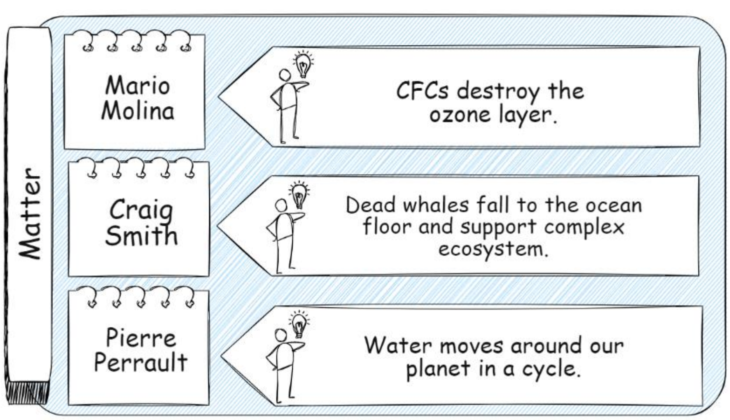


Readers engage in figuring out science mysteries using big ideas about energy. In *The Mystery of the Weird Waves*, Inge Lehmann, seismologist, puzzles over the strange behavior of earthquake waves. Readers walk through her scientific process with carefully constructed questions that ultimately lead to the discovery that Earth's core is solid.

In *The Mystery of the Hidden Lunch*, Adrianus J. Kalmijn, biophysicist, wonders if sharks and rays hunt using electric fields naturally produced by fish. Readers design a scientific investigation to test and eventually prove this theory.

In the *Mystery of the Wild Wind*, Ted Fujita, meteorologist, seeks to find a way to describe the difference between a tornado that caused minor roof damage and a tornado that wiped a town off the map. Along with Ted, readers dive into the data and realize not only how to categorize tornadoes but why the task is important.

Book 2: THINK LIKE A SCIENTIST: OZONE HOLES, WHALE FALLS, AND INVISIBLE WATER! SOLVING SCIENCE MYSTERIES WITH MATTER

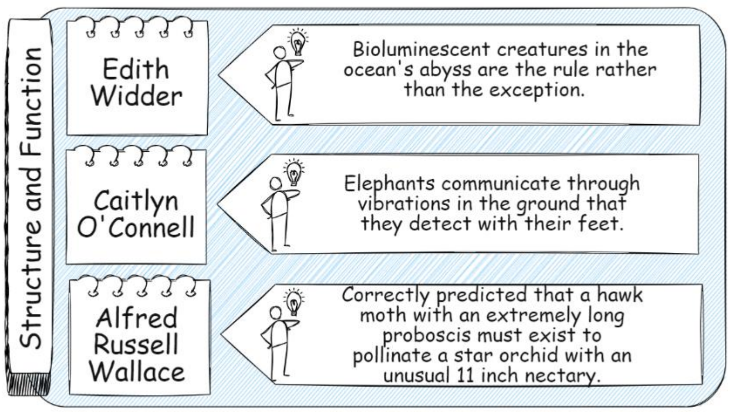


Readers engage in figuring out science mysteries using big ideas about matter. In *The Mystery of the Absent Atmosphere*, Mario Molina, chemist, wonders what happens to chemicals once they burst from a can or are leaked from a refrigerator in a landfill. Once equipped with basic knowledge about chlorofluorocarbons (CFCs), readers examine diagrams to figure out where the chemicals may be traveling, what effects they may be causing, and why this discovery is important.

In the *Mystery of the Disappearing Whale*, Craig Smith, oceanographer, discovers a flourishing ecosystem on the ocean floor made possible by a dead whale carcass. Readers examine diagrams of the ecosystem over time and compare mass measurements to discover that even death cannot destroy matter.

In *The Mystery of the Invisible Water*, Pierre Perrault, hydrologist, seeks to prove that rainfall is the primary source of river water. Readers analyze data in charts and diagrams to prove his theory, to explore the water cycle, and to support the idea of conservation of matter during physical changes.

Book 3: THINK LIKE A SCIENTIST: THE ABYSS, ELEPHANTS, AND HAWK MOTHS! SOLVING SCIENCE MYSTERIES WITH STRUCTURE AND FUNCTION

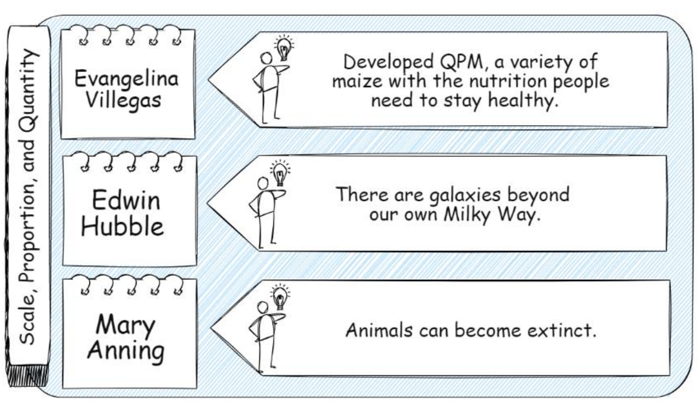


Readers engage in figuring out science mysteries using big ideas about structure and function. In *The Mystery of the Underwater Fireworks*, Edith Widder, marine biologist, wonders about creatures she observes creating a bioluminescent light display in the deep ocean. Children ideate a recording device and analyze data to find out what creatures are emitting light and why.

