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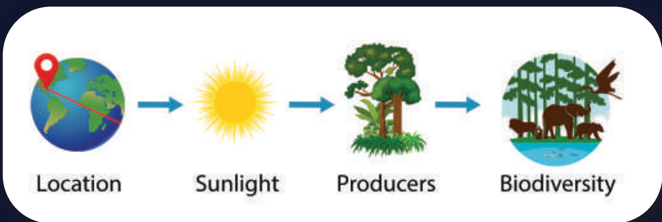
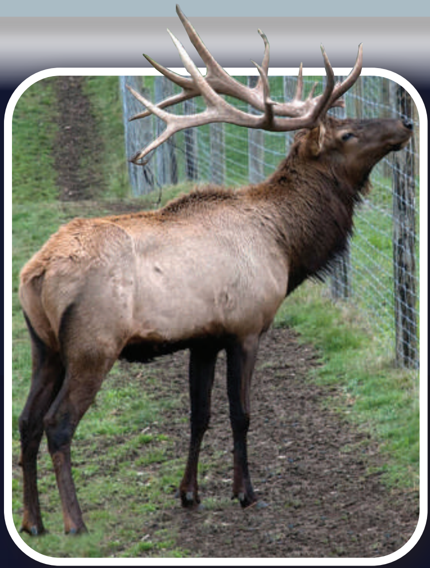
Using Science Knowledge

Science Literacy Student Reader

Understanding and reasoning





Predictable phenomena

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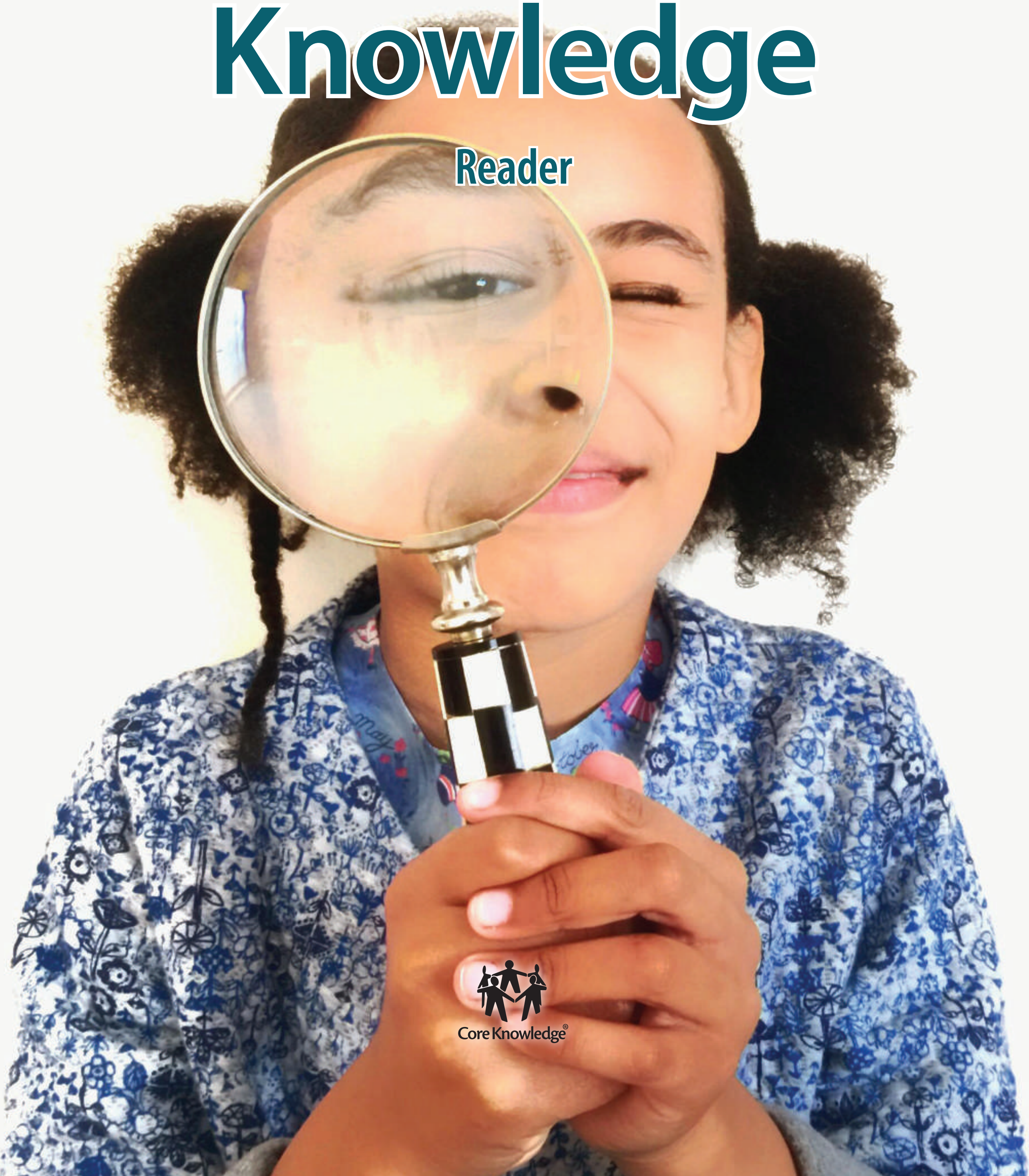
Using Science Knowledge

Reader



Core Knowledge®

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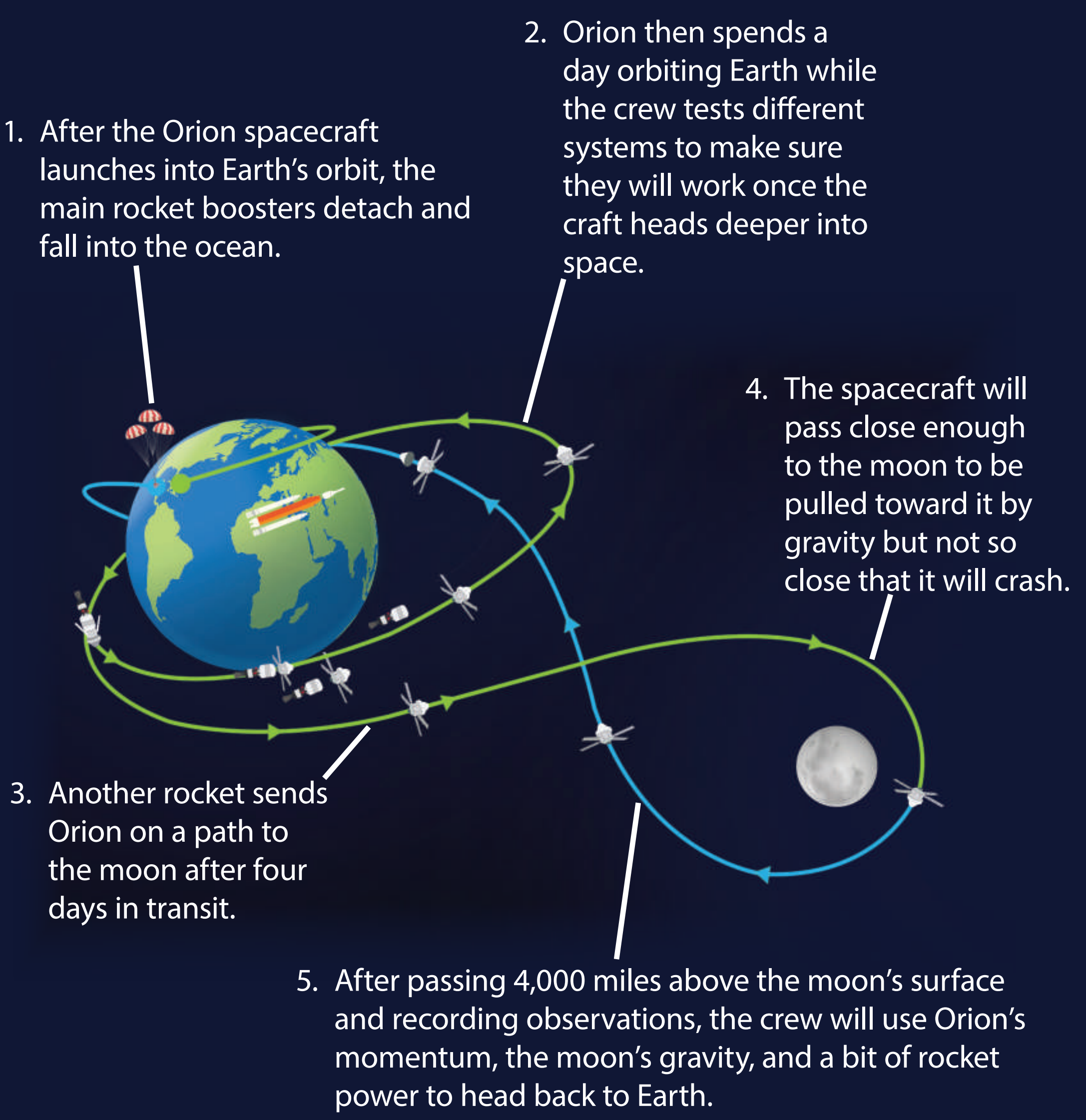
Science Teamwork

Chapter 1

The Artemis program is a series of NASA space missions. In 2022, Artemis I, an uncrewed Orion spacecraft, went to the moon and back. Artemis II, scheduled for 2024, will carry four astronauts on a similar trip.



For Artemis II, the four astronauts are highly qualified, educated, and experienced. Sometimes things change during complex projects, but at the time this chapter was written, the planned Artemis crew includes these astronauts:

Reid Wiseman

Commander, Artemis II

- **Experience:** 165-day mission on the International Space Station (ISS), conducting 300 science experiments in human physiology, medicine, physical science, Earth science, and astrophysics. Helped set a space record of 82 hours of research in one week. 2 spacewalks. Fighter pilot for the U.S. Navy. 2 years astronaut training at the Johnson Space Center.
- **Education:** Bachelor of Science, Computers and Systems Engineering; Master of Science, Systems Engineering; Certificate of Space Systems, U.S. Naval Postgraduate School.

Victor Glover

Pilot, Artemis II

- **Experience:** Pilot for the U.S. Air Force and U.S. Navy. Accumulated 3,000 flight hours in more than 40 aircraft, performed over 400 aircraft carrier landings, and flew 24 combat missions. Worked as a Legislative Fellow in the U.S. Senate. 168 days aboard the SpaceX Crew-1. 4 spacewalks.
- **Education:** Bachelor of Science, General Engineering; Master of Science, Flight Test Engineering; Master of Science, Systems Engineering (PD-21); Master of Military Operational Art and Science.

Christina H. Koch

Mission Specialist 1, Artemis II

- **Experience:** Flight engineer on three ISS expeditions. 328 days in space. 6 spacewalks. Research associate in Antarctica. Developed numerous instruments used on space missions.
- **Education:** Bachelor of Science, Electrical Engineering and Physics; Master of Science, Electrical Engineering; Honorary PhD.

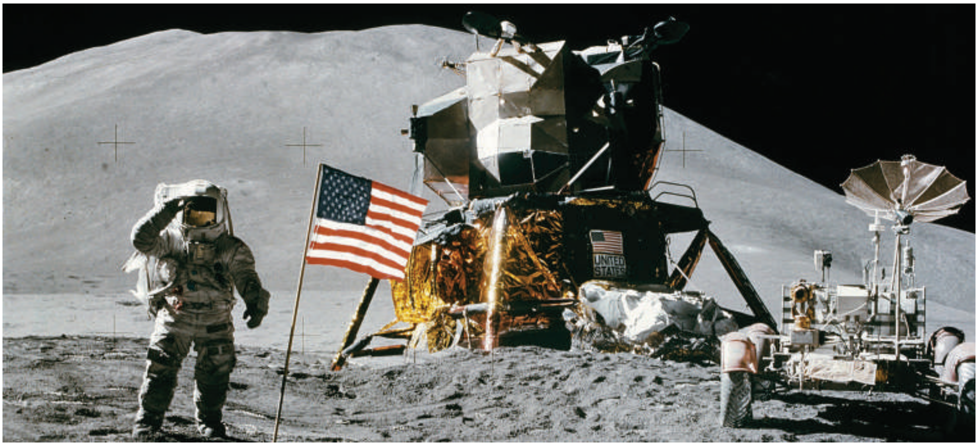
Jeremy Hansen

Mission Specialist 2, Artemis II

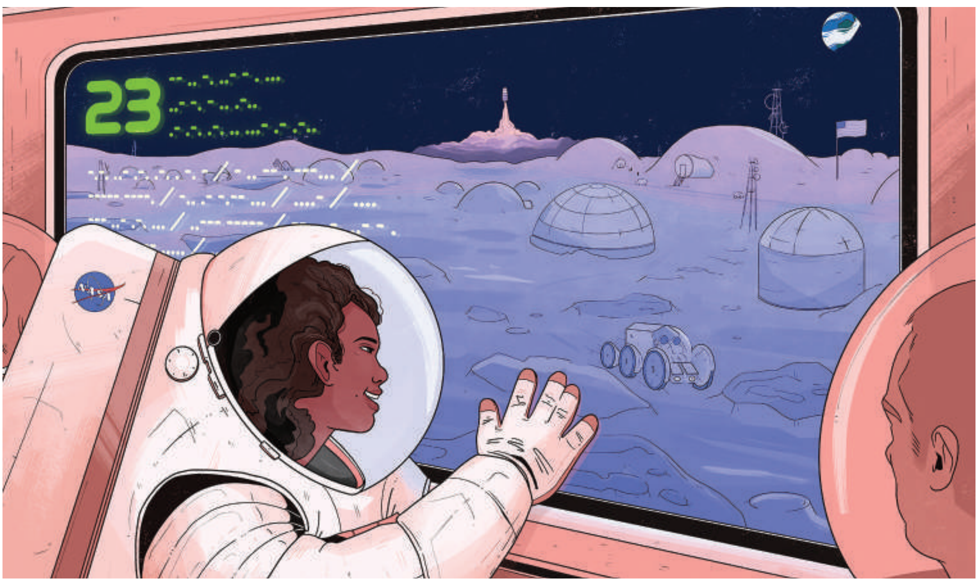
- **Experience:** Fighter pilot for the Canadian Air Force. Explored the deep sea in submarines as well as underground cave systems.
- **Education:** Bachelor of Science, Space Science; Master of Science, Physics.

The goal of the Artemis program is to return people to the surface of the moon and eventually build a staging ground there to be used for trips to Mars.

An Artemis base camp will be built on the moon's surface. An orbiting station, called Gateway, will make it easier for arriving astronauts to transfer to and from the moon's surface. If the base camp project succeeds, the moon could become a place to stop and refuel on the way to Mars. It will also be a place to study the moon itself.



This photograph was taken on the moon's surface by the astronauts of the Apollo 15 mission in 1971.



This is an illustration of what the Artemis base camp will look like.

Sending a spacecraft to the moon is complex and dangerous. The people who plan the mission and build the vehicle and equipment must think about everything that could go wrong. They must anticipate the tiniest problem and have backup plans.

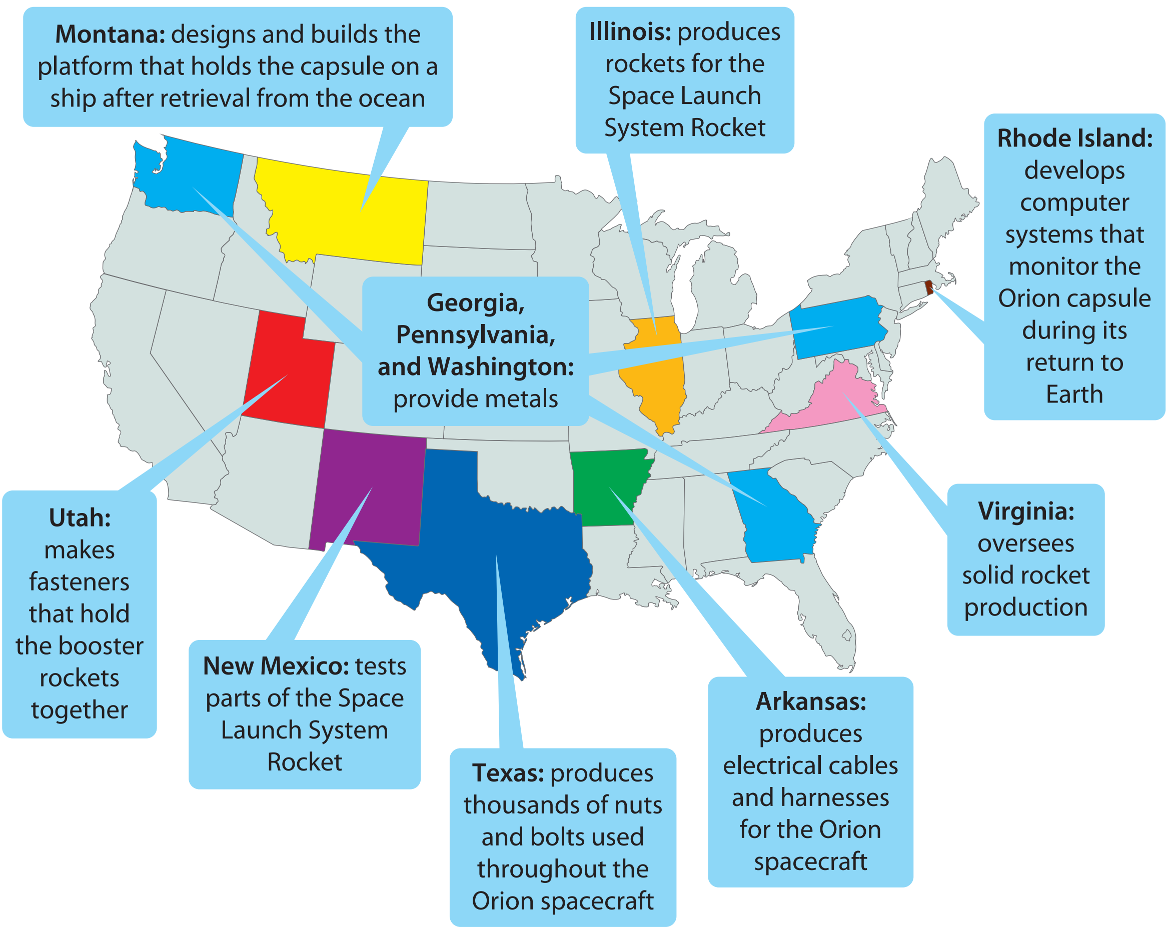
In engineering, having backup plans is called redundancy. Many of the physical components have built-in redundancy. For example, second or third versions of communication channels provide backup if the first channel malfunctions.

The four Artemis II astronauts are likely to get the most attention of anyone working on the mission. But there are thousands of people involved in the program. For example, NASA's Search and Rescue team is responsible for tracking the Orion capsule as it descends back to Earth after the ten-day mission to the moon and back. The capsule cannot gently swoop down and land in a specific place like an airplane.

- It enters Earth's atmosphere at high speed (producing extreme heat!).
- Then a parachute slows the capsule so it gently falls into the ocean.
- The Search and Rescue team tracks a beacon on the capsule so it can estimate where and when the capsule will splash down.
- If the capsule remains afloat, it will be pulled onto a ship.
- If the capsule is sinking, the astronauts can escape and be rescued by helicopter.
- Each astronaut's spacesuit has its own beacon that can activate and be tracked if the astronauts become separated.

A team practices the rescue of astronauts from a space capsule.

Companies from all fifty U.S. states are contributors to the mission. Some supply raw materials. Others lead in design and planning. And still others manufacture components. All materials and processes go through rigorous testing, no matter where they come from.



Main Science Idea

Great scientific accomplishments always involve teams of people working together.

Scientific Explanations

Chapter 2

Long before humans performed investigations, they still came up with explanations for the way things happen. Storytelling passed the explanations down from generation to generation. But the explanations in many cases were not scientific. Explanations for how the natural world works are often what we now call mythology.

People still study mythological storytelling, but it's a study of cultures. Scientific explanations are something different, and they require evidence. Let's contrast some mythological stories and the scientific explanations related to them.