In *The Mystery of the Frozen Elephants*, Caitlyn O'Connell notices an entire herd of elephants freezing in place, mid-stride, as if instantly turned to stone, and wonders if the elephants could be "listening" with their feet. Readers design a scientific investigation to test and eventually prove this theory.

In *The Mystery of the Puzzling Pollinator*, Alfred Russel Wallace, naturalist, is fascinated by a star orchid with the longest nectar tube he has ever seen and wonders what creature would be capable of pollinating the bloom. Readers brainstorm what structure would allow a pollinator to sip the nectar by considering the structures of known pollinators. Then, they are asked to figure out how they could prove what creature is the true pollinator.

Book 4: THINK LIKE A SCIENTIST: CORN, THE UNIVERSE, AND FISH LIZARDS! SOLVING SCIENCE MYSTERIES WITH SCALE, PROPORTION, AND QUANTITY

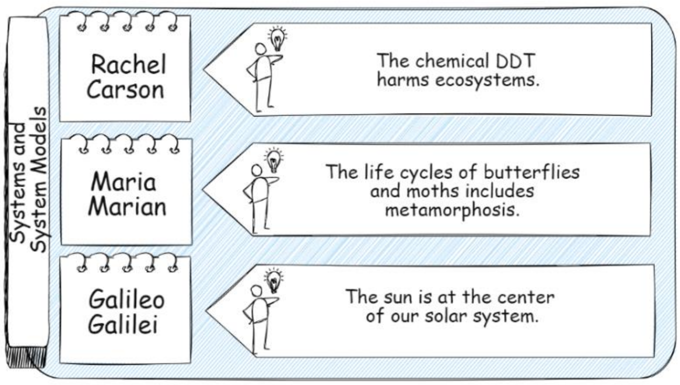


Readers engage in figuring out science mysteries using big ideas about scale, proportion, and quantity. In *The Mystery of the Malnourishing Maize*, Evangelina Villegas, chemist, works to help people who are starving because their primary food source is corn, which lacks protein and essential nutrients. Readers brainstorm how they can help people receive more nutrition without changing the foods they eat and consider why scale is an important factor in any solution.

In *The Mystery of the Blinking Star*, Edwin Hubble, astronomer, notices a pulsating star deep inside the Andromeda nebula, dimming and brightening in a predictable pattern, as if sending a coded message just for him. Readers engage in examining data to realize that the new star is actually in another galaxy and strategize how to convey to another person the scale of something as large as our known universe.

In *The Mystery of the Missing Creatures*, Mary Anning, paleontologist, uncovers a fossilized skeleton nearly as big as a blue whale. Readers consider how Mary's find changed the way people thought about the stability of Earth's organisms and the time scale of life on Earth.

Book 5: THINK LIKE A SCIENTIST: INSECTS, POISON, AND PLANETS! SOLVING SCIENCE MYSTERIES WITH SYSTEMS AND SYSTEM MODELS

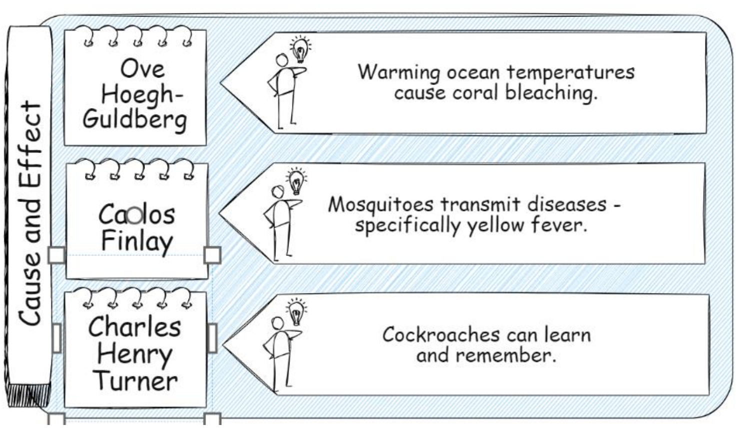


Readers engage in figuring out science mysteries using big ideas about systems and system models. In *The Mystery of the Insect Magic Trick–Now You See Me, Now You Don't*, Maria Merian, entomologist, seeks to figure out the origin of butterflies and moths, which people in 1660 thought were evil, emerging spontaneously out of mud or rotting meat. Readers decide how to investigate insects around their homes, document their observations, support their claims with evidence, and share their findings.

In *The Mystery of the Killer Chemicals*, Rachel Carson, conservationist, unearths a cascade of devastating effects caused by the insecticide DDT. Readers analyze data to uncover the chemical's effects on entire ecosystems, to make claims about those effects, and to support those claims with evidence.

In *The Mystery of the Moving Sun*, Galileo Galilei, astronomer, notices that Venus has phases–an impossibility if Earth is at the center of our solar system. Readers examine Galileo's drawings of Venus's phases and view models to discover why phases are only possible if all planets revolve around the sun–a controversial idea in the 1600s.

Book 6: THINK LIKE A SCIENTIST: GHOSTLY CORAL, YELLOW FEVER, AND COCKROACHES! SOLVING SCIENCE MYSTERIES WITH CAUSE AND EFFECT

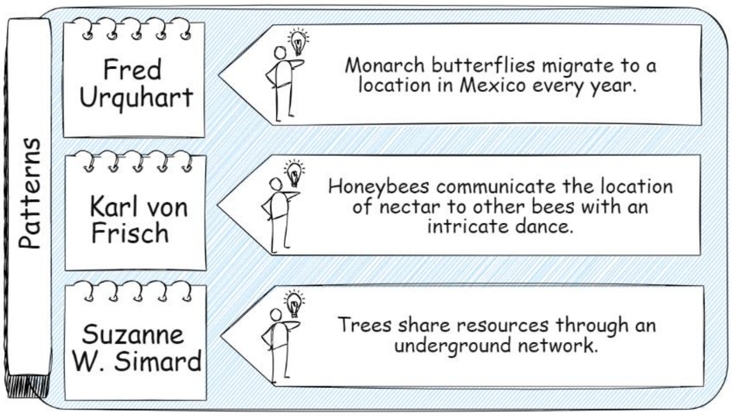


Readers engage in figuring out science mysteries using big ideas about cause and effect. In *The Mystery of the Ghostly Coral*, Ove Hoegh-Guldberg, climate scientist, wonders why some corals are losing their color, called coral bleaching. Readers design an investigation and analyze evidence to figure out what is causing the bleaching and why this discovery is important.

In *The Mystery of the Deadly Disease*, Carlos Finlay, epidemiologist, puzzles over the identity of the organism that is efficiently transmitting deadly yellow fever throughout Cuba in the late 1800s. Readers analyze evidence to identify the vector and ideate solutions to prevent people from getting infected.

In *The Mystery of the Clever Cockroaches*, Charles Henry Turner, entomologist, puzzles over the behavior of cockroaches. Readers develop a question to investigate, analyze data, and ultimately discover that the small, skittering insects can learn and remember.

Book 7: THINK LIKE A SCIENTIST: HIDE AND SEEK MONARCHS, DANCING BEES, AND TALKING TREES! SOLVING SCIENCE MYSTERIES WITH PATTERNS

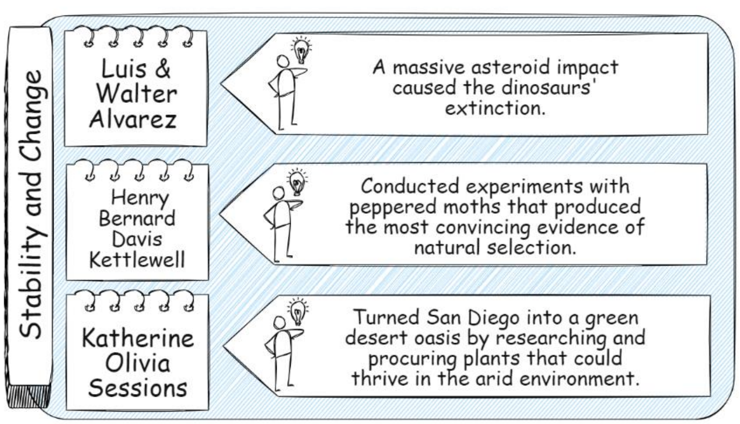


Readers engage in figuring out science mysteries using big ideas about patterns. In *The Mystery of the Migrating Monarchs*, Fred Urquhart, zoologist, wonders where monarchs spend the winter. Readers brainstorm how they could figure out the answer, analyze a map of butterfly flight data to discover a pattern, and determine why the discovery of the monarch's winter respite is useful information.

In *The Mystery of the Dancing Bee*, Karl von Frisch, ethologist, observes a honeybee, returning to the hive after slurping up nectar, breaking into what appears to be an elaborate dance. Readers brainstorm methods to decode the strange behavior, analyze data for patterns, and consider real world implications.

In *The Mystery of the Talking Trees*, Suzanne W. Simard, ecologist, wonders if trees pass resources to one another underground. Readers look for patterns in tree growth, analyze diagrams, and apply what they discover to develop improved forest conservation practices.

Book 8: THINK LIKE A SCIENTIST: ASTEROIDS, COLOR-CHANGING MOTHS, AND GREEN DESERTS! SOLVING SCIENCE MYSTERIES WITH STABILITY AND CHANGE



Readers engage in figuring out science mysteries using big ideas about stability and change. In *The Mystery of the Dead Dinos*, Luis and Walter Alvarez, a father and son physicist and geologist team, wonder why very different fossils rest above and below a mysterious layer of clay found all over the world. Readers infer what this revelation means and use data as evidence to predict what could have deposited the clay layer.