Folklore: Maui the demigod slowed the sun.

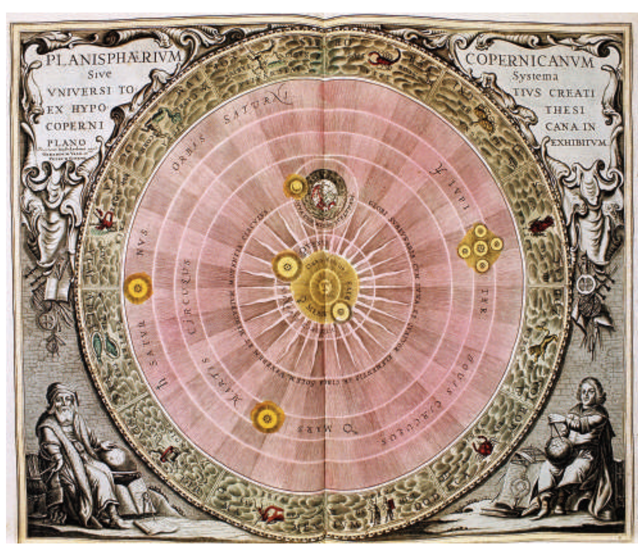
Origin: Polynesian people of the Pacific Islands, from New Zealand to Hawaii

In myth, long ago, the sun traveled across the sky so quickly that it bothered Maui, a demigod, along with his brothers. Maui had already accomplished many amazing feats, including hauling entire islands out of the sea. He decided to slow down the sun so days would be longer and life easier. Maui and his brothers wove long, sturdy ropes and journeyed with them to the far-off place where the sun rose every morning. There, they built clay huts that would protect them from the scorching heat of the rising sun.

When the sun rose, Maui's brothers screamed from the heat and light and tried to run away. Maui, being the bravest, told them to stay and fight. They used their ropes to lasso the sun. The sun grew angry, demanding to be freed. But Maui insisted that the sun was too quick in his path across the sky each day. The sun gave up and agreed from then on to take more time crossing the sky. Since then, days have remained longer, giving people more time to fish, work, eat, play, and more.

What Science Says About the Sun

Nicolaus Copernicus was a Polish scientist. He was the first person to use evidence to show that Earth revolves around the sun and that Earth's rotation explains the appearance of the sun arcing across the sky. He provided evidence that included measurements of when and where the sun appeared from different vantage points on Earth. Recorded observations also included seasonal changes in how the sun and stars appeared, the patterns in the cycle of the moon, and more. All these observations helped Copernicus develop and test his ideas. In other words, Copernicus provided evidence for why we see the sun move across the sky. Importantly, other people could check and recheck his evidence.



This artwork shows the orbits of the planets marked by circles. They move around the sun.

Folklore: Earthquakes and tsunamis are caused by giant beasts in battle.

Origin: Native American peoples from California to British Columbia

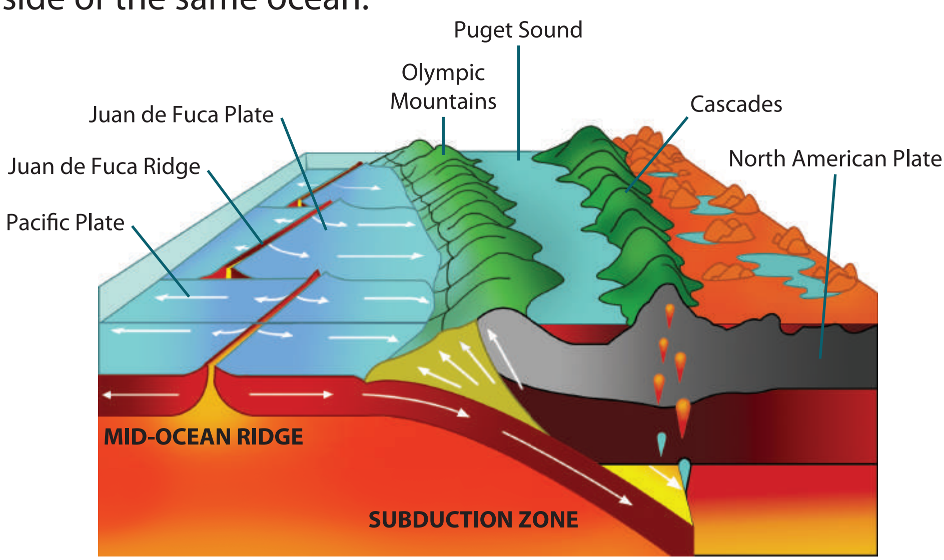
The giant whale had eaten all the fish in the sea, causing people to starve. The thunderbird felt sorry for the people and attacked the whale. The thrashing of the whale and bird as they battled in the water sent huge waves crashing onto the land. Finally, the bird succeeded in pulling the whale from the sea and dropped it onto the land, causing the ground and mountains to shake. The thunderbird, with help from the wolf and the serpent, dragged the whale back into the sea. This has been the cycle for many centuries.

What Science Says About Earthquakes and Tsunamis

Science tells us earthquakes are the product of movements of parts of the planet. It also tells us that most tsunamis are produced by the same activity.

Scientific explanations and myths often have things in common. Detailed accounts of an earthquake and tsunami that wiped out entire coastal villages of the Pacific Northwest suggest a specific event that happened around 1700, and so does the physical evidence. That evidence includes layers of ocean sediment that washed inland from Puget Sound, which is a large body of water that connects the Pacific Ocean to inland areas and rivers of Washington State. Sediments that shouldn't be found far from the ocean are buried under layers of soil that have accumulated since 1700.

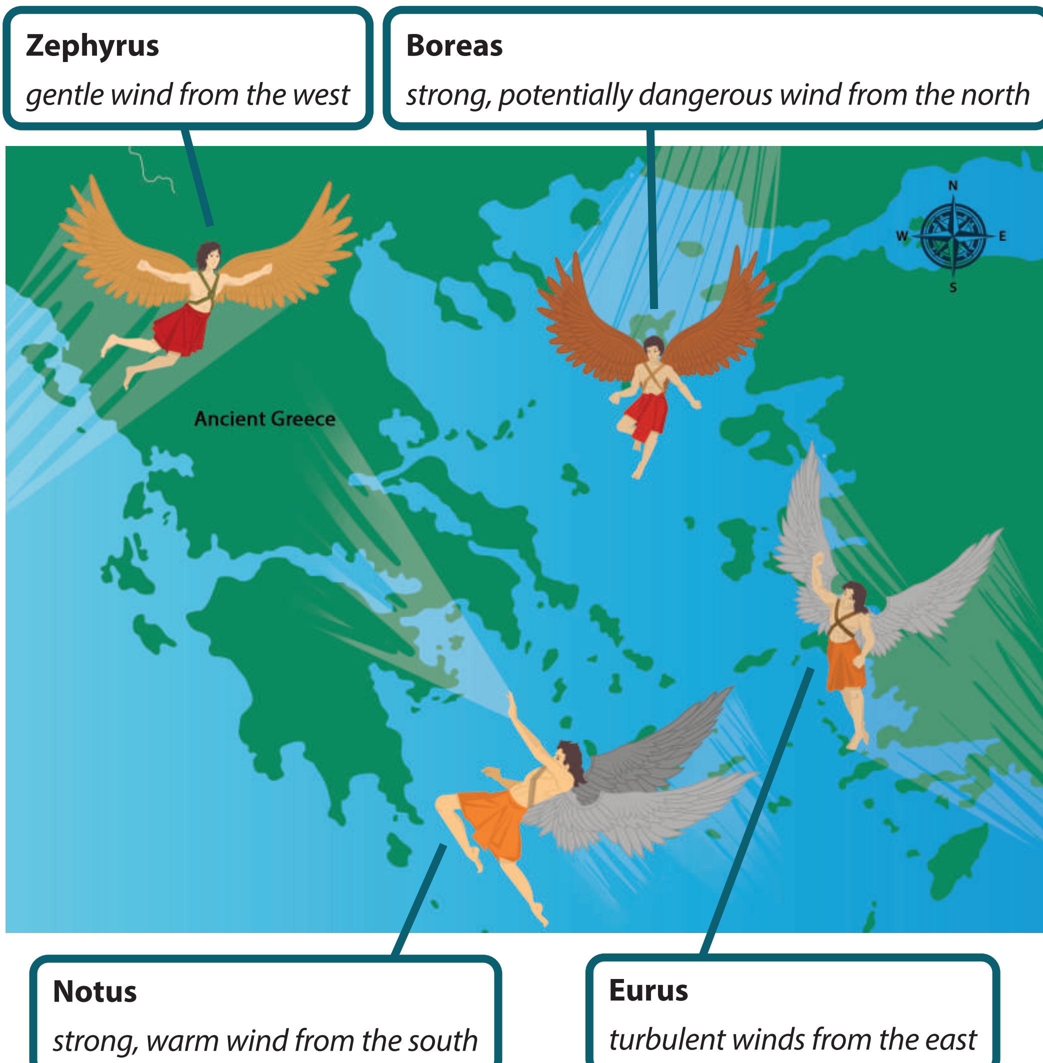
Meanwhile, written records from coastal harbors in Japan describe tsunami waves that washed ashore that year. In fact, those Japanese records can pinpoint the exact day: January 26, 1700. The tsunami that struck the Pacific Northwest affected Japan, on the far side of the same ocean.



Folklore: The winds are caused by four gods known as the Anemoi.

Origin: Ancient Greece and Rome

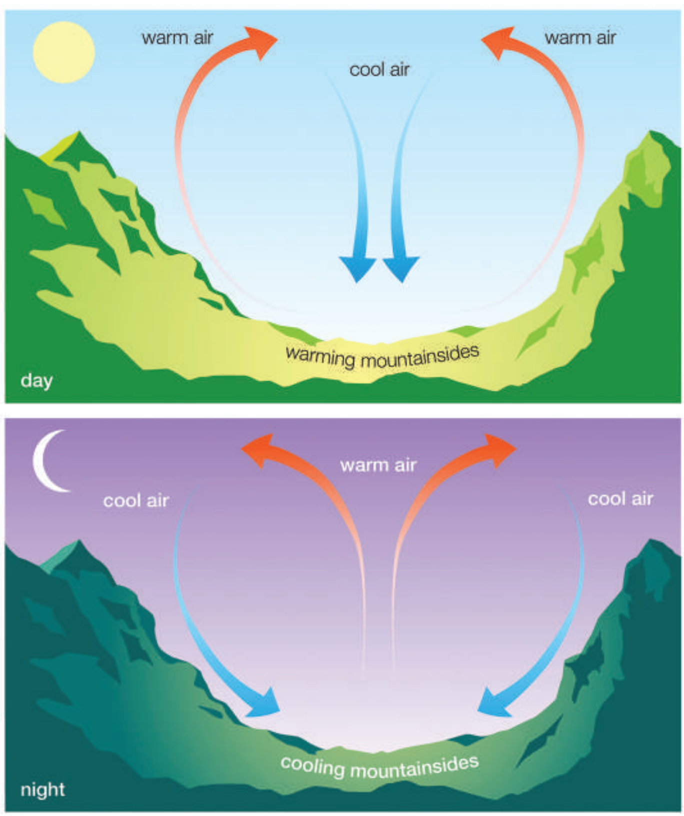
The four Amenoi, or wind deities, are the children of Eos, goddess of dawn, and Astraeus, god of dusk. Each of the Amenoi produces winds that blow from a specific direction and have certain characteristics. Some of them occur with certain seasons. They are sometimes represented in ancient Greek art as humans with wings on their backs.



What Science Says About Wind

Measuring temperatures in the air at different altitudes and determining the connection between temperature and pressure helped people figure out that the atmosphere is made of different air masses that move around as they warm and cool. In general, air near Earth's surface tends to warm up during the day thanks to energy from the sun. The warm air expands and rises, which leaves a void behind it. Cool, dense air flows into the void. This movement of air across Earth's surface is what we experience as wind.

Valley and Mountain Breezes



Main Science Idea

Evidence is what makes an explanation scientific.

New Data and Evidence

Chapter 3

For many years, people interested in the great white shark did not think the fish was a leaper. Other shark species, such as the mako, had been observed leaping out of the water. The great white seemed slower, and it was certainly heavier, so it seemed less likely to get airborne.

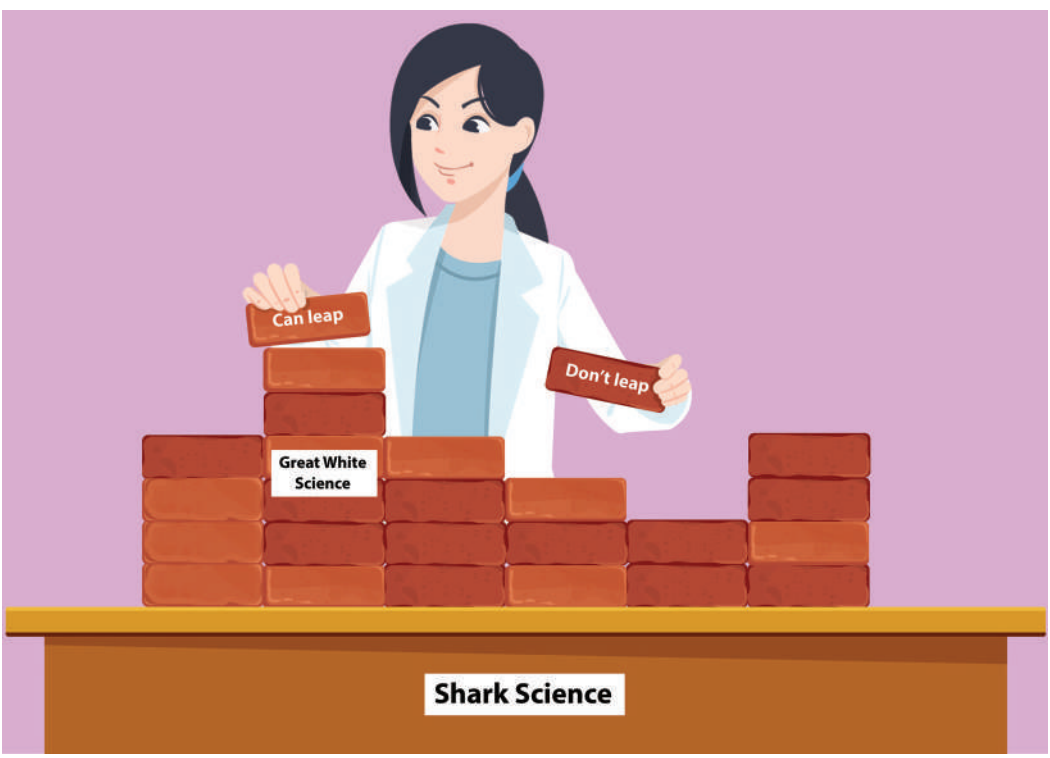
Then, in the 1990s, reports came out of South Africa about a population of great white sharks that leaped clear out of the water while attacking swimming seals from below. Reports reached shark scientists, and they were skeptical. They had not observed this behavior themselves, and it just seemed hard to believe because of white sharks' observed behavior. They debated the idea and even used physics equations of mass, velocity, and the resistance of water to calculate how fast a large shark would need to be swimming to become airborne. Without visual evidence, some of the experts dismissed the reports as highly improbable.

Then, advances in photography showed that the reports were true. White sharks around Seal Island, off the coast of South Africa, *could* launch themselves out of the water. This was observed by scientists and captured by photographers. They teamed up to conduct experiments, towing seal decoys behind boats as bait. What had been considered improbable was now a demonstrated fact. The research continues, and shark biologists now think that juvenile white sharks—large and agile seal hunters but not too heavy—are more likely to be leapers than adult sharks.

The example of a changing idea about great white sharks shows how scientific ideas change over time. Conclusions are made, and these can become known as scientific facts. Then those facts are tested and questioned by new discoveries or observations.

Science is a vast body of knowledge, and it's also the way of acquiring and building that body of knowledge. An idea can eventually be discarded and replaced. Overall, the body of knowledge tends to grow over time, but new knowledge comes in, and some old beliefs go out of date.

As science knowledge changes, so do science methods. Something that happens in one corner of science can affect another corner almost overnight.

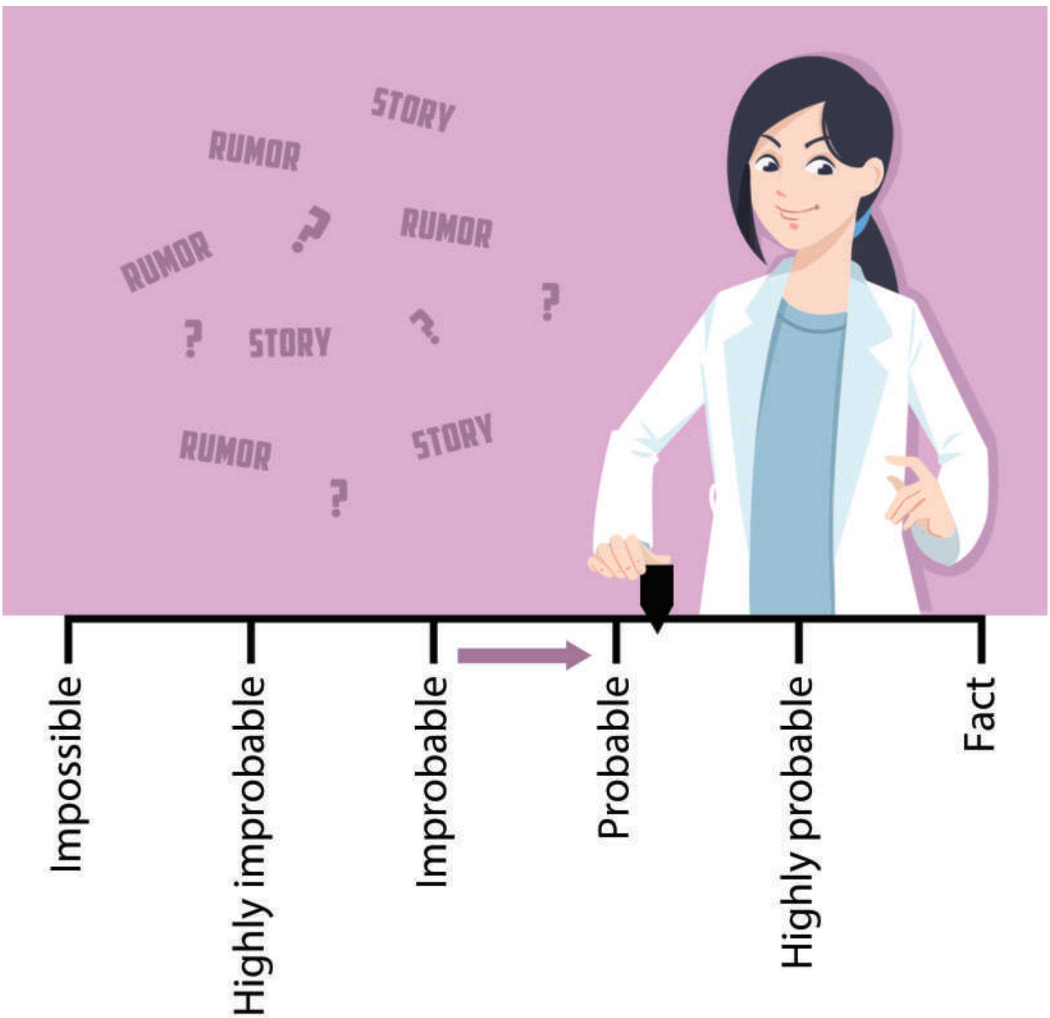


Think of science observations as building blocks of knowledge. A scientist building knowledge about great white sharks builds information on top of a foundation of general knowledge about all shark science. If any building blocks of knowledge turn out to be inaccurate, those blocks are replaced with new, accurate blocks.

For example, the invention of digital photography was not intended to help shark science. The people who develop sensors, microchips, and other components of digital cameras tend to be engineers who are experts in physics, electronics, and the behavior of light.