In *The Mystery of the Color-Changing Moths*, Henry Bernard Davis Kettlewell, lepidopterist, wonders why there are more charcoal-colored peppered moths in some areas in England and more black and white speckled moths in other areas. Readers predict why the phenomenon is occurring, analyze data from Kettlewell's experiment, and draw conclusions about color changes in the peppered moth population.

In *The Mystery of the Green Desert*, Katherine Olivia Sessions, botanist, desires to turn the barren, brown San Deigo landscape into a lush, green desert oasis. Readers predict why different plants flourish in different areas, determine how to find plants that require limited rainfall, and apply what they have learned by brainstorming ideas to improve areas in their communities.

The Research Process

Although the texts focused on scientific discoveries and not the lives of the scientists themselves as in a traditional biography, I felt compelled to research the lives of each of the scientists so I could accurately portray the way they approached the question they were attempting to answer. Researching one scientist for a picture book is often a months-long task, so at the outset, researching 21 scientists seemed particularly daunting. Yet as my research progressed, I found that a deep dive into the breadth of their lives wasn't nearly as important as a thorough understanding of the discoveries I was highlighting, how they came to be, and the implications of their scientific achievements on the world and future research.

Whenever possible, I read their published research that detailed the discovery. (Though sometimes the science was beyond my realm of understanding as was the case with Inge Leghman's paper P' that detailed her discovery of Earth's solid core. In that instance, I contacted a university physics professor to summarize the data for me.) I found Adrianus J. Kalmijn's paper: *The electric sense of sharks and rays* particularly intriguing both because of the meticulous detail paid to his investigative procedures and because the paper was so clearly written that a layperson, like myself, could thoroughly understand his work.

Caitlyn O'Connell's book *The Elephant's Secret Sense*, detailing her discovery of elephant communication through ground vibrations, was told in such an engaging fashion that it brought the reader more fully into the life she led during her initial years in Africa. In *T. Rex and the Crater of Doom*, Walter Alvarez explained his discovery of what caused the mass extinction of the dinosaurs–and three-fourths of the flora and fauna on Earth 65 million years ago–in a systematic and clear way. The book was not only interesting and entertaining, but it also models for middle and high school readers what the process of scientific discovery truly entails (i.e., fewer brief "Eureka!" moments and more dogged determination to spend time thinking, researching, and scouring for evidence to support reasoned argumentation).

Crosscutting Concepts: Strengthening Science and Engineering Learning edited by Jeffrey Nordine and Okhee Lee deepened my knowledge of the crosscutting concepts and my understanding of how educators should be using them to support student sensemaking in the elementary classroom. Additionally, *Sharing Books Talking Science* by Valerie Bang-Jensen and Mark Lubkowitz is a highly accessible text written for educators that explains each of the crosscutting concepts and how they can be used to analyze both fiction and nonfiction picture books. It is a text I continue to recommend to educators who are new to the crosscutting concepts and would like a general overview integrated with practical applications for their classroom instruction.

Conclusion

It is my sincere hope that the *Think Like a Scientist* picture book series will provide teachers and parents a pedagogically sound instructional tool for helping students to understand and use the crosscutting concepts. That it will provide students inspiration for further inquiry into the scientists and their discoveries and ultimately spark an interest in STEM careers. And that it will provide the children's literature community at large a new construct for organizing expository nonfiction as well as an introduction to the crosscutting concepts–that they may be a consideration during the creation of future picture books.

Works Cited

Alvarez, Walter. *T. Rex and the Crater of Doom*. Princeton University Press, 2015.

Bang-Jensen, Valerie, and Mark Lubkowitz. *Sharing Books, Talking Science: Exploring Scientific Concepts with Children's Literature*. Heinemann, 2017.

Bardoe, Cheryl. *Gregor Mendel*. Abrams Books for Young Readers, 1 Sept. 2006.

Berne, Jennifer, and Vladimir Radunsky. *On a Beam of Light: A Story of Albert Einstein*. Chronicle Books, 2016.

Brown, John Seely, et al. "Situated Cognition and the Culture of Learning." *Educational Researcher*, vol. 18, no. 1, 1989, pp. 32–42, https://doi.org/10.2307/1176008.

Brown, Patrick L, and Rodger W Bybee. "Promoting Sensemaking through an Impactful Instructional Sequence." *The Science Teacher*, vol. 90, no. 6, 1 July 2023, pp. 22–27, https://doi.org/10.1080/00368555.2023.12315951.

Buhrman-Deever, Susannah, and Matthew Trueman. *If You Take Away the Otter*. Candlewick Press, 2020.

Crispin Boyer. *Why?: Over 1,111 Answers to Everything*. National Geographic, 2015.

Duschl, Richard A, et al. *Taking Science to School: Learning and Teaching Science in Grades K-8*. National Academies Press, 2007.

Ferry, Beth, and Lorena Alvarez. *Marsha Is Magnetic*. Houghton Mifflin Harcourt, 2021.

Fukawa-Connelly, Tim, et al. "An Online Professional Development Model to Support Teachers' Ability to Examine Student Work and Thinking." *Mathematics Teacher Educator*, vol. 6, no. 2, 2018, p. 39, https://doi.org/10.5951/mathteaceduc.6.2.0039. Accessed 18 Oct. 2019.