But their inventions helped the shark research around Seal Island. Instead of relying on film cameras, digital photographs and videos of sharks leaping out of the water provided better images in real time. The quality of the images produced by these new technologies gave shark biologists such clear glimpses of the phenomenon that they could identify individual sharks, determine whether they were male or female, estimate their sizes, and, of course, observe and analyze their behavior. Just years earlier, even with the use of film, it would have been much more difficult and time-consuming to do the same type of research.

Even when shark biologists were leery of the stories of airborne great whites, their minds were not closed. That's because science and scientists are skeptical. This means that they question everything and continue to be concerned about the accuracy of what they read or hear, even from other scientists. Scientists question continuously.



Here is another example of how the known facts about great white sharks needed adjustment.

In the 2010s, the carcasses of great white sharks began washing up on the South African shoreline. Unlike sharks that are killed accidentally by fishing gear and then discarded at sea, these sharks were missing their livers and other internal organs, as if something had opened their bellies looking for a particular organ—almost like a surgeon. In 2022, killer whales, also known as orcas, were spotted attacking great white sharks and biting their bellies where their large, oil-filled livers are found. Several orcas were recorded by cameras in drones and helicopters hovering above, and the footage showed them working as a team to kill a shark and remove its liver. Then they did it again with several more sharks.

It also may have been an example of science changing because nature itself was changing. Whales are intelligent, so these orcas may have been learning to hunt a new type of prey that was relatively abundant in the area.

Main Science Idea

Scientists are skeptical. They question things. New data and evidence require scientific ideas to be reevaluated and often changed. There's nothing wrong with that! It's an important part of the scientific process.

Criteria and Constraints

Chapter 4

James lives in the Bahamas, a chain of islands southeast of Florida. The islands are small, flat, and isolated. Cargo boats and small planes bring food and goods that cannot be harvested or made on the islands. Shipments include beef, gasoline, boat engines, fishing gear, televisions, and golf carts. Some of the larger imports to the islands are automobiles.

James is an auto mechanic who helps maintain and repair those cars. Something James and other Bahamians struggle with is what to do with cars that break down and can't be used. Unlike the North American mainland, there isn't much space in the Bahamas to store "junk" cars. On islands around the world, space is a major constraint on all kinds of activities. A constraint is a limitation or restriction.

Another constraint is the lack of resources to recycle or reuse parts of cars that are no longer roadworthy. In Florida, it's easy for a car to be "scrapped"—tires are recycled, frames are melted down into raw metals, and so on. There are ways to dispose of parts that cannot easily be reused or recycled, too. People in the Bahamas don't have those same resources. They also cannot afford to export thousands of junk cars to Florida or elsewhere.

Despite the serious constraints, James and other Bahamians want to solve the problem. Rusty, abandoned cars are unsightly, and they take away from the natural beauty that brings so many tourists to the islands. Also, the chemicals that are in abandoned cars can leak out over time, damaging the local water supply and fragile habitats.

The constraint is space. Space prevents James from keeping his island clean and beautiful. James and others are overcoming these constraints by proposing the following:

- **Salvage all recyclable materials, such as rubber tires and steel frames, from all automobiles that have reached junk status.**
- **Materials that can be exported for sale should be exported and sold.**
- **Materials that cannot be sold should be recycled for other purposes, such as turning tire crumb (ground-up car tires) into components of asphalt for paving roads.**
- **Sink unsalvageable but cleaned cars in areas around the islands to become artificial reefs.**
- **Help pay for these efforts by charging a tax on automobile rentals, which would be paid for mostly by tourists.**

James must meet some criteria. Criteria are the standards by which something is judged. The criteria James will use to evaluate the success of the project are the following:

- **The number of junk automobiles in the Bahamas declines by a measurable amount every year.**
- **Measurable amounts of materials salvaged from the automobiles are used in other projects, such as paving roads or building artificial reefs.**

Cars can serve as bases for coral reef development, but chemicals they contain could leak into the ocean if they are not removed before being sunk.

Thousands of miles away, two high school students, Gabby and Phoebe, are also facing constraints. They are trying to clear the plastic pollution that's washing up on the beaches. It's ugly and can harm wildlife.

Gabby and Phoebe organize monthly cleanup beach walks to help collect the waste. But what do they do with the debris once it's collected? It can be buried in a landfill or burned in a trash incinerator, but that just relocates the problem.

Gabby and Phoebe are also avid sea kayakers. They sometimes use kayaks to explore the coastline and gather pollution. This gives them an idea: What if sea kayak manufacturers could recycle the plastic garbage that's washing up on coastlines or drifting in the ocean? Could they use it to make kayaks? The manufacturers might be able to save on the costs of materials. Also, anyone who wants to reduce their consumption of new plastic products might even be willing to pay a little more for a kayak made of recycled plastic.

The girls contact a kayak manufacturer in California to pitch their idea. The company's president emails them back right away. She loves the idea, but she shares her own constraints that might make the project unrealistic:

- *We need a specific type of plastic called high-density polyethylene, or HDPE. It's a tough, durable plastic that helps our kayaks resist scratches and avoid cracks when people crash into rocky beaches or drop the kayaks while unloading them from rooftop car racks. There is quite a bit of plastic floating around on the ocean and landing on coasts, but not all of it is HDPE. Plastics with the "2" symbol on them are HDPE, but everything else is low- or medium-density plastic that we cannot use. Clear water bottles, for example, are made of PET, and it just doesn't melt and resolidify into a durable plastic we can use.*
- *Given that constraint, the amount of recyclable HDPE we need for kayaks is probably more than could be collected—especially without spending a lot of money on collection.*

Gabby and Phoebe are disappointed, but they still think their idea could work. Instead of relying solely on HDPE plastic collected from coastal garbage, what if the kayak manufacturer also got some of the HDPE plastic that is currently collected by curbside recycling programs all over the country? A lot of that plastic isn't being recycled anyway, so that could be another source of the raw material that's needed to make kayaks.

Can this constraint be overcome? The students think so. They write a proposal and send it to the kayak maker and to recycling companies in California.

1. *Kayak manufacturers need HDPE plastic to make their products. This is a specific type of plastic that can be expensive.*
2. *The plastics industry relies too heavily on fossil fuels instead of recycling plastic that's already out in the world.*
3. *Plastic pollution is littering our seas and coastlines. Not enough of it is collected, because people think it has no use. And much of what is collected isn't recycled.*

We think all three problems could be lessened if the kayak manufacturer could team up with nonprofit groups and the state government to purchase HDPE-based trash from beach cleanup volunteers and recycling companies. This would make the recyclable HDPE more affordable than new HDPE. And for the state and coastal communities, the investment would pay off by resulting in a cleaner environment. The state could also make kayaks made of recycled HDPE more affordable by removing the sales tax from those kayaks specifically. This would encourage kayakers to buy those kayaks.

Please let us know if you are interested in hearing more about our idea or collaborating with our group.

Sincerely,

Gabby Martinez and Phoebe McClain

Gabby and Phoebe also have criteria for their undertaking. They will meet their criteria when the beach is clean and the animals are safe.

Main Science Idea

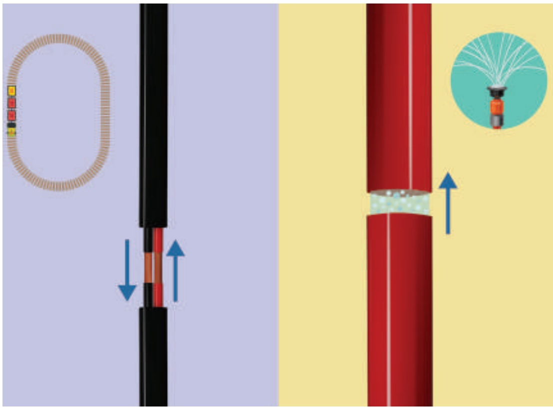
Criteria are the conditions that the solution to a problem must meet (or what it has to do). Constraints are limitations or restrictions on a solution (or what it can't do).

Comparing to Understand

Chapter
5

An analogy is a comparison between two things. Analogies can help us understand the way something is structured or how it works. An analogy says one thing is like another thing in a certain way. Analogies are especially helpful for understanding abstract ideas and processes that we can't directly observe. But always remember that analogies are just uses of language. They are not literal explanations of the way things work.

Analogy: Electric Current and Flowing Water



The way electric current transfers is similar to how water flows through a hose.

When a battery powers a model train, electrons must "flow" from the power source to the train's motor and back. One part of the circuit carries electrons to the motor, and a separate wire carries them back to the battery. The rate of the electrons' flow helps control the speed of the train. With a garden hose and sprinkler, the rate of water flow controls how far the sprinkler can spray water.

Comparing the two systems is an analogy. The key similarity in both parts of the analogy is the flow of something, but don't take the analogy too literally! The transfer of electrons doesn't involve movement of matter particles the way water flow does. The analogy helps, however.

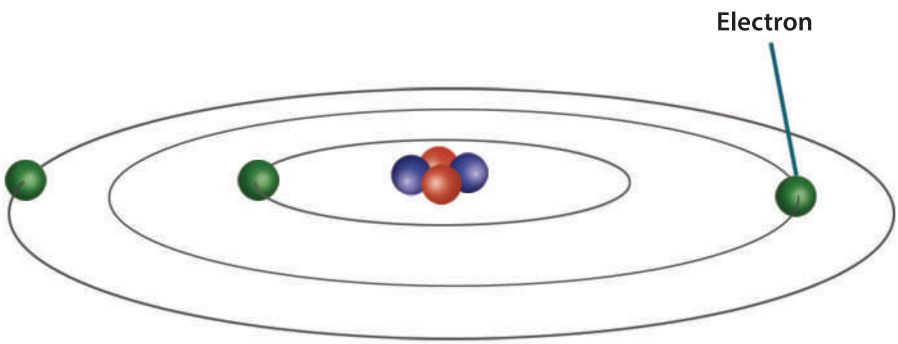
Analogy: Tendons and Bungee Cords

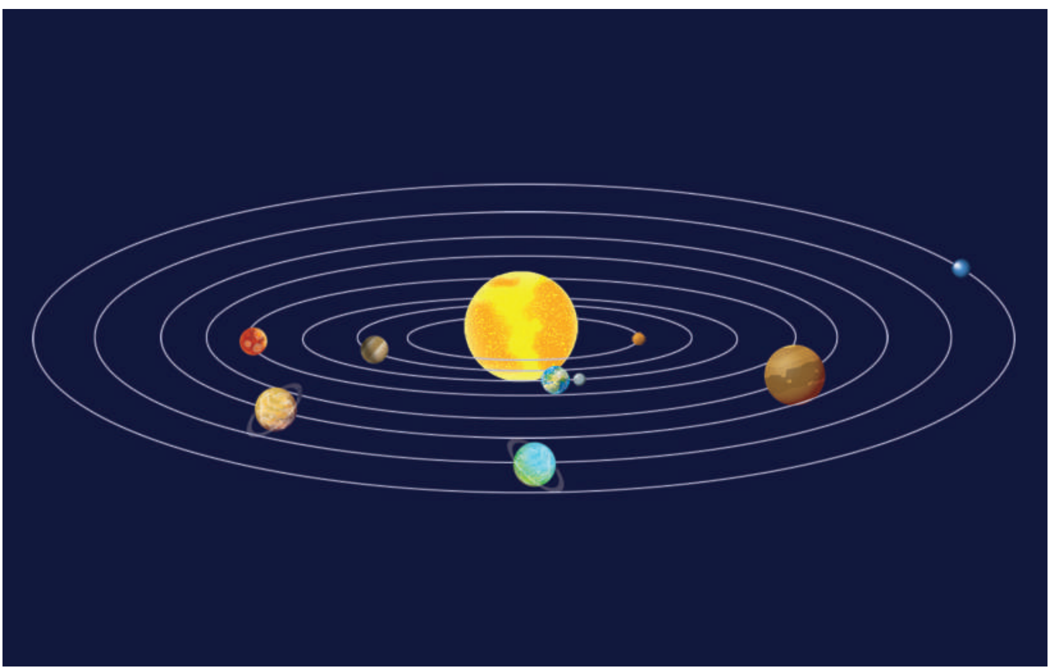
Tendons in humans and other mammals are like bungee cords. They have elastic properties, allowing them to stretch under tension. But then they contract back to their normal lengths. These elastic connective tissues help muscles and bones work together to produce movement.

Tendons and bungee cords aren't made of the same materials, but both are elastic. And both can stretch only to a certain point before they break.

Analogy: Electrons and Orbiting Planets

The way electrons occupy space around the nucleus of an atom resembles the way the planets of the solar system orbit the sun. This is another analogy.





The similarity in this analogy is that something is in the center and other things are moving around it. But again, be careful with this analogy. Electrons don't stay in predictable paths the way planets do. Electrons don't move in the same kinds of predictable orbits as planets.

Analogy: Blood Vessels and Roads

Blood vessels can be likened to highways and other types of roads. A highway is like a large artery that branches off into smaller and smaller vessels that eventually bring blood to specific places. Instead of carrying oxygen or nutrients to a specific group of cells, a road allows people to arrive at specific locations, such as their homes.

A highway system is similar to the circulatory system of a human. They are very different systems, but the analogy helps us think about routes for transporting things.

Analogy: Spark and Inspiration

A single spark can light a fire, especially if conditions are right. That fire can grow into something large and powerful. Sometimes we talk about ideas and inspiration in the same way. An idea that seems to come out of nowhere or develops from a simple thought can grow into something very large and powerful.

Legend incorrectly has it that Isaac Newton was inspired to develop his theory of gravity when an apple fell from a tree and landed on him. We say, figuratively, that such an experience sparks an idea.

Analogy: Paleontologist and Detective

A paleontologist is a scientist who studies the ancient natural history of Earth. Like a detective who may have only a few clues to work with, a paleontologist may have to piece together a larger picture—about an organism's body or how it lived—from a set of fragments or traces of organisms.

A detective investigating a burglary might rely on clues such as footprints on the ground outside a broken window or fingerprints left on surfaces in the home. A paleontologist must also rely on a small number of clues. Some of those clues might be tiny fragments of fossilized bone. Both professionals must develop a big picture from scattered clues that, on their own, don't add up to much at all.

Main Science Idea

An analogy is a type of comparison. Analogies are not comparisons of actual similarities. They are figurative. Making a figurative comparison to describe a similarity can help us understand how a thing is structured or how a process works.

Good Investigations

Chapter 6

Proposal to Investigate Earthworm Population Density

by Sam and Freyda, Mrs. Torrice's Class, Grade 5

Energy and matter move through ecosystems. As part of our study, we plan to measure the population density of earthworms in the playground soil. Population density is how many individuals live in an area. We will need to measure the total area of the playground. Then we need to set up a sample area that we can dig into and count earthworms. The sample area should be large enough to represent the total area, like around one-tenth. We will mark off the sample area with stakes before we dig into the soil.

This is a good description of how you will gather data—number of worms and total area. You can put together the data to calculate population density.

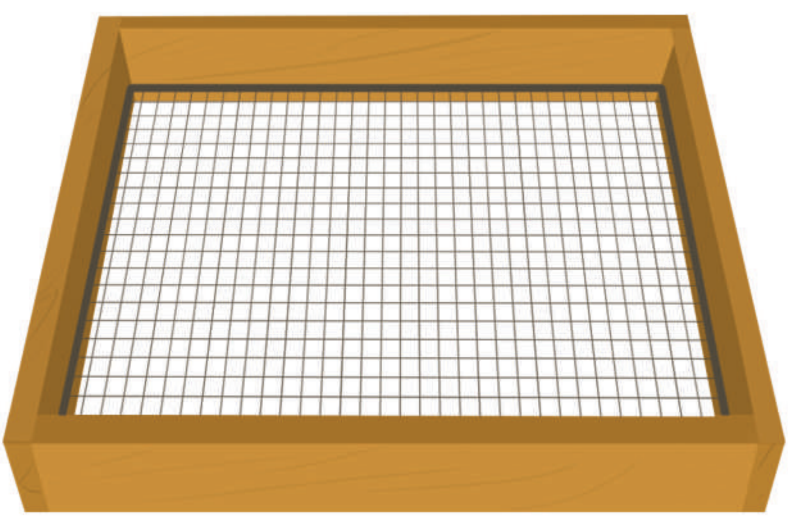
Yes, 10% is a good sample to aim for. But another approach would be to have several different, smaller sample areas that all together add up to 10% of the total area. This might give your investigation a better sample by having more dig sites scattered around the playground instead of just one site.

To find worms in the sample area, we will wait for damp conditions, like after a full night of rain. This will make it more likely for worms to be near the surface. The sample area should be relatively free of grass so it's not too hard to dig into. Also, we don't want to disturb or harm too many plants. We will use a shovel and pitchfork to dig four inches into the ground and lift the dug-up earth onto a screen. The screen holes are large enough for much of the soil to fall through the screen and back to the ground. But the holes are small enough to help us catch and count worms. Each investigator will have our own tally of worms as we work. Worms will be stored temporarily in a plastic bucket before being returned to the soil. This will prevent counting the same worms more than once.

Field investigations are not required to be 100% harmless, but if care can be taken to reduce harm, that is best.

If the soil is damp, how well will this work? Will the soil easily fall through the gaps in the screen? As long as the screen provides you with a kind of surface to sort through the soil and count worms, it sounds appropriate.

This is very important if the goal of the investigation is to get an accurate count of earthworms in each area. Double sampling would throw the results way off.



Proposal to Investigate Great Blue Heron Feeding Habits

by Charlie and Saanvi, Mr. Crocker's Class, Grade 5

Mann's Pond is home to freshwater fish species such as smallmouth bass, pumpkinseed sunfish, and bluegills. It also has several species of frog. All of these are prey of the great blue heron. Like many ponds, Mann's Pond has a well-known resident heron who has been observed for years and is known as Harry by local birdwatchers. Our proposal is to observe Harry's feeding behavior as a way of tracking what this species eats. We will visit the pond before school and in the evening, when Harry seems to prefer to feed. Using binoculars and a digital camera with a telephoto lens, we will record feeding events and the types of prey Harry consumes. We will look for patterns such as consuming one type of prey in the morning and another in the evening.

Good. Known information about the subject of the investigation is used to shape the design of the investigation.

This statement suggests what the students' hypothesis might be—the proposed explanation that is a starting point for an investigation.

Based on previous observations of Harry in the habitat of Mann's Pond, our hypothesis is that he feeds mainly on amphibians such as frogs in the morning and then feeds more on fish in the evening. We expect to test that hypothesis by seeing if the data support or disprove the hypothesis.

Good example of using a null hypothesis—an idea or question that the investigation is set up to disprove. In this case, you could hypothesize that Harry feeds on the same things morning and night, and if the results show that his diet varies with daytime, the null hypothesis would be disproved.

We propose to conduct this investigation over a two-week period, rain or shine. We will record the weather conditions and see if a pattern emerges in terms of what the heron feeds on in bright sun, cloudy weather, rain, and so on.

This is another question being posed by the investigators. The effects of weather are not the focus of the investigation or the hypothesis. However, they plan to collect weather data just in case a pattern emerges. Sometimes in science, the pursuit of an answer to one question can lead to a different discovery.

A Better Fish Hook

by Michael Mangini, Fish Biologist

Loggerhead sea turtles are unintentionally caught when people fish for tuna and swordfish. Longline gear dangles hundreds of baited stainless-steel hooks below the ocean surface, often at night, and turtles either bite down on the hooks and get caught or get snagged by the hooks when simply swimming by. The hooks are large and can result in fatal injuries for the turtles. I have designed a new hook that will succeed at catching swordfish and tuna but be less likely to hook turtles. Unlike a standard J hook, my design is more circular, making it more difficult for an animal to be hooked unless it has a mouth like a tuna or swordfish and it bites down very deliberately on the bait.

This clearly states the criteria or goals of the new hook design. It will 1) reduce bycatch of sea turtles and 2) be effective at catching the fish the gear is meant to catch.

This explains why the new design will be effective.