Gibbons, Gail, et al. *From Seed to Plant*. Holiday House, 1 Jan. 1991.

---. *Owls (New & Updated)*. Holiday House, 26 July 2022.

Hogan, M. & Alejandre, S. "Problem solving—It has to begin with noticing and wondering." *ComMuniCator*, vol. 35, no. 2, 2010, pp. 31–33.

Jenkins, Steve, and Robin Page. *The Animal Toolkit*. HarperCollins, 30 Aug. 2022.

Kalmijn, A.J. "The Electric Sense of Sharks and Rays." *Journal of Experimental Biology*, vol. 55, no. 2, 1 Oct. 1971, pp. 371-383, https://doi.org/10.1242/jeb.55.2.371.

Keating, Jess. *The Girl Who Built an Ocean*. Knopf Books for Young Readers, 25 Oct. 2022.

Krajcik, Joseph. and Shin, Namsoo. Project-based learning. In *The Cambridge handbook of the learning sciences*. 2nd ed., ed. R. Keith Sawyer, 275-297, Cambridge University Press, 14 Mar. 2022

Layne, Steven L. *In Defense of Read-Aloud: Sustaining Best Practice*. Stenhouse Publishers, 2015.

Lehmann, Inge. "P ' " *Publications du Bureau central séismologique international*. Série A: Travaux scientifiques, vol. 14, 1936, pp. 87-115, https://courses.seas.harvard.edu/climate/eli/Courses/EPS281r/Sources/Inner-Core/Lehman-Inge-1936.pdf.

Lisa Westberg Peters, and Ted Rand. *The Sun, the Wind and the Rain*. Square Fish/Henry Holt and Company, 2012.

Maltese, Adam V., and Robert H. Tai. "Eyeballs in the Fridge: Sources of Early Interest in Science." *International Journal of Science Education*, vol. 32, no. 5, 11 June 2009, pp. 669–685, https://doi.org/10.1080/09500690902792385.

Mangal, Mélina. *The Vast Wonder of the World*. Lerner Digital, 1 Jan. 2020.

McNeill, Katherine L., et al. "Shifting From Learning About to Figuring Out." *Science Scope*, vol. 45, no. 2, Nov./Dec. 2021.

Miller, David I., et al. "The Development of Children's Gender-Science Stereotypes: A Meta-Analysis of 5 Decades of U.S. Draw-A-Scientist Studies." *Child Development*, vol. 89, no. 6, 20 Mar. 2018, pp. 1943–1955, https://doi.org/10.1111/cdev.13039.

Miller, Rachel, et al. *The 101 Coolest Simple Science Experiments*. Page Street Publishing Co, 2016.

Murphy, Tony. "STEM education—It's elementary." *U.S. News & World Report*, 29 Aug. 2011, http://www.usnews.com/news/articles/2011/08/29/stem-education--its-elementary.

National Academies of Sciences, Engineering, and Medicine. 2022. *Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators*. Washington, DC: The National Academies Press, 2022. Available: https://doi.org/10.17226/26215.

National Center for Education Statistics, U.S. Department of Education. *The Nation's Report Card: 2019 Science at Grades 4, 8 and 12*. NCES 2016162, 2017. Available: https://www.nationsreportcard.gov/highlights/science/2019/

Nordine, Jeffrey, and Okhee Lee. *Crosscutting Concepts: Strengthening Science and Engineering Learning*. National Science Teaching Association, 2021.

O'Connell, Caitlin. *The Elephant's Secret Sense: The Hidden Life of the Wild Herds of Africa*. University of Chicago Press, 2008.

Pattison, Darcy. *Clang!* Mims House, 10 Mar. 2018.

---. *Eclipse*. Mims House, 8 Oct. 2019.

President's Council of Advisors on Science and Technology (U.S.) & United States. *Report to the president, engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics.* Executive Office of the President, President's Council of Advisors on Science and Technology. 1 Feb. 2012. Accessed 2 Aug. 2023.

R Keith Sawyer. *The Cambridge Handbook of the Learning Sciences*. Cambridge University Press, 2016.

Horizon Research. *Highlights from the 2018 NSSME+*. Jan. 2019. Available: https://horizon-research.com/NSSME/wp-content/uploads/2019/01/Highlights-from-2018-NSSME.pdf.

Saltz, Joanna. *The Delish Kids (Super-Awesome, Crazy-Fun, Best-Ever) Cookbook*. Hearst Home & Hearst Home Kids, 31 Aug. 2021.

Schwarz, Christina V, et al. *Helping Students Make Sense of the World Using next Generation Science and Engineering Practices*. Arlington, Virginia, NSTA Press, National Science Teachers Association, 2017.

Shumar, W., et al. "Technologically mediated noticing & wondering @ The Math Forum," Paper presented at the annual meeting of the American Educational Research Association, Washington, DC. April 2016.

Simon, Seymour. *Tornadoes*. HarperCollins, 18 Apr. 2017.