To test the hook, I have supplied a longline vessel with a supply of three hundred prototype hooks. These will replace every other J hook in the vessel's longline gear. I will be on the vessel's next fishing trip as an observer. As each hook comes up from the ocean, I will record which type of hook it is and record the catch if there is any. This will give me a clear comparison of both criteria:

1) If any turtles are caught, I will see whether there is a pattern in which hook type is usually involved.
2) For the target species such as tuna and swordfish, I will see if there is a pattern in which hook type caught the most fish.

My expectation is for the circle hooks to catch as many fish as the J hooks but fewer turtles.

It is important for the design and engineering process to involve the development of prototypes that can be tested in some way, whether in a lab or in the real world.

A good way to test a potential solution is to set up an experiment that will produce a clear comparison. Here, two different types of hooks are being used very close to each other, so the main variable is the hook type. The data collected can be compared across fishing gear that has hundreds of hooks and may fish for many days or even weeks. Lots of data!

This repeats the criteria that were mentioned before. In a way, it is also a hypothesis.

Main Science Idea

All investigations are not equally effective. We should examine how an investigation is planned and carried out to help decide whether its results are trustworthy.

Put Yourself in These Scenes

Chapter 7

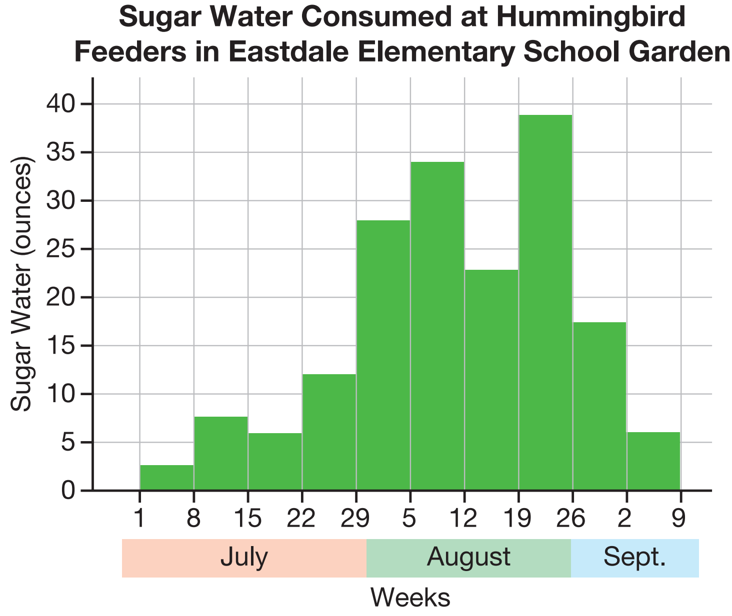
Case Study 1

Ruby-throated hummingbirds spend their winters in Mexico and Central America. They spend spring and summer in the eastern United States. Beginning in August, adult males leave, followed by adult females with their babies. Young hummingbirds are the last to leave. Hummingbirds need a lot of energy for their long migration south.

You volunteer at Eastdale Senior Center, where hummingbirds visit the bright red flowers in the garden. The seniors want to help hummingbirds get energy for their migration. They plan to set up hummingbird feeders in three locations around the garden. Each feeder holds 8 ounces of sugar-water "nectar." Seniors will refill them with sugar water each week from July 1 to August 31.

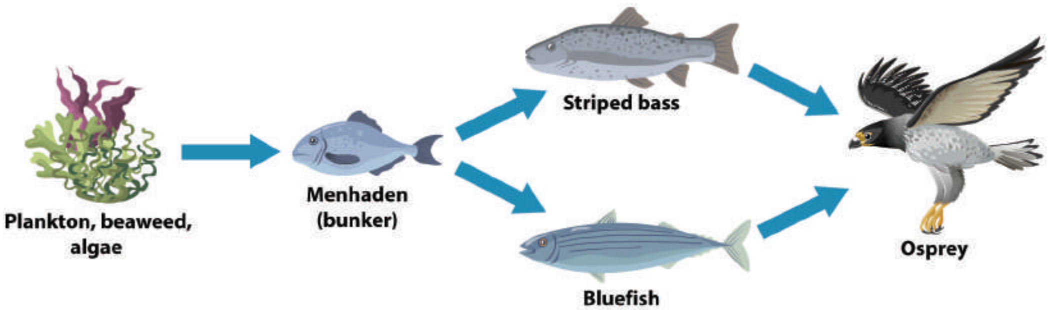
- **Goal: To best help hummingbirds survive the migration south**
- **Solution: Place three feeders in the garden. Refill 8-oz feeders weekly, July–August.**

The data in the graph were recorded by a student at nearby Eastdale Elementary School. How could you use the data to help the Eastdale Senior Center with its plan?



Case Study 2

Rocky Coast Bay is a marine ecosystem in the United States on the Atlantic Ocean. The bay is a popular place for striped bass fishing, and many people visit to see the osprey, a bird that eats fish. The diagram shows a food web in the bay ecosystem.



People were catching so may striped bass that their population began to decrease. To conserve fish, people passed laws that limit how many fish can be caught. In 2020, the Rocky Coast Bay Association changed the limit on how many fish could be caught. It lowered the limit for striped bass. It raised the limit for a smaller fish, called menhaden or bunker. This change allowed people and fishing companies to catch more bunker.

- **Goal: To conserve the striped bass population**
- **Solution: Raise the limit on menhaden (bunker), and lower the limit on striped bass.**

Examine the data in the table. Did the change made by the Rocky Coast Bay Association achieve its goal? Why? What would you suggest to the association?

Rocky Coast Bay Populations 2018–2022

	2018	2019	2020	2021	2022
Menhaden (bunker)	50 million	51 million	34 million	29 million	30 million
Striped bass	700,000	689,000	382,000	348,000	357,000
Bluefish	576,000	580,000	275,000	277,000	269,000
Osprey	43	43	33	27	28

Case Study 3

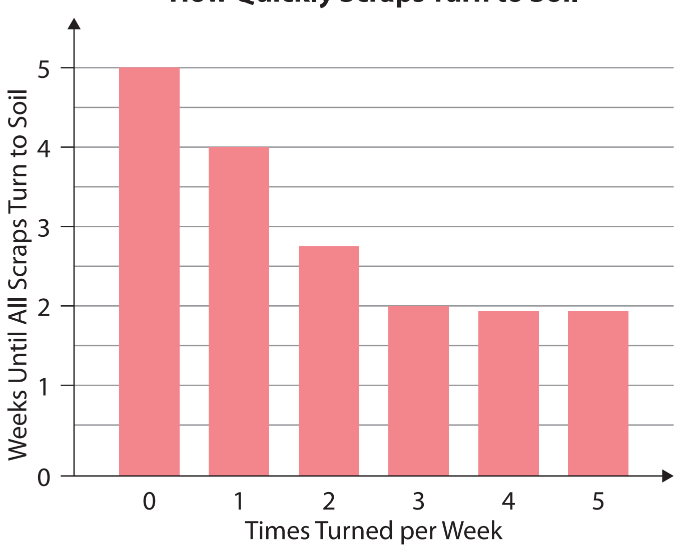
The senior center needs soil for its garden. Volunteers are testing ways to create soil enrichment by composting kitchen scraps. Composting breaks down the food scraps, changing them into nutrient-rich matter that is good for growing plants. In a compost bin, decomposers such as bacteria, fungi, and earthworms break down the scraps.

The volunteers make six small compost bins out of identical plastic trash cans. The seniors bring in fruit and vegetable peels, eggshells, and other kitchen scraps to compost. They add water and turn the bins regularly to speed up decomposition. Your job is to check the bins each week to see if all the food scraps have decomposed.

- **Goal: To change kitchen scraps to soil in the least amount of time**
- **Solution: Build compost bins; water and turn them regularly.**

Each of six seniors was responsible for turning one of the bins. But they didn't all turn them at the same rate. And one senior sprained his wrist and couldn't turn his bin at all! You collect the data shown in the graph. How can you use these data to improve the senior center's plan for composting?

Effect of Turning a Compost Bin on How Quickly Scraps Turn to Soil



Case Study 4

The Long Island pine barrens in New York State are an important ecosystem. The ecosystem is named for the pitch pines found there. They provide habitats for many endangered and unique species. Pitch pine trees are threatened by a pest, the southern pine beetle.

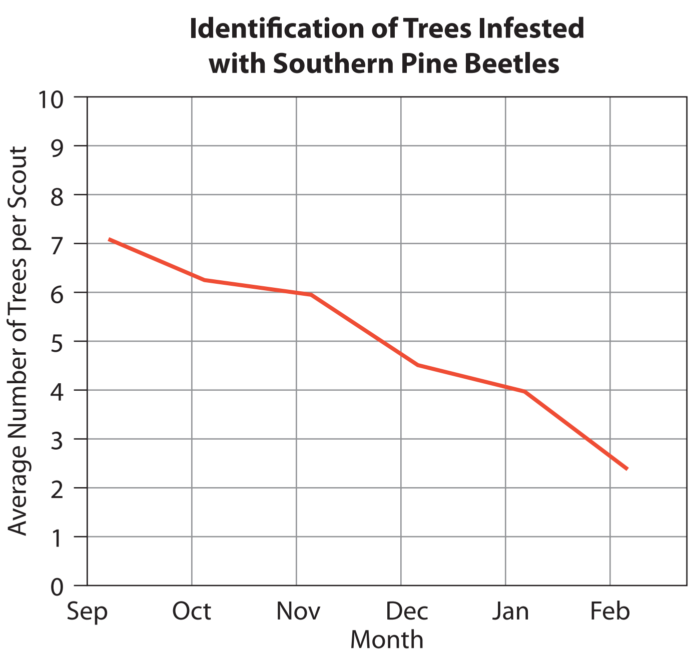
The beetles drill holes into a tree's bark. They nest inside the tree and lay their eggs. The beetles also carry a fungus that harms the pine trees. Once a tree is infested, it is killed in just a few months.

Cutting down infested trees kills the beetles, keeping them from harming other trees. Infested trees can be identified by the red resin "popcorn" on their trunks. They produce this resin to try to push out the beetles.

A local scout troop has a plan to help the forest service. Every month, scouts will hike into the pine barrens to identify infested trees. They will mark the trees with ribbons to make it easier for the forest service to find and remove them.

- **Goal: To reduce the number of pitch pines infested with southern pine beetles**
- **Solution: Identify infested trees so they can be cut down.**

The scout troop collected the data shown in the graph. Based on the data, what should the troop be doing to meet its goal?



Discussion: Case Study 1

Goal: To best help hummingbirds survive the migration south

Solution: Place three feeders in the garden. Refill 8-oz feeders weekly, July–August.

Eastdale Senior Center plans to put out three feeders, and each feeder holds 8 ounces of nectar. That's a total of 24 ounces each week. The data from Eastdale Elementary show that hummingbirds consume more than 24 ounces of nectar during the busiest weeks.

The graph also shows that hummingbirds keep drinking the nectar during the first week of September. To best help the hummingbirds, the senior center should provide more feeders or use larger feeders that hold more nectar. It should also provide nectar in September, when young hummingbirds are preparing to leave.

Discussion: Case Study 2

Goal: To conserve the striped bass population

Solution: Raise the limit on menhaden (bunker), and lower the limit on striped bass.

The data table shows that in 2020, when the new limits were passed, the striped bass population decreased instead of increasing. Menhaden (bunker), bluefish, and osprey populations also declined.

Examining the food web shows that striped bass, bluefish, and osprey all depend on menhaden for energy. Because more menhaden were being fished, there was less energy available for the animals higher in the food web. The association should lower the limit on the number of menhaden that can be removed from the bay.

Rocky Coast Bay Populations 2018–2022

	2018	2019	2020	2021	2022
Menhaden (bunker)	50 million	51 million	34 million	29 million	30 million
Striped bass	700,000	689,000	382,000	348,000	357,000
Bluefish	576,000	580,000	275,000	277,000	269,000
Osprey	43	43	33	27	28

Discussion: Case Study 3

Goal: To change kitchen scraps to soil in the least amount of time

Solution: Build compost bins; water and turn them regularly.

The graph shows that it takes two weeks or longer for the kitchen scraps to completely turn to soil in the compost bins. Turning the bins causes this to happen more quickly. Turning the bins three times per week results in a two-week wait. However, turning the bins more than three times per week does not speed up the process.

The data can be used to refine the solution. Compost bins should be turned three times per week. There is no benefit to turning them more often than three times. Turning them less often means waiting longer for soil.

Discussion: Case Study 4

Goal: To reduce the number of pitch pines infested with southern pine beetles

Solution: Identify infested trees so they can be cut down.

The graph shows that the average number of infested trees that each scout identifies decreases from September to January. This means that the scouts are identifying fewer infested trees. The data show that the scouts' plan is working. If they are identifying fewer infested trees, it is probably because there are fewer of them.

Because their plan seems to be working, the scouts should continue to do what they have been doing. They might want to share their plan with other scout troops so that even more infested trees can be identified.

Main Science Idea

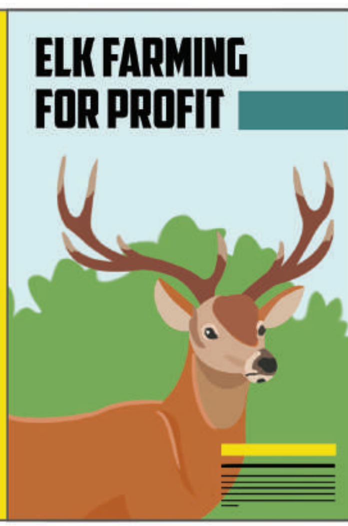
Studying data helps us refine goals and solutions.

The M in STEM

Chapter 8

Science, **t**echnology, and **e**ngineering are all supported by **m**ath. Measurement data contributes to all kinds of discoveries. Math formulas can be used to help evaluate a possible design solution, too. Remember that designed solutions are not only devices to be built. Solutions also include thought-out processes. Math can be a big part of that thinking. Here's an example. This brochure promotes elk farming as a business. Does it seem like a good deal? Look at all the math examples that help with decision-making in this scenario. The answers are shown. See how they are figured out.

Adult male elks, or bulls, grow and shed their antlers every year. While a new antler is still growing, it is covered in soft, fuzzy velvet. The velvet's rich blood supply nourishes the growing antler. When the antler is fully grown, the velvet is shed.



Elk antler velvet is in high demand! It is used to make supplements that treat stress and arthritis.

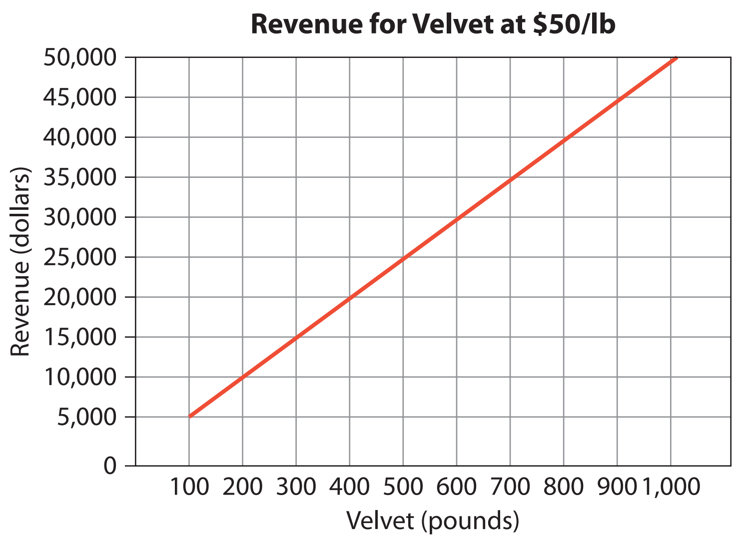
Health companies will pay high prices for quality elk velvet. The current rate is $50 per pound of velvet! Learn more to find out if elk farming is right for you!

All the money a business earns is called *revenue*. The revenue from elk farming can be calculated using a math **formula**. Revenue equals the pounds of velvet the farm produces multiplied by the price each pound can be sold for. Notice that the formula includes two types of units, dollars ($) and pounds (lb).

Revenue ($) = Velvet (lb) × Price of velvet ($/lb)

The graph is based on the formula for revenue and a price of $50 per pound of velvet.

Revenue ($) = Velvet (lb) × $50/lb

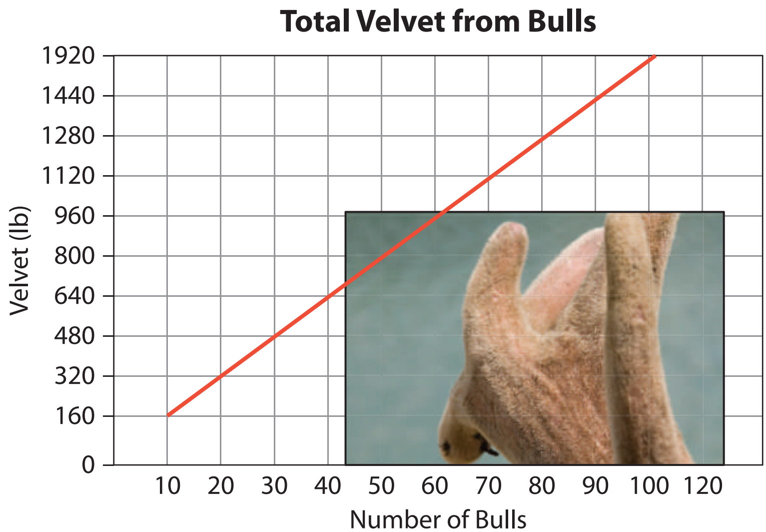


Knowing the formula for revenue can help when making decisions. Formulas help an elk farmer design and set up an elk farm.

- How much revenue can be earned by harvesting and selling 1,000 pounds of velvet at $50/lb? The answer is $50,000!
- So, an elk farmer who wants to make $100,000 in revenue in a year must be able to harvest 2,000 pounds of velvet.

Only the adult male elk, called bulls, produce antlers and velvet. On average, a bull produces 16 pounds of velvet each year. Elk farmers must decide how many bulls will be in their herd. The formula below shows how much total velvet can be harvested from different numbers of bulls.

Total velvet (lb) = Number of bulls × Velvet (lb) per bull



Knowing the formula for the total amount of velvet from bulls can help an elk farmer decide how many bulls to keep in the herd.

- How many bulls does an elk farmer need to make 2,000 pounds of velvet? (125 bulls)
- Will 60 bulls be enough to earn $50,000 in revenue? If not, how many more are needed? (It is not enough; at least 63 bulls are needed.)

A herd of elk is not made up of only bulls. It includes female elk, called cows, and elk calves. A small number of elk die each year. Young elk are needed to keep the herd a constant size. A herd that is made up of 40% bulls, 40% cows, and 20% young will have the best chance of staying the same size year after year.

The table on the next page shows how many bulls will be in a herd of a given size. It is based on the following formula:

Number of bulls = 0.4 × Herd size

Herd Size	Bulls	Cows	Calves
125	50	50	25
130	52	52	26
135	54	54	27
140	56	56	28
145	58	58	29
150	60	60	30
155	62	62	31
160	64	64	32
165	66	66	33
170	68	68	34
175	70	70	35
180	72	72	36
185	74	74	37
190	76	76	38
195	78	78	39
200	80	80	40
205	82	82	41
210	84	84	42

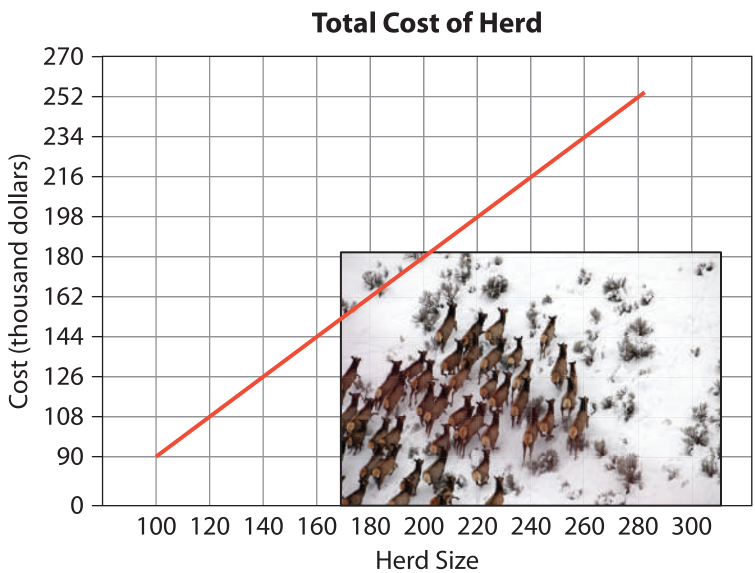
Herd Size	Bulls	Cows	Calves
215	86	86	43
220	88	88	44
225	90	90	45
230	92	92	46
235	94	94	47
240	96	96	48
245	98	98	49
250	100	100	50
255	102	102	51
260	104	104	52
265	106	106	53
270	108	108	54
275	110	110	55
280	112	112	56
285	114	114	57
290	116	116	58
295	118	118	59
300	120	120	60

Knowing the formula for the makeup of a herd helps an elk farmer decide how many bulls, cows, and calves to buy.