Stewart, Melissa. *"Behind the Books: A Whole New Nonfiction Family Tree. Celebrate Nonfiction Exploring the Joy of Nonfiction Reading and Writing." Celebrate Nonfiction Exploring the Joy of Nonfiction Reading and Writing*. 2013, May 8. Available: http://celebratescience.blogspot.com/.

Stewart, Melissa, and Sarah S Brannen. *Feathers: Not Just for Flying*. Charlesbridge, 2014.

Stewart, Melissa, and Marlene Correia. *5 Kinds of Nonfiction*. Taylor & Francis, 10 Oct. 2023.

Tai, R. H. "CAREER CHOICE: Enhanced: Planning Early for Careers in Science." *Science*, vol. 312, no. 5777, 26 May 2006, pp. 1143–1144, https://doi.org/10.1126/science.

The Next Generation Science Standards. "Three Dimensional Learning." Nextgenscience.org, 2014, http://www.nextgenscience.org/three-dimensions. Accessed 2 Aug. 2023.

"Using Phenomena in NGSS-Designed Lessons and Units." Nextgenscience.org, 2014, http://nextgenscience.org/resources/phenomena. Accessed 2 Aug. 2023.

Wilhelm, Jeffrey D. *Improving Comprehension with Think Aloud Strategies: Modeling What Good Readers Do*. Scholastic Teaching Resources, 2013.

Williams, Lily. *If Sharks Disappeared*. Wayland, 2018.

Woodward, John, et al. *Dinosaur!: Dinosaurs and Other Amazing Prehistoric Creatures as You've Never Seen Them Before*. DK Publishing, 2019.

APPENDIX

Expository Nonfiction

13 Ways to Eat a Fly by Sue Heavenrich
A Butterfly is Patient by D. Aston
A Cool Drink of Water by Barbara Kerley
A Day and Night in the...series by Caroline Arnold (Rainforest, Desert, Prairie, Forest)
A Drop Around the World by Barbara Shaw McKinney
A Drop of Water by Gordon Morrison
A Drop of Water by Walter Wick
A Few Beautiful Minutes by Kate Allen Fox
A Forest in the City by Andrea Curtis
A Garden in Your Belly by Masha D'Yans
A House in the Sky and Other Uncommon Animal Homes by Steve Jenkins
A Kangaroo Mob by Johanna Burke
A Peek at Beaks: Tools Birds Use by Sara Levine
A Place for Birds by Melissa Stewart
A Pod of Whales by Lucia Raatma
A Pride of Lions by Amy Kortuem
A River of Dust by Jilanne Hoffmann
A River Ran Wild by Lynne Cherry
A River's Gifts: The Mighty Elwha River Reborn by Patricia Newman
A Rock Can Be. . . by Laura Purdie Salas
A Rock Is Lively by Dianna Hutts Aston
A Seed Is Sleepy by Diana Hutts Aston
A Seed Is the Start by Melissa Stewart
A Shell is Cozy by Dianna Hutts Aston
A Tree Is a Plant by Clyde Robert Bulla
Above and Below: Lift the Flaps to See Nature's Wonders Unfold by Hanako Clulow
Ada's Violin by Susan Hood
All the Water in the World by George Ela Lyon and Katerine Tillotson
Almost Gone: The World's Rarest Animals by Steve Jenkins
Amazing Animal Homes by Chris Packham
Amazing Animal Journeys by Chris Packham
An Ambush of Tigers: A Wild Gathering of Collective Nouns by Betsy Rosenthal
An Egg is Quiet by Dianna Aston
Animal Antipodes: Global Opposites by Carly Allen-Fletcher
Animal Architects by Amy Cherrix
Animal Dads by Sneed B. Collard III
Animal Homes by Mary Holland
Animal Noses; Animal Skins; Animal Tails; Animal Ears; Animal Eyes; Animal Mouths; Animal Legs by Mary Holland
Animal Talk: How Animals Communicate Through Sight, Sound, & Smell by Etta Kaner
Animals at Night by Ann Jankeliowitch
Animals Should Definitely Not Wear Clothing by Judi Barrett
Ants Don't Wear Pants by Kevin McCloskey
Apex Predators by Steve Jenkins