- To keep 108 bulls in a herd, how many cows and calves (combined) must it include? What is the total size of the herd? (108 cows + 54 calves = 162 combined, 270 elk total)
- How large must a herd be to include enough bulls to make 1,120 pounds of velvet? (Refer to the previous page to find how many bulls are needed; 70 bulls and 175 herd size)

Elk bulls cost $1,200 each. Cows cost $1,000, and calves cost $100. The total cost for a herd of a given size can be found using the following formula:

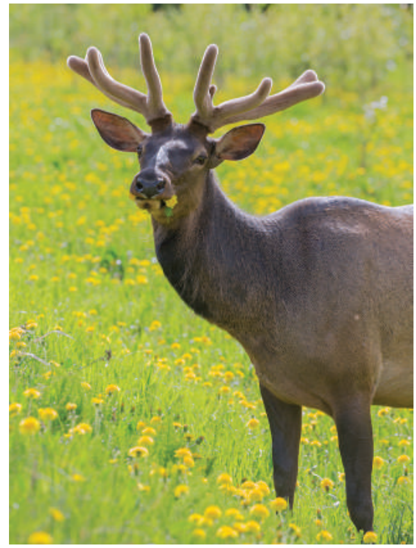
Herd cost = Herd size × $900



An elk farmer has $150,000 set aside to purchase a herd.

- Does the elk farmer have enough to buy a herd of 160 elk? (Yes, it costs $144,000.)
- Does the elk farmer have enough to buy a herd with 100 bulls? (No, it costs $225,000.)
- How much revenue can the elk farmer make from the herd she is able to buy? (64 bulls make 1,024 lb velvet and $51,200 in revenue.)

To get food, elk need land to graze and browse. The amount of land a herd needs depends on its size. The formula for the minimum area of land needed for a herd of elk is the following:



Land area = Number of elk × 0.1 acres

- How many acres of land are needed for a herd of 160 elk? (16 acres)
- How many acres of land are needed for a herd that includes at least 80 bulls? (200 elk, 20 acres)

During winter, there is very little vegetation for elk to eat. The elk farmer must buy additional food. Enough food to feed one elk through the winter costs $150. The formula for the cost of food needed for a herd of elk each year is the following:

Food cost = Number of elk × $150

- What is the cost of food needed for a herd of 160 elk? ($24,000)
- How much revenue is left over after subtracting the cost of food? ($27,200)

Main Science Idea

Mathematical formulas are often helpful for developing or evaluating a solution.

Handy Dandy Rubrics

Chapter 9

SCIENCE NIGHT IS COMING UP!

Science night is coming up! Submit your idea, and get it approved by your teacher ahead of time. Use the rubric below to figure out whether it's likely to be approved.

RUBRIC

- ☐ **Size** It is small enough to fit in a 2 x 2-foot area.
- ☐ **Shape** It should be a three-dimensional model. No posters!
- ☐ **Interactive** It must have parts that you can move to demonstrate what you know.
- ☐ **Informative** The parts have labels that tell people important information.
- ☐ **Low cost** It is made from cheap or free materials. (Be creative!)
- ☐ **Easy cleanup** It cannot require a mop. (Projects that leave sand or glitter behind are a no-go.)

A rubric spells out what something must be like. Features that must be included, or goals that must be met, are called criteria. A rubric can also list constraints. A constraint is a limit, such as expense or size.

Can you find both criteria and constraints in the rubric above?

The engineering designers who imagined this bridge in Russia were faced, before they even started, with a rubric of criteria and constraints.

You and your partner decide to build a model of a volcano. You each come up with a design. You could read about each idea and compare them using a rubric like this.

Does it meet requirements for:	Design 1	Design 2
Size	Yes No	Yes No
Shape	Yes No	Yes No
Interactive	Yes No	Yes No
Informative	Yes No	Yes No
Low-cost	Yes No	Yes No
Easy cleanup	Yes No	Yes No

Design 1

We make a volcano model out of cardboard and paper-mache. We can make paper-mache out of flour, water, and newspaper. We paint it to look like a real volcano. A plastic water bottle, with the top cut off, can be in the center of the volcano. Then, we can pour baking soda, vinegar, and food coloring into the plastic center to model how it erupts.

Design 2

We make a volcano model out of cardboard, paper-mache, and paint. The model can be a cross section. One side will look like the outside of the volcano, with lava going down the side. The other side will show what the inside of the volcano looks like. It will show where the magma is and how the volcano is made up of layers of lava. For the magma, we can use red clay that we can pull out. We can put the whole thing on a turntable to easily show both sides.

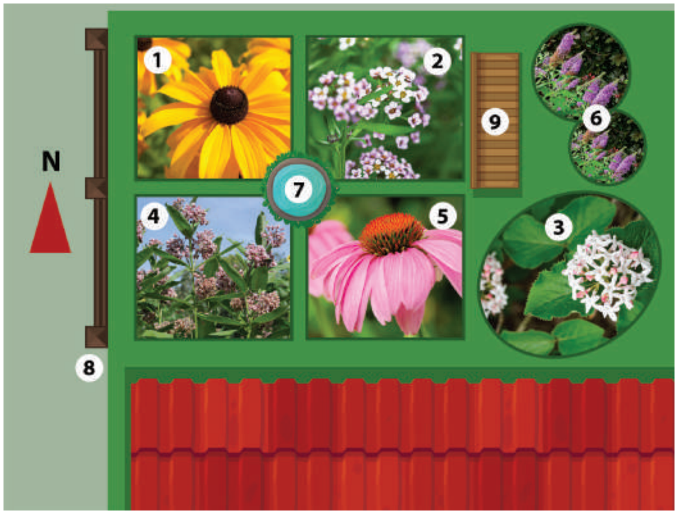
The gardening club finally got permission to plant a butterfly garden. But a butterfly garden must be planned with care. Butterflies like flowers that have a lot of nectar for them to drink. Flowers with flat surfaces make it easier to reach the nectar. Butterflies like certain colors and prefer to visit flowers at different heights.

A butterfly garden should get as much sunshine as possible. Butterflies are cold-blooded and need sunlight to keep warm. They rest on hard surfaces while warming themselves. Butterflies also drink water. Muddy water is best for nutrients! A puddling station, with stones, is a good source of muddy water.

Butterflies start out as caterpillars. A butterfly garden should also include plants that caterpillars eat. Adult butterflies will lay their eggs on these plants.

The gardening club can build the garden on either the north or the South side of the potting shed. Students came up with two possible plans, but they can choose only one. The rubric below could help evaluate the two plans. Which should they pick? Why?

Rubric	Plan A	Plan B
1. Full sun Butterflies need sunlight.		
2. Hard surfaces Butterflies need places to rest and warm themselves.		
3. Water A puddling station provides muddy water for butterflies to drink.		
4. Flower heights Flowers should be at all different heights.		
5. Flower color Butterflies like purple, red, pink, orange, and yellow flowers.		
6. Caterpillar plants Caterpillars feed on mock orange and viburnum.		
7. Viewing Have a place for people to sit and enjoy the butterflies.		



Plan A

1. Black-eyed Susan (24–36 inches)
2. Allysum (4–6 inches)
3. Viburnum bush
4. Milkweed (24–48 inches)
5. Coneflower (24–48 inches)
6. Butterfly bush (over 48 inches)
7. Stone birdbath
8. Fence
9. Bench

Plan B

1. Ageratum (6–12 inches)
2. Milkweed (24–48 inches)
3. Mock orange tree
4. Heliotrope (12–14 inches)
5. Phlox (12–36 inches)
6. Butterfly bush (over 48 inches)
7. Puddling station
8. Garden statue
9. Bench

An assignment asks students to make posters showing what they have learned about Earth's systems. Each poster should describe an ecosystem or part of an ecosystem. The rubric below could help grade the two blue posters on these pages.

Rubric for Grading (Assign 10 points to each criterion.)	
1. Plants	
2. Animals	
3. Decomposers	
4. The role of oxygen	
5. The role of carbon dioxide (CO_2)	
6. An interaction between the biosphere and atmosphere	
7. An interaction between the biosphere and geosphere	
8. An interaction between the biosphere and hydrosphere	
9. At least TWO of the following **(10 points each)**: An interaction between the hydrosphere and atmosphere An interaction between the hydrosphere and geosphere An interaction between the geosphere and atmosphere	

Forest Floor Ecosystem

Water travels from tree roots to leaves, where it evaporates.

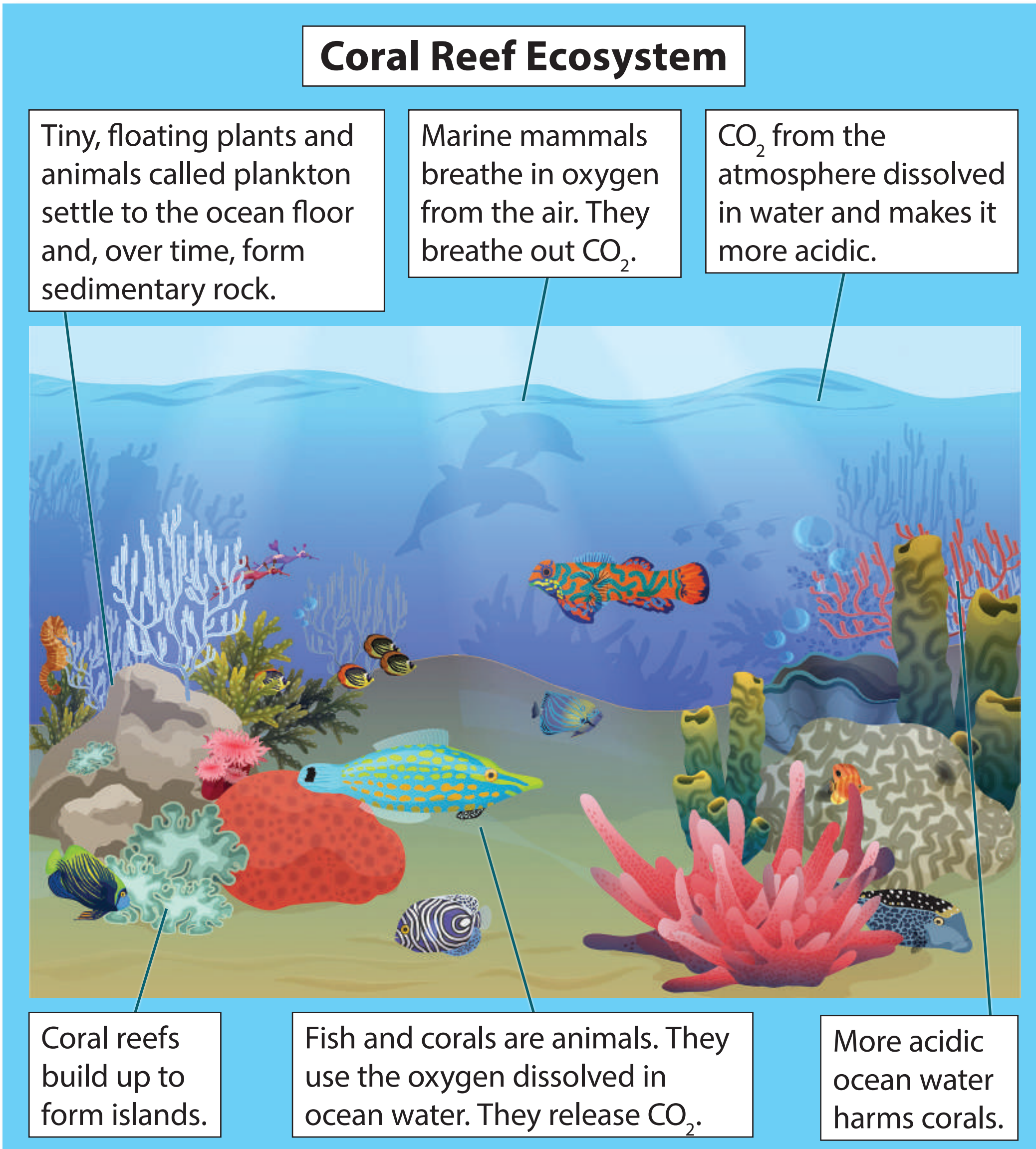
Like animals, mushrooms take in oxygen from the air and release CO_2.

Plants produce more oxygen than they need. They release the extra oxygen into the air. Plants use CO_2 from the air to make food.

Mushrooms are decomposers. They break down dead trees and build up the soil.

Forests act as "recharge basins" for aquifers. The soil absorbs rainwater. The water joins the groundwater stored deep beneath the forest.

What grade did you give each of the posters? Did using a rubric make it easier or harder to grade the posters? What did you like about using rubrics? What did you dislike?



Main Science Idea

We should use organized methods to compare multiple design solutions or designs so that we choose the best one.

Friendly Feedback

Chapter 10

Ouch! That critique was certainly *critical*. But it wasn't very constructive. What is a constructive critique? Constructive critique (also called constructive criticism) is a kind of feedback that helps the person receiving it. It is objective, specific, helpful, and kind.

Objective

A critique may be objective or subjective. *Objective* means based on facts and evidence. For example, the critique can point out that an assignment is missing a required graph. Objective critiques can also point out factual errors. *Subjective* refers to the way a person feels. Opinion words are a clue that a critique is subjective.

Specific

Constructive critique is specific. It states exactly what needs to be added, removed, or changed.

Helpful

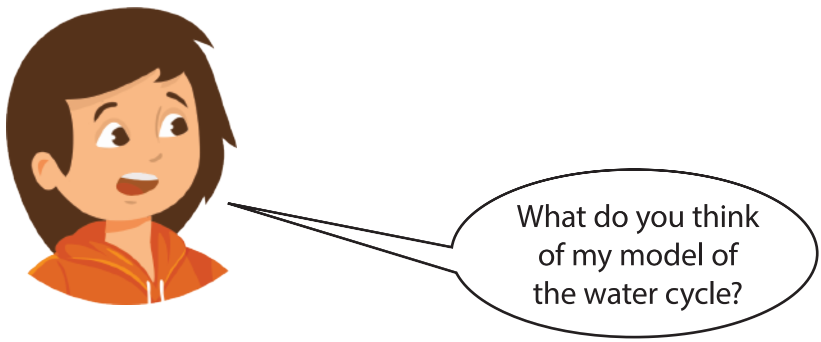
For a critique to be constructive, it should do more than point out what is wrong. It should also suggest a way to improve things.

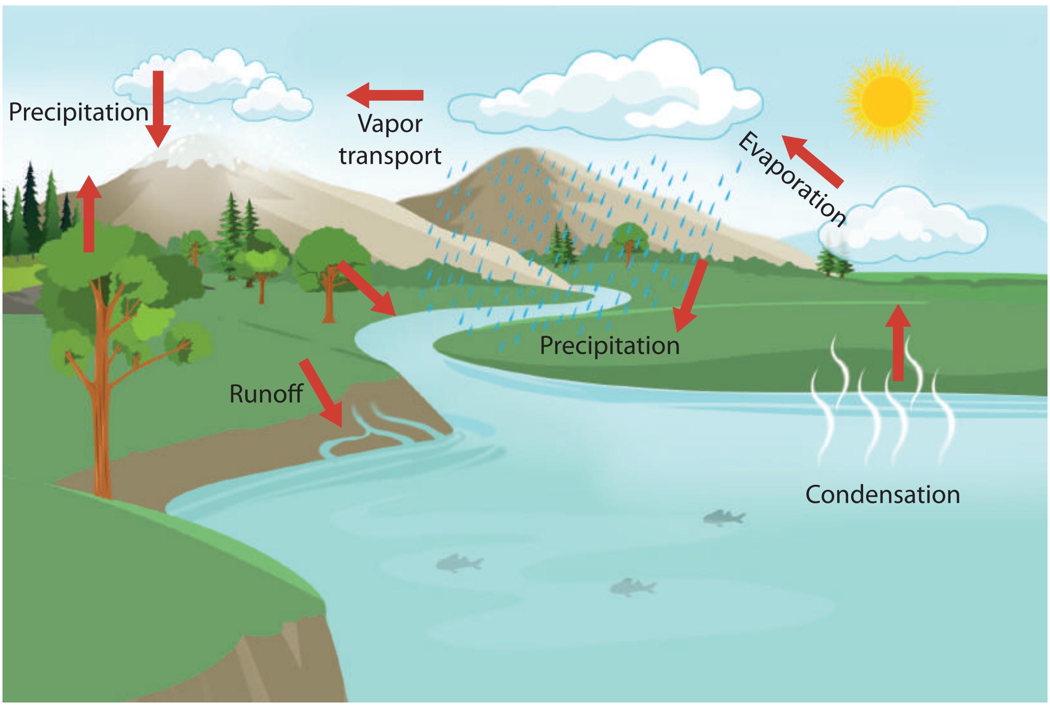
Kind

Constructive critique points out what is good as well as what is not so good. It includes praise for things done well.

One way to be kind is to "sandwich" critical comments by saying something positive both before and after mentioning what needs to be changed.

Read the critique on the previous page again. Why is it not constructive? How would you feel if you received this kind of critique? Would it help you make your design better?





Wow! It's so bright and fun to look at! I can tell you must have worked hard. The arrows make it very clear how the water is moving in every part of the cycle. But I'm wondering why the arrows color are so similar. It's a little confusing. Maybe it would be better if very different arrow colors went with the different parts of the cycle. Like, just the two arrows showing precipitation could be red. Condensation arrows could be another color. Oh, and I think you switched up "evaporation" and "condensation." But other than that, it looks terrific!

Read the critique on the previous page. Is it constructive?

- The critique is <u>objective</u>. It is based on fact rather than a feeling or impression. Which label should say “condensation” or “evaporation” can be verified or checked. Any two people should come to the exact same answer.
- It is <u>specific</u>. It points out particular things, such as the arrow colors, that need to be improved.
- The critique <u>helpfully</u> suggests ways to improve the design. It recommends a way to change the colors of the arrows and make the labels less confusing.
- The critique is <u>kind</u>. Notice that it includes positive comments about the design. The critical comments are sandwiched between the positive comments.

How would you feel if you received this kind of critique? Would it help you to improve your design?

Even the kindest feedback is sometimes difficult to hear. It is important to choose words carefully to keep a positive tone, even when you are suggesting changes. Consider sentences like these:

- I really like how ________________. I would like to see more of it.
- ________________ works really well. I think you should use it more.
- ________________ makes it really clear. Maybe you could use the same idea for ________________.
- This part of the design worked really well to ________________. I don't think this other part is necessary.
- ________________ might be too much of a good thing. In this case, less is more!

How could you critique this younger student's project in a way that is objective, specific, helpful, and kind?

The Student's Assignment: Design a model that shows one way in which the geosphere changes.

How could you critique this student's project in a way that is objective, specific, helpful, and kind?

The Student's Assignment: Model one of Earth's biomes. Show how Earth's systems (atmosphere, hydrosphere, geosphere, biosphere) interact to make the biome the way it is.