Arctic Lights, Arctic Nights by Debbie Miller
As the Crow Flies: A First Book of Maps by Gail Hartman
At the Marsh in the Meadow by Jeanie Mebane
Autumn Calf by Jill Haukos
Aviary Wonders Inc. by Kate Samworth
Backyard Bears: Conservation, Habitat Changes, and the Rise of Urban Wildlife by Amy Cherrix
Beaks by Sneed B. Collard III
Beastly Bionics by Jennifer Swanson
Beauty and the Beak by Deborah Lee Rose and Jan Veltkamp
Beaver Pond Moose Pond by Jim Arnosky
Because of an Acorn by Lola M. Schaefer and Adam Schaefer
Bee Dance by Rick Chrustowski
Begin with a Bee by Liza Ketchum, Jacqueline Briggs Martin, and Phyllis Root
Better Together: A Story of Family by Barbara Joosse and Anneke Lisberg
Beware of the Crocodile by Martin Jenkins
Big and Little by Steve Jenkins
Big Brown Bat by Rick Chrustowski
Bigger Than You by Hyewon Kyung
Birds and Their Nests; Spiders and Their Webs; Bears and Their Dens; Bees and Their Hives by Linda Tagliaferro
Birds of a Feather: Bowerbirds and Me by Susan L. Roth
Birds of Every Color by Sneed B. Collard III
Birds: Nature's Magnificent Flying Machines by Caroline Arnold
Blackout by John Rocco
Blast Off!: How Mary Sherman Morgan Fueled America Into Space by Suzanne Slade
Blizzard by John Rocco
Bone by Bone by Sara Levine
Bone Collection: Animals by Rob Colson
Bones by Steve Jenkins
Bones in the White House by Candice Ransom
Bones, Bones, Dinosaur Bones by Byron Barton
Born to Be Giants: How Baby Dinosaurs Grew to Rule the World by Lita Judge
Boy, Were We Wrong About the Solar System by Kathleen V. Kudlinski
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Gabi's If/Then Garden, Adi's Perfect Patterns and Loops, and Adi Sorts with Variables, and Gabi's Fabulous Functions by Caroline Karanja
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Giant Squid by Candace Fleming
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Go for the Moon: A Rocket, A Boy, and the First Moon Landing by Chris Gall
Good Eating: The Short Life of Krill by Matt Lilley
Good Night to Your Fantastic Elastic Brain by Joann Deak and Terrence Deak
Goodbye Summer, Hello, Autumn; Goodbye Autumn, Hello Winter; Goodbye Winter, Hello Spring by Kendard Pak
Grandmother Fish: A Child's First Book of Evolution by Jonathan Tweet
Gravity by Jason Chin
Great Carrier Reefby Jessica Stremer
Green City by Allan Drummond
Grow: Secrets of Our DNA by Nicola Davies
Guess What Is Growing Inside This Egg by Mia Posada
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How Mountains Are Made by Kathleen Weidner Zoehfeld
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How to Be an Elephant by Katherine Roy
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How to Code a Sandcastle by Josh Funk
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Hurricane! by Corinne Demas
I am NOT a Dinosaur! by Will Lach
I Am Smoke by Meeg Pincus
I Am the Storm by Jane Yolen
I See a Kookaburra! by Steve Jenkins and Robin Page
I See Animals Hiding by Jim Arnosky
If Sharks Disappeared by Lily Williams
If You Take Away the Otter by Susannah Buhrman-Deever
I'm Trying to Love Rocks by Bethany Barton
In November by Cynthia Rylant
In the Past by David Elliott
In the Tall, Tall Grass and In the Small, Small Pond by Denise Fleming
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My Animal Family by Kate Peridot
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Name That Animal! series by Wayne Lynch (*Whose Teeth Are These? Whose Nose Is This? Whose Bottom Is This? Whose Feet Are These?*)
Nano: The Spectacular Science of the Very (Very) Small by Dr. Jess Wade
Nature Did It First by Karen Ansberry
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One Day on Our Blue Planet Series by Ella Bailey
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Redwoods by Jason Chin
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Rivers of Sunlight: How the Sun Moves Water Around the Earth by Molly Bang & Penny Chisholm
Robins! How They Grow Up by Eileen Christelow

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Roller Coaster by Marla Frazee
Rumble, Boom! A Book About Thunderstorms; Whiteout! A Book About Blizzards; Eye of the Storm! A Book About Hurricanes; Twister! A Book About Tornadoes by Rick Thomas
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Snow Rabbit, Spring Rabbit by Il Sung Na
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Solitary Animals: Introverts of the Wild by Joshua David Stein
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Subway by Beth Anderson
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Sun by Steve Tomecek
Sunshine Makes the Seasons by Franklyn M. Branley
Sunshine: A Book About Sunlight by Josepha Sherman
Superlative Birds by Leslie Bulion
Survival at 40 Below by Debbie S. Miller
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Ten Ways to Hear Snow by Cathy Camper
Terrific Tongues by Maria Gianferrari
The Animal Toolkit by Steve Jenkins & Robin Page
The Beak Book by Robin Page
The Big Bang Book by Asa Stahl
The Big Book of the Blue by Yuval Zommer
The Busy Tree by Jennfier Ward
The Case of the Vanishing Honeybees: A Scientific Mystery by Sandra Markle
The Coquies Still Sing by Karina Nicole Gonzalez
The Curious Garden by Peter Brown