Sometimes, you will be the one receiving a critique instead of giving it. Think about how you would feel and respond. What would make it easier for you to use the feedback you receive? What would make it more difficult? A good thing to remember is that a critique is not personal. It is about an idea or thing that you created, but it is not about YOU. When you hear an opinion about your work, try to take a step back and look as if you are seeing it for the first time.

Tip: Critique the design, idea, or project, not the person.

Main Science Idea

Feedback is an important part of making projects better. It's important to provide feedback in a constructive way. It's also important to receive feedback without hurt feelings.

Presenting Science

Chapter 11

Talking in front of a group of people might make you feel like you have butterflies in your stomach. Or maybe you can't wait to do it! Either way, the key to presenting what you know about a subject is being prepared. Gathering information, organizing your information, and practicing well ahead of time will help you nail it!

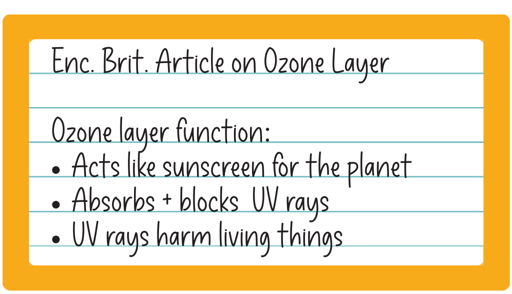
The first step is gathering information. Find sources like books, encyclopedias, articles, web pages, and videos. Visit your public or school library or look online to find information.

If you're not sure where to start, ask a librarian for help. If you want to find information online, ask an adult for help using a search engine. You can find information by entering keywords related to your topic. You can find videos online as well as things to read.

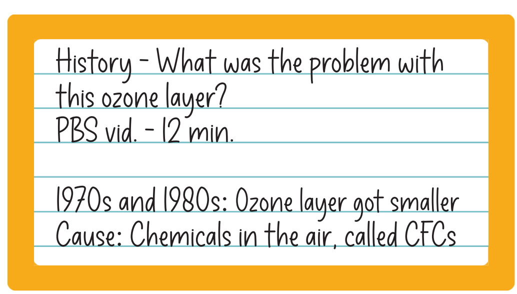
Take Notes

As you read and watch videos, take notes. Write down key points, important facts, and interesting details. Also jot down any questions that come up. Try to answer them as you gather more information. You can write your notes in a notebook, on a set of index cards, or in a digital document on a computer. Your notes will be the building blocks of your presentation.

You might prepare an outline or a set of questions before you begin taking notes. Then you can add information that you learn. Or you can take notes as you go through each information source. Then you can organize the notes later. Either way, be sure to jot down your sources. It's important to know and share where your information came from. For important details that come from videos, it's a good idea to note the time in the video. That way, you can easily find it again.



Note-taking by source: Write a key point from the source.



Note-taking by outline/question: Information answers the question.

Organize and Order Your Information

An outline is like a recipe for your presentation. It tells you what you will talk about and in what order. Make an outline to organize all the information you've gathered. In the outline, you will group related details together and put the groups in an order that your listeners will be able follow and understand.

For example, if you were researching the ozone layer of the atmosphere, then your outline might look like this.

Start with an introduction to explain why your topic is important or interesting.

Creating an outline early, before you begin your research, can help you organize information as you gather it. If you do this, you will probably make changes to the outline along the way.

Outline

Introduction What is the ozone layer? Why is it important?

Background Where is the ozone layer located in Earth's atmosphere? What is it made of?

Explanation How does the ozone layer protect life on Earth?

Discovery How did people first learn about the ozone layer?

History What destroyed the ozone layer in the 1980s? How did people fix it?

Conclusion Why should we continue to pay attention to the ozone layer?

An outline groups information into sections. The information in your notes will go under each of the sections.

Each section should cover a key point or answer an important question (or two).

Conclude by answering the question posed in your introduction.

Pack In the Evidence

Use your notes to fill in the details of your outline. If your notes are on index cards, you can move them around to place them in the order given by the outline. In a digital document on a computer, you can move text around.

Write Speaking Notes

You already know all the information you will be sharing. Speaking notes just remind you what to talk about next. You won't simply read the speaking notes. You can ask questions of your listeners and answer their questions during the presentation so it's a conversation.

Have you ever wondered why you need to wear sunscreen? It's because . . .

So that's where we find ozone. Next, I'm going to talk about the history of the disappearing ozone layer. . .

Display Some Text

If your presentation uses a slideshow, each slide should show a picture, chart, or graph. Slides should have as little text as possible.

SLIDE DON'Ts	SLIDE DO's
• Write full sentences.	• Include images.
• Read text off your slides.	• Show charts or graphs.
• Have only text on a slide.	• State key points.
• Make one slide per sentence.	• Use few words.

The ozone layer acts as sunscreen for the planet. It is made up of ozone (O_3), which is made up of oxygen atoms. Ozone absorbs UV rays from the sun. It blocks the UV rays from reaching Earth's surface.

This protects living things from the harmful rays.

Introduction

<u>The Ozone Layer</u>

Earth's
Sunscreen

Grab Attention

The introduction states why your topic is important. A great introduction captures your audience's attention and interests them in what you have to say. Besides just saying why it is important, you can introduce a topic in creative ways. For example, you might share a fact that's surprising or take a quick poll of the audience.

So there I was, at the beach, thinking everything was fine . . .

Did you know that the North Pole doesn't stay in one place?

How many of you shut off the faucet when you're brushing your teeth?

Use Objects

If it makes sense, bring a visual aid to your presentation. This can be a prop, a model, or an everyday item that relates to your topic. Maybe part of your presentation is a demonstration of the way an object works.

Practice

Practice your presentation a few times, in full. Get a family member or friend to be your audience. Ask if they have any questions. You might decide to change something if it seems unclear to others. Check the amount of time your presentation takes. Make sure it matches what is expected.

Being prepared is the key to feeling confident. Have your notes, your slides, and any items you will need ready to go. Pick out your outfit the night before. Get a good night's sleep, and start the day with a healthy breakfast to feel your best.

It's normal to feel nervous in front of an audience, even if they are the same people you see every day. But just remember that your classmates will have their turn up front, too. When you are presenting what you know about science, you share facts as evidence and let people draw their own conclusions from that evidence. You are ready to present because you have done the preparation!

Main Science Idea

Part of doing science investigations and learning about science is presenting what you know. You do a science presentation by finding information, organizing it, and preparing what you will show and say.

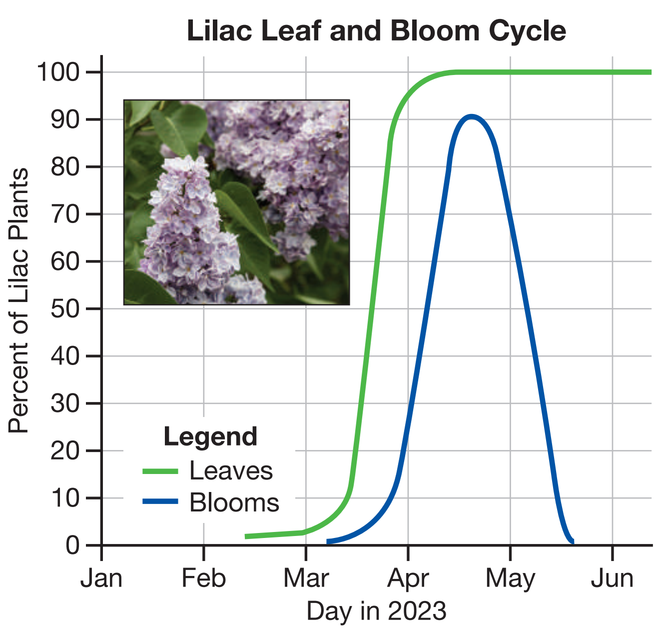
Things That Happen Together

Chapter 12

You might notice that certain things tend to happen together or at the same time. If so, then you've noticed a pattern, or something that repeats in a predictable way. Seasonal patterns are easy to notice. For example, tree leaves change color when the weather cools.

A lilac bush starts to "leaf out" in early spring. Soon after, hundreds of tiny flower buds open. They bloom into clusters of fragrant purple flowers. One change predictably follows the other, and both happen at around the same time each year. Noticing when these changes happen allows you to make predictions.

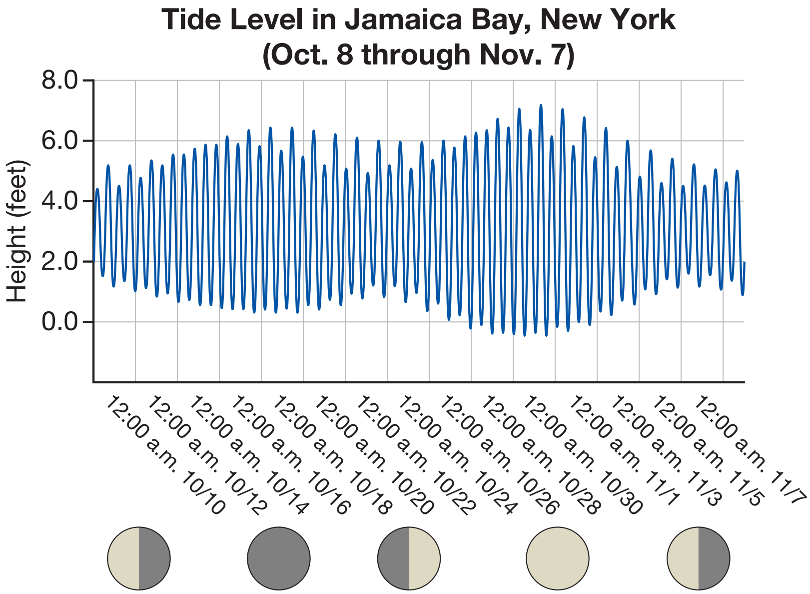
Lilac blooms only last a few weeks. The graph shows the blooming of lilacs in an area. If you wanted to cut a bouquet of lilacs next year, when should you plan to do this?



Heavy rains and storms often cause flooding. But in some places, flooding can happen on clear, sunny days when there is no rain. This is the case for Jamaica Bay, New York. The "sunny day" flooding happens when tides are at their highest.

Tides follow a regular pattern. The highest high tides are called spring tides. Spring tides take place just after a full moon or new moon. Rising sea levels raise the highest tides and make sunny day flooding more likely.

On which day in November is Jamaica Bay, New York, most likely to experience flooding?



Some patterns involving things that occur together have to do with where things are located. For example, temperatures can be much higher in cities than in the areas surrounding them. This is known as the *urban heat island effect*. Each city, or urban area, acts like a warmer island compared to the land around it. The temperature difference can be 7°F (or 3.9°C) or more for very large cities.

City	Temperature Difference (°F)
New Orleans, LA	+8.94
New York City, NY	+7.62
Houston, TX	+7.46
San Francisco, CA	+7.37
Chicago, IL	+7.24
Miami, FL	+7.24
Baltimore, MD	+7.08
Detroit, MI	+6.97

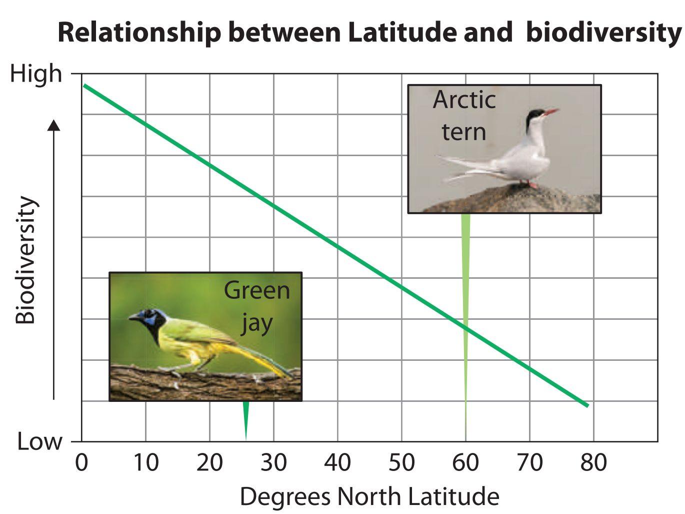
Philadelphia has a population of 1.5 million. The nearby city of Reading is home to 95,000 people. If it is 78°F on a summer afternoon in Reading, would you expect it to be hotter or cooler in Philadelphia?

Could you guess how many species live in an ecosystem just by knowing where it is on a globe? It turns out that there is a relationship between latitude and biodiversity. These two things occur together.

Latitude is 0 degrees at the equator and increases to 90 degrees toward the North and South Poles. As latitude increases, biodiversity decreases. Biodiversity is based on both the number of species and how greatly the species differ. Ecosystems with high biodiversity have many species, and the species are all quite different from one another.

Low latitudes, close to the equator, are where you find tropical rainforests or jungles. The Amazon rainforest is home to millions of species. Biodiversity is high.

At higher latitudes closer to the poles, like in the arctic tundra, fewer species are found. Biodiversity is lower.

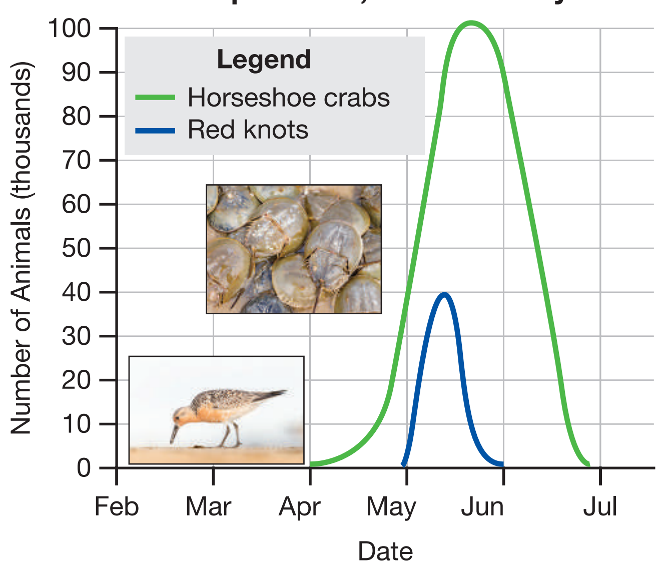


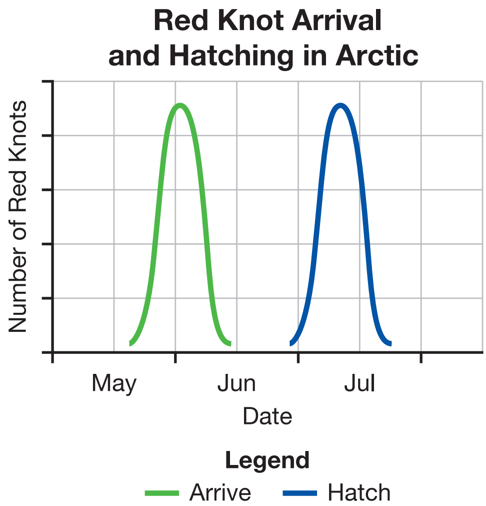
Which bird shares an ecosystem with more species: the green jay in Brownsville, Texas, or the arctic tern in Alaska’s Potter Marsh?

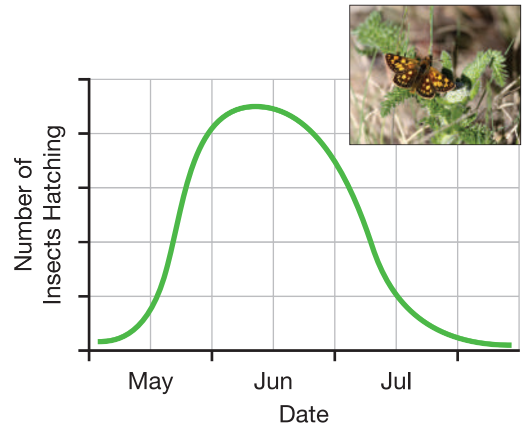
Many animals migrate. Migration paths are patterns in time and place. Red knots have some of the longest migrations of any animal. These small birds spend their summers north of the Arctic Circle. Some red knot populations journey there from the southern tip of South America, sometimes flying for several days without stopping.

An important stop in the spring migration is Delaware Bay, New Jersey. In May, red knots arrive tired and hungry. Fortunately, the beaches of Delaware Bay are full of horseshoe crabs. Hundreds of thousands of horseshoe crabs show up in May and June to lay eggs. The red knots eat the eggs. Because there are so many eggs, this does not harm the horseshoe crab population.

Horseshoe Crab and Red Knot Populations, Delaware Bay







Once they have fed and rested, the red knots continue their migration to the Arctic, where they lay eggs. By arriving just as the snow begins to melt, the red knots have plenty to eat. This is when insects begin to hatch. The parents and newborn chicks feed on the plentiful insects.

What would happen to the red knots if fewer horseshoe crabs came to Delaware Bay?

What would happen to the red knots if they arrived in the Arctic a week earlier?

How can understanding migration patterns help scientists to conserve this species?

Main Science Idea

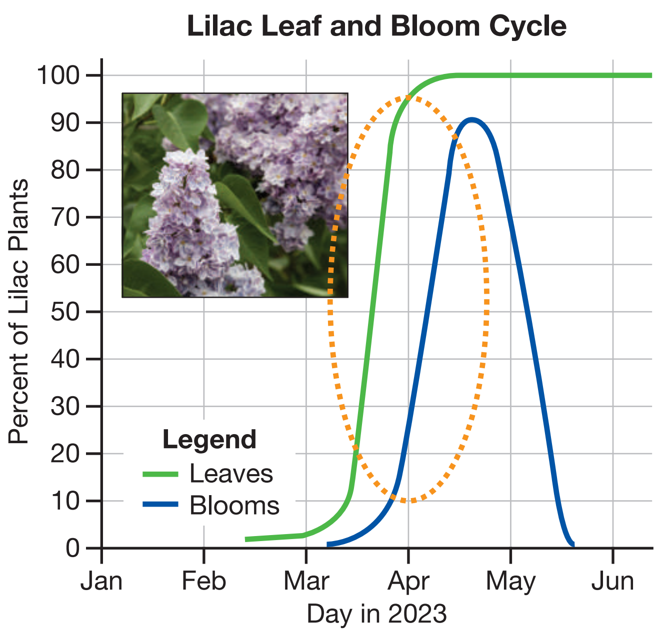
When two things happen together in a repeating pattern, the occurrence of one thing can often be used to predict the occurrence of the other.

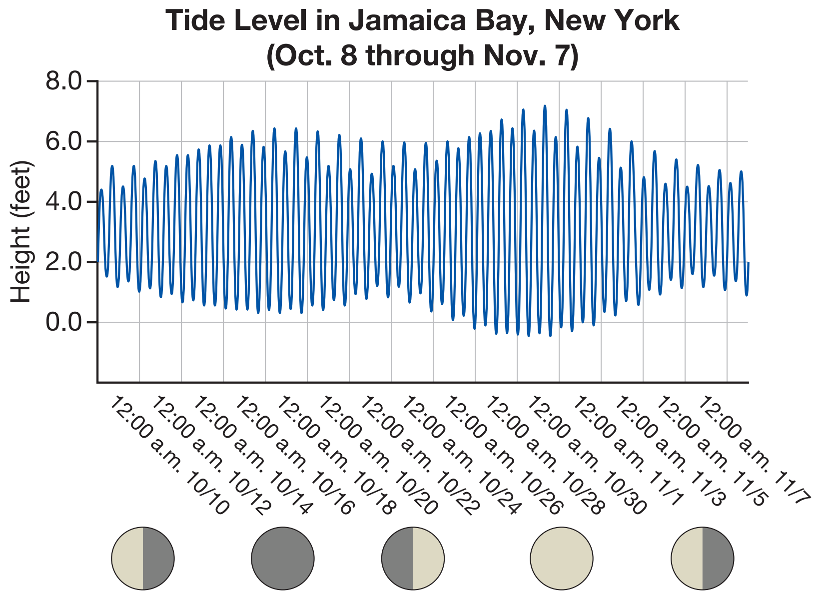
Correlation

Chapter
13

Patterns can show that two things tend to be found in the same place or happen at the same time. Things related in this way have a correlation. Break down the word *correlation* into *co-* (which means "with or together") and *-relation*. A correlation is a relationship between two things. As one changes, so does the other.

The graph shows a correlation between the first lilac leaves and lilac flowers. Leaves increase in early spring, and blooms increase soon after. Things that are correlated change together.





It's not difficult to find correlations in nature. Many things happen in predictable cycles. For example, the tides change with the cycle of the moon. The highest high tides (and lowest low tides) happen just after a full or new moon.

The tides are correlated with the moon's phases because the moon is what causes the tides. When the moon, the sun, and Earth are lined up in a row, the pull of gravity causes the spring tide. When they are aligned in this way, we also see the full or new moon phases. The moon's position causes both effects.

Things that have a cause-and-effect connection are said to have a causal relationship. The word *causal* resembles the word *casual*, but look more carefully. It is similar to the words *cause* and *because*. One thing causes the other. The moon *causes* the tides. A causal relationship is also called causation.

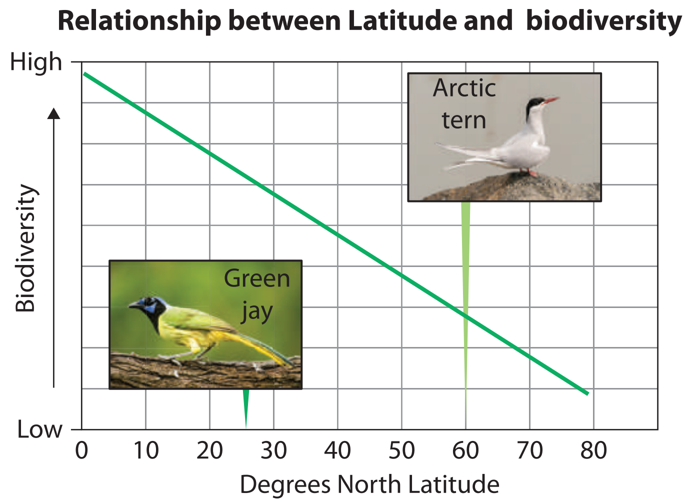
Consider the urban heat island effect. Big cities with large human populations are warmer than the areas around them. The temperature is higher in places where there are more people. There is a correlation between population and temperature.

But is there causation? Are people and their body heat causing cities to be warmer? Not exactly. There are several things humans *do* that cause the heat island effect.

Cause	**Effect**
Cut down trees	Without shade and transpiration from trees, land is hotter.
Replace vegetation with hard surfaces	Brick, concrete, and asphalt absorb more heat than plants and soil.
Build tall buildings	Buildings block wind and retain heat, warming the air.
Drive vehicles, run air conditioners, burn fossil fuels	These activities produce heat.

The relationship between population and warmer cities is **indirect**. People don't *directly* cause the cities around them to be warmer. Instead, they build structures and do activities that cause a heat island to form. Many correlations are due to indirect relationships.

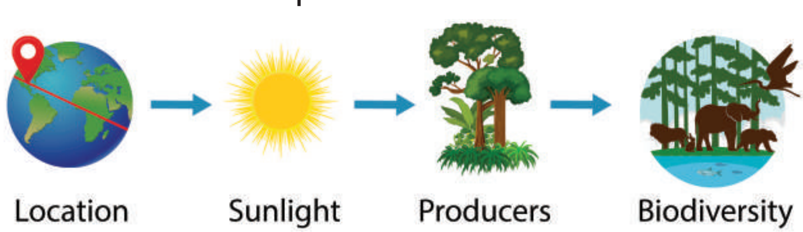
As latitude increases, biodiversity decreases. Even though they are changing in opposite directions, there is a correlation between them. Is it direct or indirect?



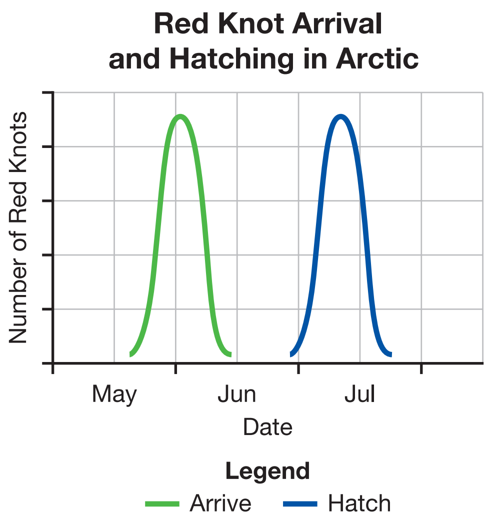
Think about how lower latitude leads to more biodiversity. Ecosystems near the equator get the most sunlight. Sunlight causes plants to grow. More producers means there is more food for consumers. Low-latitude ecosystems can support many different species. Tropical rainforests like the Amazon have the highest biodiversity in the world.

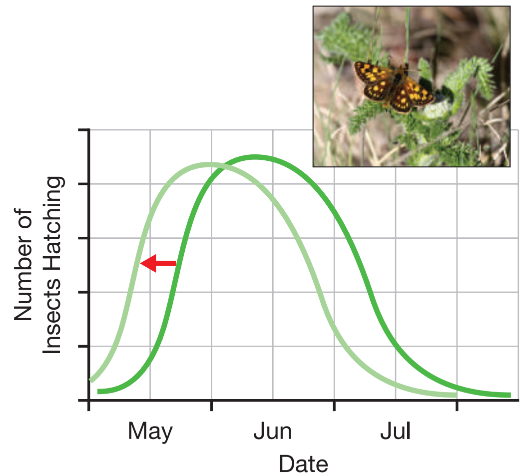
(You might think that deserts are nearest to the equator. Most hot deserts are found about 30 degrees north and south of the equator.)

Simply being close to the equator isn't what causes high biodiversity. The location provides more sunlight, which results in many producers, which in turn allows consumer species to survive. It is an indirect relationship.



When two things are correlated, it might be hard to figure out which is the cause and which is the effect. Examine the graphs describing red knots and insects in the Arctic. Which is a cause, and which is an effect?





Obviously, having birds around does not cause insects to hatch. Insects hatch when the snow melts. But do insects hatching cause the red knots to arrive? In a way, yes. Birds that arrive too soon, before the snow has melted, or too late do not find enough food to survive.

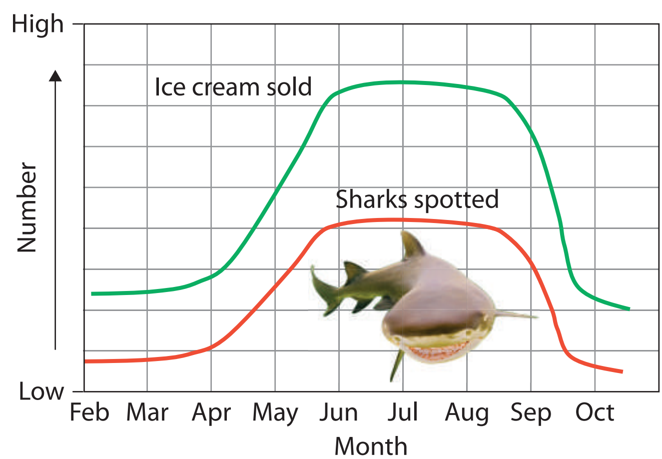
As global temperatures get warmer and Arctic snow melts earlier, insects hatch earlier, too. How will this change affect the red knots? What will happen if they keep migrating at the same time?

A correlation can be seen when there is a direct cause-and-effect relationship between two things. It can be seen when one thing causes another indirectly, too. Or two things that change together can share the same cause.

If there is a cause-and-effect relationship, or causation, there will be a correlation. But is the opposite always true? If we observe a correlation, does it mean that there must be a cause-and-effect relationship? In other words, is it possible to have correlation without *any* causation?

Correlations can also happen when there is no causal relationship at all. For example, ice cream sales follow the same pattern as shark sightings. Does buying ice cream make sharks appear? (Or vice versa?) Obviously not. But both increase in the summer months because that is when people buy more ice cream AND visit beaches.

Correlation BetweenIce Cream Sales and Sharks



Can you think of any examples of correlations? Can you think of any correlations without causation?

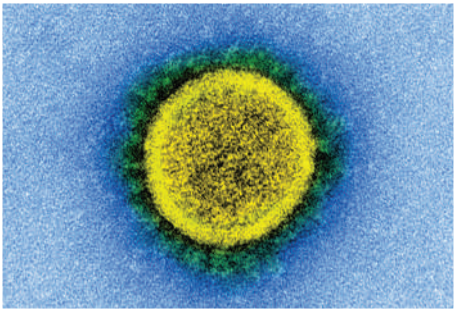
Main Science Idea

Just because two things seemingly always happen together does not mean that one of the things causes the other.

Extreme Measurement

Chapter 14

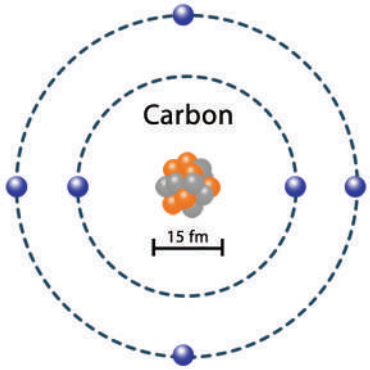
The diagrams in this chapter are not to scale. They are models to give you an idea of what the structures that are discussed here are like.



This transmission electron microscope image shows SARS-CoV-2 viruses, the cause of COVID-19 infection.

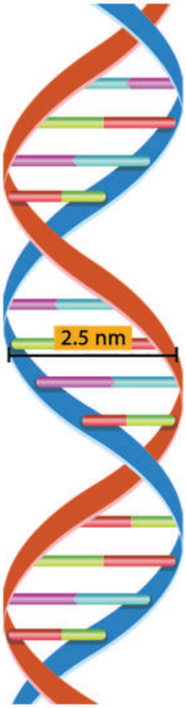
femtometer = one quadrillionth of a meter

Things such as parts within atoms can be measured on the scale of femtometers. For example, the nucleus of a carbon atom is about 15 femtometers wide.



nanometer = 1,000,000 times larger than a femtometer; one billionth of a meter

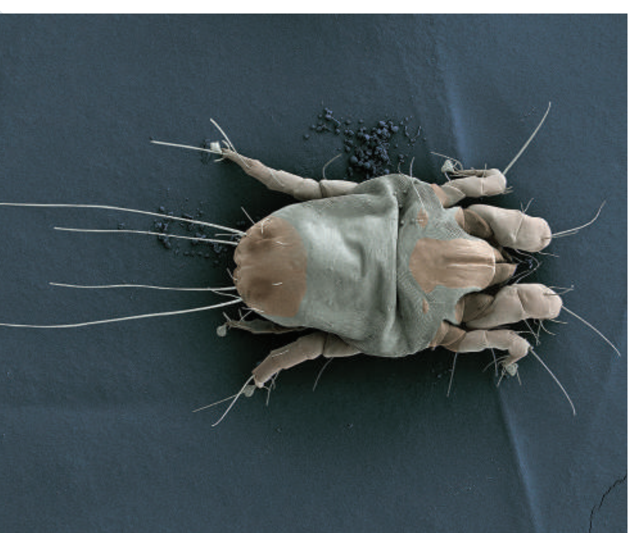
Viruses and molecules can be measured in nanometers. A typical virus is about 100 nanometers wide. A DNA molecule is 2.5 nanometers wide.



micrometer = 1,000 times larger than a nanometer; one millionth of a meter

Cells and some microscopic organisms are measured in micrometers, also known as microns. The limit of human eyesight to perceive things is about 40 microns. To see things measured in microns in any detail requires a microscope.

This dust mite is probably 100 microns in length. Most humans have lots of dust mites living on their skin and eyelashes.



These calipers can measure widths in whole and partial millimeters.

millimeter = 1,000 times larger than a micrometer; one thousandth of a meter

The millimeter is usually the smallest unit of space that can be marked on a meterstick, tape measure, or other tool. There are 10 millimeters in 1 centimeter. Some tools are designed to measure objects in millimeters.

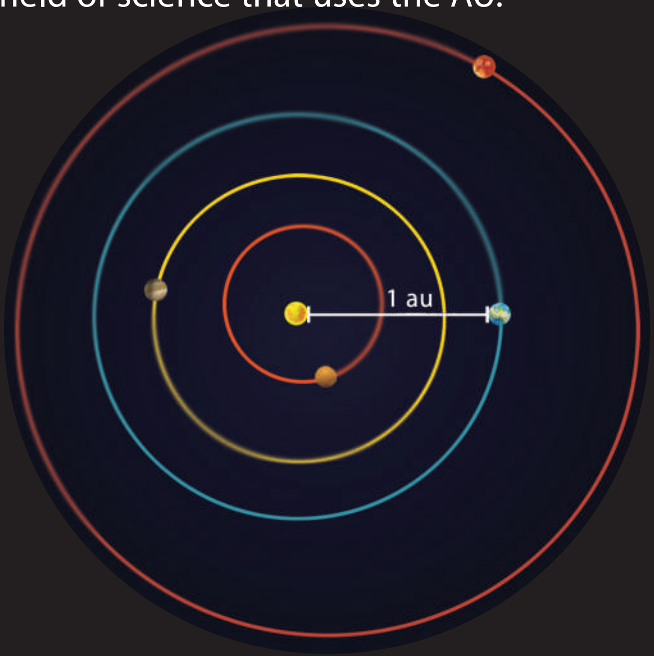
kilometer = 1,000 meters

A kilometer is a unit of length or distance. It is used to describe distances between cities, landmasses, and objects in space that are relatively close to each other.

The monuments in Washington, DC, would be measured in meters. The moon's distance from Earth is 384,400 kilometers away.

astronomical unit = about 150 million kilometers

The kilometer is useful for lots of large-scale distances that humans must deal with or talk about here on Earth or even when talking about the moon. For longer distances, we use the term astronomical unit (AU). One AU is a distance about the same as the average distance between the sun and Earth. Astronomy—the study of stars, planets, and other objects in space—is a field of science that uses the AU.



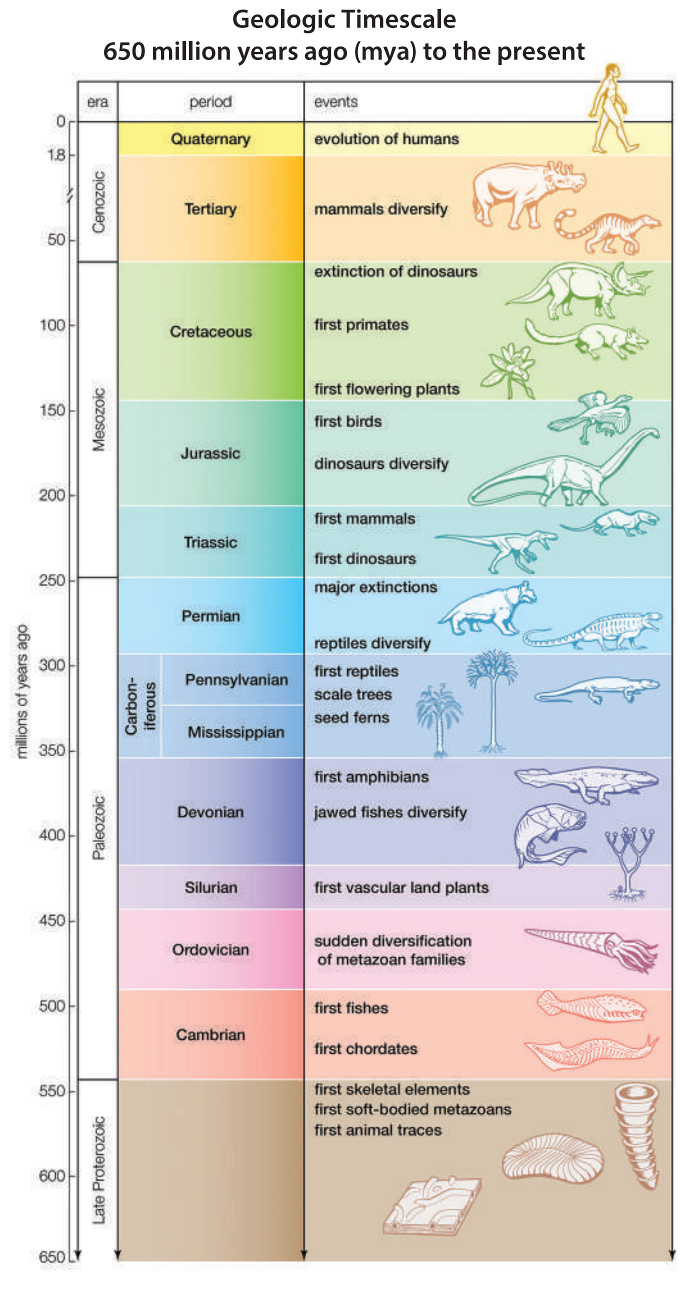
light-year = about 63,241 times larger than the AU

A larger unit used in astronomy is the light-year. It is based on how far light travels in one year. Because light moves at a speed of 300,000 kilometers per second, light can travel extremely long distances in one year, which means a light-year is a distance so great that it's hard to grasp. Astronomers measure distances between stars and galaxies in light-years.

This cluster of stars is thousands of light-years from Earth.

Timescales

You might think a second is a tiny bit of time. But in science, time is often measured for things that take just parts of a second to occur. Extremely brief time measurements include milliseconds (thousandths), microseconds (millionths), and nanoseconds (billionths). We can't see things happen in these amounts of time.



More directly observable units of time include whole seconds, minutes, hours, days, months, and years. To describe larger spans of time, we describe epochs, periods, eras, and eons. These are used mostly in the study of Earth's history, or geology. They are not uniform in length. The geologic timescale is shown here. It shows how many millions of years ago these time periods or events occurred.

A Scale That's Not to Scale

The geologic timescale on the opposite page is designed to capture Earth's history, but if you look closely you can see that the durations of the different eras and periods are not consistent. The diagram is not to scale.

Human History

The entire history of humans fits into the Pleistocene and Holocene Epochs. That's a span of about 2.5 million years that is too skinny to even show up on a scale like the one on the opposite page. Contrat that with how long dinosaurs lived—nearly 300 million years, or over a hundred times longer than humans have existed.

Humans have only been on Earth for a small fraction of its long history.

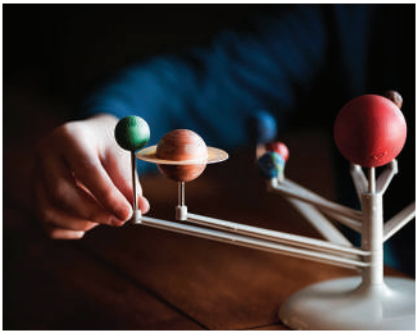
Main Science Idea

In science, people can measure things that are too small, too large, too fast, or too slow to directly observe.

Model It!

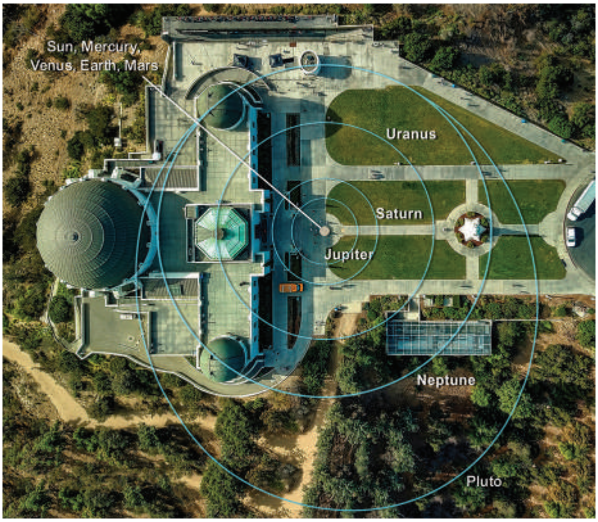
Chapter 15

Models are useful tools, but they have limitations. Have you ever seen a model of the solar system that looks something like this?



A hands-on solar system model is useful for showing the positions of objects in relation to each other. For example, this model makes it obvious that the sun is at the center and Earth is the third planet from the sun. However, the scale of the model isn't accurate. The sun is many times larger than the other objects. And all the objects should be much farther apart.