The Deadliest Creature in the World by Brenda Z. Guiberson
The Elephants Come Home by Kim Tomsic
The Emperor Lays an Egg by Brenda Z. Guiberson
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The Gravity Tree by Anna Crawley Redding
The Great Shark Rescue, The Great Monkey Rescue, The Great Penguin Rescue, The Great Rhino Rescue by Sandra Markel
The Honey Makers by Gail Gibbons
The Honeybee by Kirsten Hall
The Invention Hunters Discover How Sound Works by Korwin Briggs
The Last Plastic Straw by Dee Romito
The Life Cycle of an....(Oak Tree, Bean, Sunflower, Apple Tree, Carrot, Pine Tree) series by Linda Tagliaferro
The Magic and Mystery of Trees by Jen Green
The Moon Book by Gail Gibbons
The Moon Seems to Change by Franklyn M. Branley
The Mouse in a Meadow by John Himmelman
The New Ocean: The Fate of Life in a Changing Sea by Bryn Barnard
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The Sea Below My Toes by Charlotte Guillain
The Shortest Day: Celebrating the Winter Solstice by W. Pfeffer
The Sky Is Full of Stars by Franklyn M. Branley
The Stars Beneath Your Bed: The Surprising Story of Dust by April Pulley Sayre
The Story of Climate Change by Catherine Barr and Steve Williams
The Story of Snow: The Science of Winter's Wonder by Mark Cassino with Jon Nelson, PhD
The Street Beneath My Feet by Charlotte Guillain and Yuval Zommer
The Sun Shines Everywhere by Mary Ann Hoberman
The Sun, the Wind, and the Rain by Lisa Westberg Peters
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The Tide Pool Waits by Candace Fleming
The Tiny Seed by Eric Carle
The Tornado Scientist: Seeing Inside Severe Storms by Mary Kay Carson
The Tree in the Ancient Forest by Carol Reed-Jones
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The Triumphant Tale of the House Sparrow by Jan Thornhill
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Tree Hole Homes: Daytime Dens and Nighttime Nooks by Melissa Stewart
Trout Are Made of Trees by April Pulley Sayre
Uma Wimple Charts Her House by Reif Larsen and Ben Gibson
Under Earth, Under Water by Aleksandra Mizielinska and Daniel Mizielinski
Under One Rock: Bugs, Slugs, and Other Ughs by Anthony D. Fredericks
Under the Snow by Melissa Stewart
Under Your Feet: Soil, Sand, and Everything Underground by Wenjia Tang
Vulture View by April Pulley Sayre
Wait, Rest, Pause: Dormancy in Nature by Marcie Flinchum Atkins
Warbler Wave by April Pulley Sayre
Watching Desert Wildlife by Jim Arnosky
Water Can Be... by Laura Purdie Salas
Water in the Park by Emily Jenkins
Water is Water by Miranda Paul
Water Land: Land and Water Forms Around the World by Christy Hale
Water Wow! An Infographic Exploration by Antonia Banyard & Paula Ayer
We Are Water Protectors by Carole Lindstrom
We Build Our Homes by Laura Knowles
We Planted a Tree by Diane Muldrow
We're Not Weird: Structure and Function in the Animal Kingdom by Michael Garland
Weeds Find a Way by Cindy Jenson-Elliott
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When the Stars Come Out by Nicola Edwards
When the Wolves Returned: Restoring Nature's Balance in Yellowstone by Dorothy Patent
Where in the Wild by Jonny Lambert
Where in the Wild by Poppy Bishop
Where in the Wild? Camouflaged Creatures Concealed…and Revealed by David M. Schwartz and Yael Schy
Where the Forest Meets the Sea by Jeannie Baker
Whoo-Ku Haiku: A Great Horned Owl Story by Maria Gianferrari

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Why Do Leaves Change Colors by Betsy Maestro and Leaves Fall Down by Lisa Bullard
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Young Thomas Edison by Michael Dooling
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Zee Grows a Tree by Elizabeth Rusch
Zombie Makers: True Stories of Nature's Undead by Rebecca L. Johnson
Zoobots: Wild Robots Inspired by Real Animals by Helaine Becker

Narrative Nonfiction (Biographies)

A Computer Called Katherine by Suzanne Slade
A Dream of Flight by Jef Polivka and Rob Polivka
A Life Electric: The Story of Nikola Tesla by Azadeh Westergaard
A Passion for Elephants: The Real Life Adventure of Field Scientist Cynthia Moss by Toni Buzzeo
A Weed Is a Flower: The Life of George Washington Carver by Aliki
Ada and the Galaxies Exploring the Night Sky and Light Pollution by Alan Lightman and Olga Pastuchiv
Ada Byron Lovelace and the Thinking Machine by Laurie Wallmark
Ada Lovelace Poet of Science: The First Computer Programmer by Diane Stanley
Ada's Ideas: The Story of Ada Lovelace, the World's First Computer Programmer by Fiona Robinson
A.I.: How Patterns Helped Artificial Intelligence Defeat World Champion Lee Sedol by Darcy Pattison
All In a Drop: How Antony Van Leeuwenhoek Discovered an Invisible World by Lori Alexander
Anne and Her Tower of Giraffes: The Adventurous Life of the First Giraffologist by Karlin Gray
Annie Jump Cannon, Astronomer by Carole Gerber
Aquarium: How Jeannette Power Invented Aquariums to Observe Marine Life by Darcy Pattison
Barnum's Bones: How Barnum Brown Discovered the Most Famous Dinosaur in the World by Tracey Fern
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Building a Dream: How the Boys of Koh Panyee Became Champions by Darshana Khiani
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Counting the Stars: The Story of Katherine Johnson NASA Mathematician by Lesa Cline-Ransome
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