A true scale model of the solar system is built into the grounds of the Griffith Observatory in Los Angeles. It is accurate in terms of the sizes of the objects compared with each other and their distances apart. But as scale models go, this one is very large. It can't be viewed all at once from ground level. In a view from above, it's difficult to spot the three planets closest to the sun and their orbits. This model helps us understand how very far apart the planets really are.



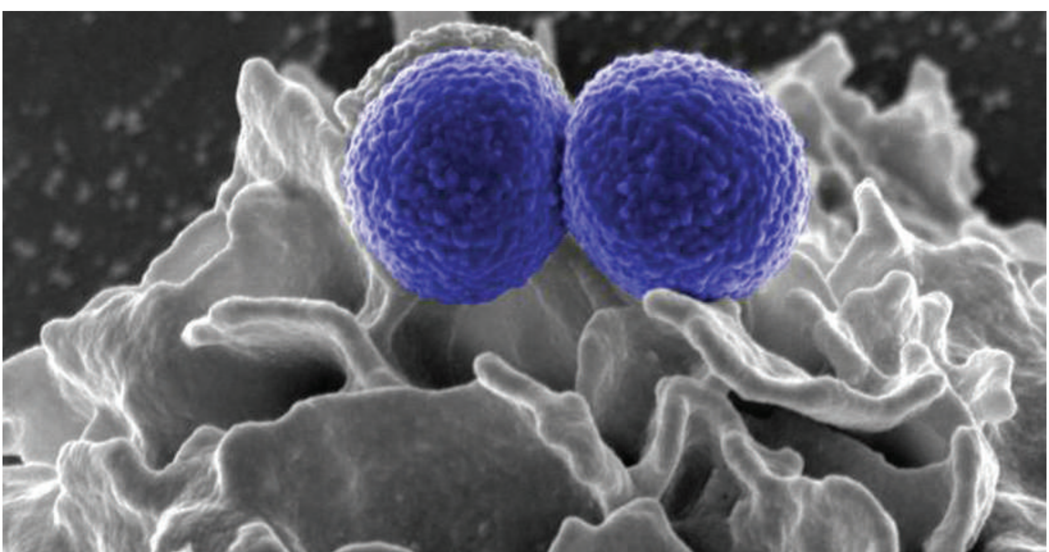
The vastness of space also makes it challenging for astronomers to visualize what's out there. Some things are near enough to be spotted with the unaided eye. And they can be viewed more clearly with telephoto camera lenses and telescopes. For example, you can see the moon on a clear night, and with a telescope you can zoom in and see the craters on its surface.

With more distant objects, including other galaxies, optical tools such as camera lenses and telescopes don't work well. Instead, astronomers and engineers have developed space telescopes that receive different types of radiation that we cannot see with our own eyes. The spectacular image below was produced by the James Webb Space Telescope. The telescope is in space, one million miles from Earth. A computer took the telescope data and made a model of this phenomenon rather than capturing an image the way a camera does.

This is an image of the Carina Nebula from the James Webb Space Telescope.

Another tool used to show what can't be seen using visible light and lenses is the scanning electron microscope (SEM). First, a sample to be viewed under the SEM is coated with a thin layer of gold or other conductive material. Inside the SEM, the sample is bombarded with beams of electrons, which are very tiny particles. Electrons reflect off the sample and interact with electron detectors. The detectors use data to form a picture that shows the surface of the sample in detail. SEM technology allows for magnification from 10 times to 3 *million* times.

The level of surface detail that SEMs can reveal is hard to match with any other microscope technology. But there are limitations to SEM imaging. The samples cannot be alive, and the pictures produced are in black and white. Any colors shown in SEM images, called micrographs, are added to call out certain features or simply to make the pictures more interesting to look at.

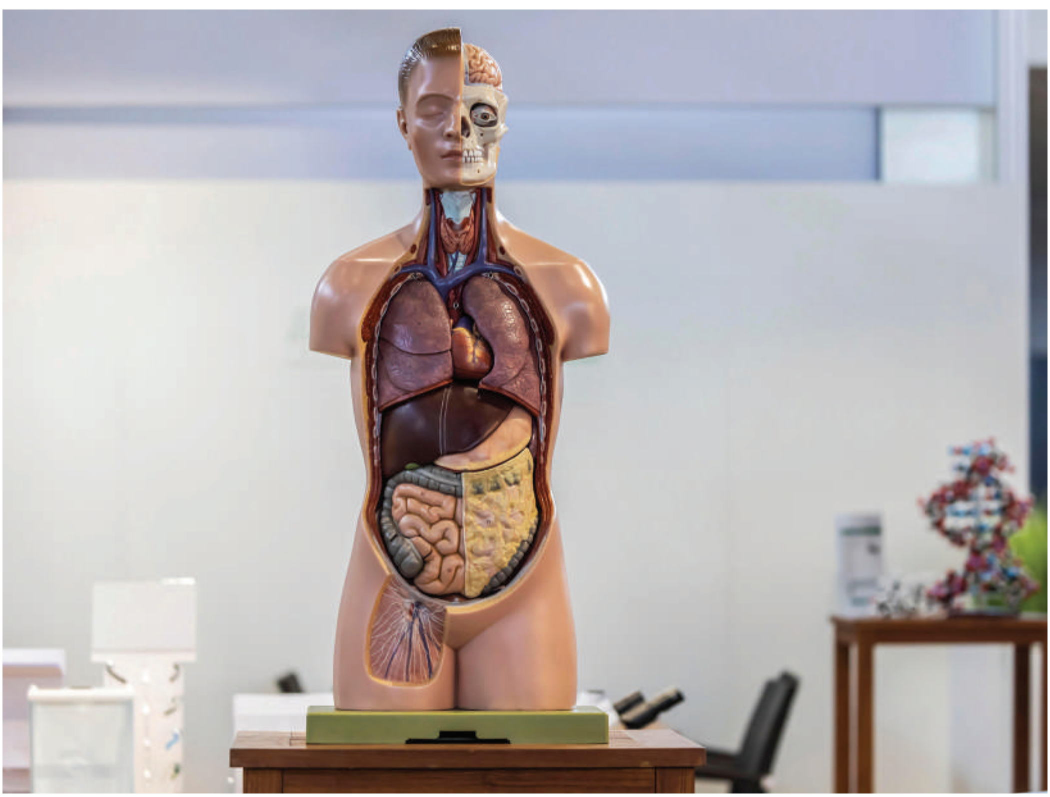


This SEM micrograph shows two *Staphylococcus aureus* bacteria on the surface of a white blood cell. The bacteria have been colorized to make them stand out. If you could see them with your own eyes, they would not have this blue color.

The human body is a system that can be modeled in a variety of ways, from detailed illustrations to hands-on plastic models to animations. For example, an orthopedic surgeon might use a hands-on model made of plastic bones, ligaments, and cartilage to show an injured patient what happened to one of their knee ligaments while playing basketball.

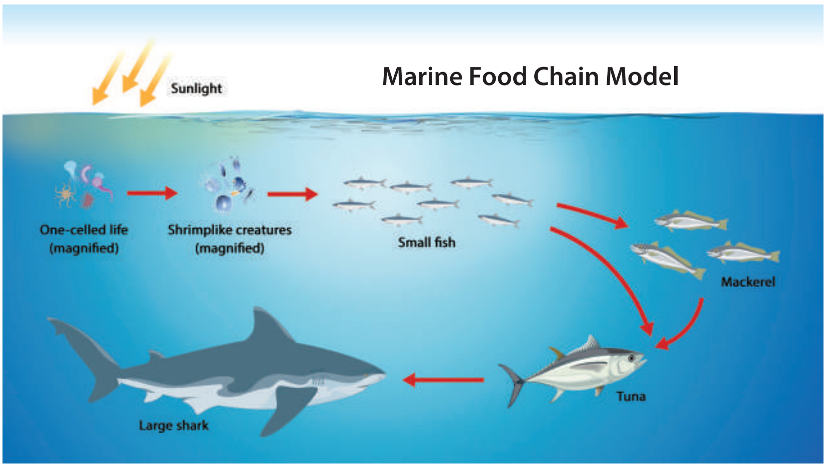
A plastic model shows the structure of a knee joint.

A larger human body model might show whole systems or all the structures in a part of the body. The model shown here features organs of the torso, neck, and head.

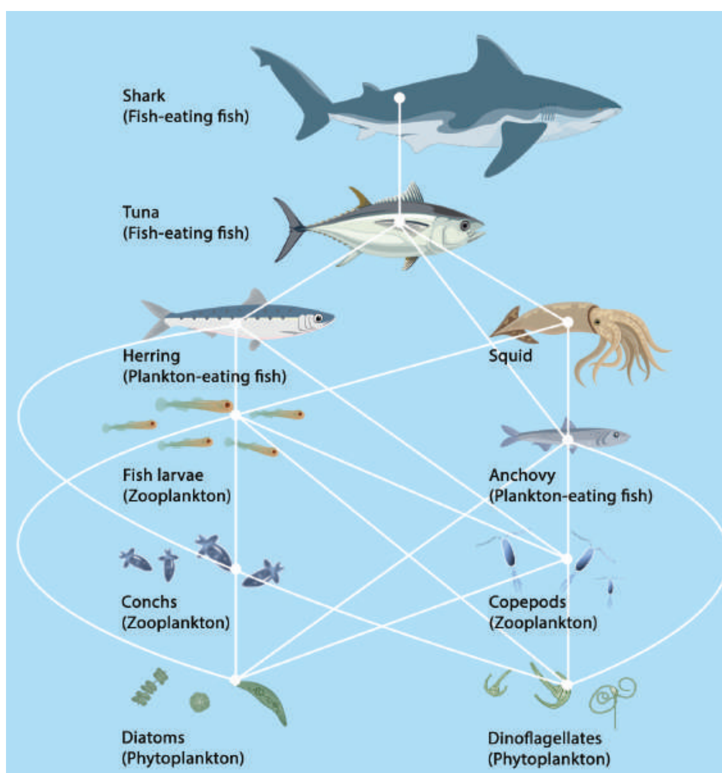


A plastic model shows a human head, neck, and torso and the organs in those areas.

A food chain is another type of system that can be visually modeled. Here, the movement of energy from the sun to the food chain is represented with yellow arrows. Red arrows indicate the movement of energy and matter from the base of the food chain all the way up to the apex predator, a large shark. The food chain shows straight paths from one ecological level to the next.

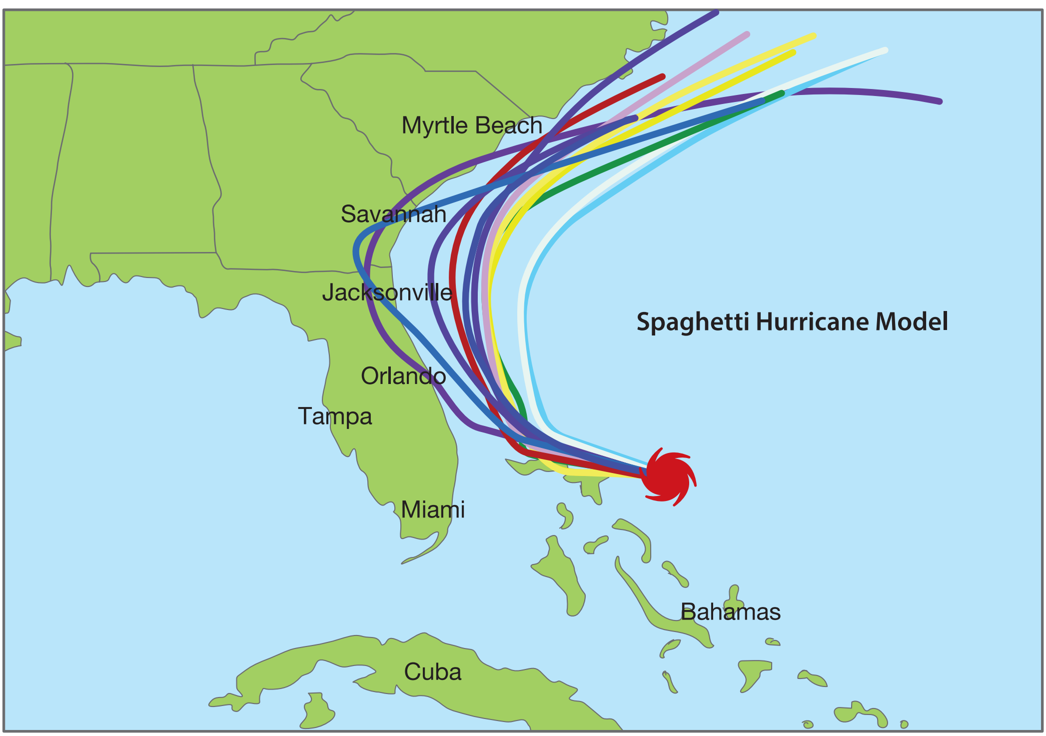


A more complicated visual model of what occurs in ecosystems is a food web. A food web is a combination of multiple food chains. The food web model does a better job of showing the complexity in an ecosystem. How do the food chain and food web, both of which are models, differ?



Meteorologists, people who study and predict weather, often model weather systems, such as snowstorms and hurricanes. Once a hurricane forms, weather scientists feed whatever data they have about the storm into computer programs. The computer generates predictions about where the storm is likely to move and how fast. This is called a predictive model.

One type of computer-generated storm model is referred to as a spaghetti model. Its visual representation looks like a pile of spaghetti on a map. Each strand of spaghetti represents a possible path of the storm if conditions add up in a certain way.



Main Science Idea

Models can be physical objects. They can also be diagrams of systems, cycles, and predicted outcomes or events.

What Is Efficiency?

Chapter 16

Suppose you walk to the kitchen to get some cereal. You need cereal, milk, a bowl, and a spoon. You make one trip to the table with the cereal, then you go back for the milk. Then you make two more trips—one for the bowl and one for the spoon.

A more efficient way would be to pour the cereal and milk into the bowl, put the spoon in, and carry it all back to the table together in one trip. You get the same outcome at the end with less work to get there. That's the concept of efficiency. A process is efficient if it uses a minimum of wasted energy to achieve a result.

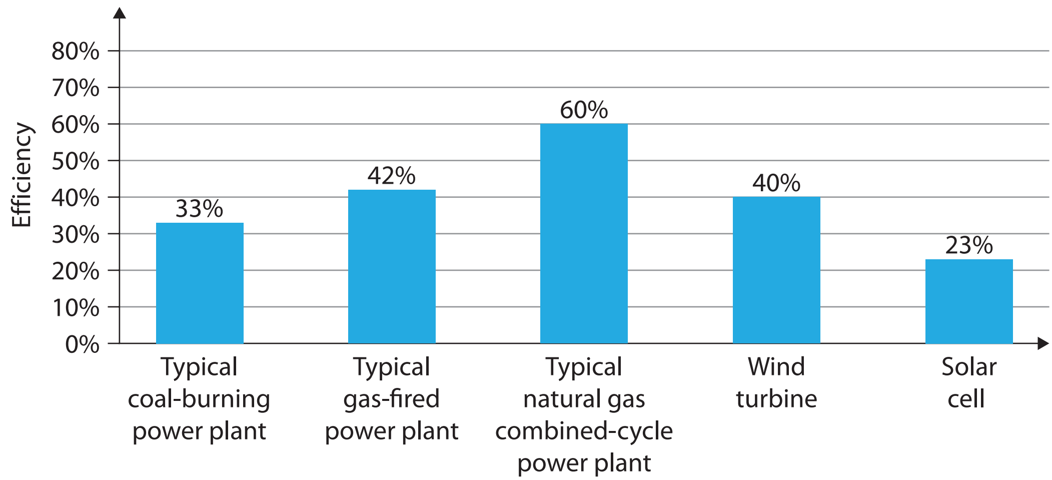
Efficiency is a number-one concern for engineers. Think about space missions. Because Earth's gravity forcefully pulls things downward, it takes a tremendous amount of energy—from a lot of burning fuel—to launch a rocket into orbit or beyond. And if humans are onboard, they need a lot of supplies and equipment to stay alive and safe. All that gear is heavy. More to lift means more energy needed to lift it. More energy needed means more fuel. And more fuel adds even more weight to the rocket! It is important in space travel to be efficient. We want to use a minimum of wasted energy to achieve a launch.

Most of the mass of a launching spacecraft is fuel, fuel storage tanks, and rocket engines. The actual "payload" that gets to space is small by comparison.

For a space launch and mission to be successful, engineers must design systems that are energy efficient. This means the systems use the least possible amounts of material (no waste) and energy to do what they need to do. An inefficient system is one that has too much mass or wasted energy to work as desired.

This Orion service module has solar array "wings." They extend outward to absorb sunlight and convert it to electricity. Each array turns on an axis so the panels can continually face the sun, getting the most out of the solar cells. This maximizes their efficiency. Solar cells provide a way to make electricity so the spacecraft does not have to carry heavy batteries that run out of charge. It's an efficient solution for the Orion's electrical needs.

Efficiency of Various Generators Producing Electrical Power



Electric power plants burn fossil fuels. The heat released by the combustion is converted into motion and then electric current. Solar cells convert sunlight directly into electrical energy. Wind turbines convert the energy in wind to electrical power.

All these require materials and energy to produce electricity. The most efficient solution is the one that puts out the most electricity with the least combined amount of material and energy put into the process.

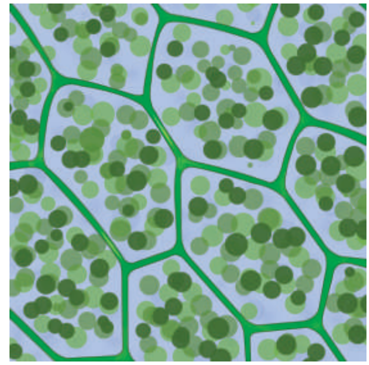
Although wind and solar power are not as efficient as natural gas, their efficiencies compete with coal and oil. Also, wind and solar are renewable, which means they are basically inexhaustible.
In time, the costs of extracting fossil fuels may outweigh their benefits. At that point, the renewable energy sources will be the most efficient.

Think about the efficiency of the human body. Chemical energy enters the body in the form of food. The digestive system breaks down food to access the usable form of energy, sugar. Some food energy is stored for later use in the form of body fat.

Lot of products claim they provide energy for athletic competition or to help people “power” through the day. Only about 5 percent of the energy from what a person eats ends up being used to do work like climbing stairs or playing basketball. Most of the energy from food is used to keep cells and tissues going and to maintain the body’s temperature.

Some of the energy in food is never successfully absorbed by the digestive system at all. For example, the cellulose in leafy greens is indigestible in humans. It passes through the digestive system. And yet, the human body functions well. The body is efficiently carrying out the process of living.

A very efficient natural system is photosynthesis, which is the process that makes sugar from light and carbon dioxide.



The green dots in this plant's leaves are structures where light is absorbed. Plants' green appearance is a sign of their efficiency—using the best wavelengths of light.

Science has shown that photosynthesizers, like plants, are quite efficient at absorbing sunlight. Nearly every photon of light that reaches a leaf gets used in reactions that produce food. Photosynthesizers have also evolved to absorb the best parts of light.

Algae are so efficient at absorbing sunlight that they can quickly take over habitats such as small ponds.

Photosynthetic organisms have pigments that absorb the best blue and violet light and make the most of the energy it packs. They also have pigments that absorb orange and red light. Green light is less useful to the plant. Some green light is absorbed, but a lot of it is reflected. That's why so many plants and algae are green. They are reflecting the green wavelengths of light while absorbing the other wavelengths.

Main Science Idea

Efficiency means getting the best outcome out of a system or process in relation to the amounts of material and energy that go into the system.

Choosing for Designs

Chapter 17

Getting things from Earth's surface up into space is a hard engineering challenge. Even more challenging is getting things back down to Earth without destroying them!

The Artemis program seeks to send astronauts to the moon. The Orion crew module, also known as a capsule, is a key component in the Artemis missions. The capsule must withstand tremendous forces as it's propelled through Earth's atmosphere into space. It must keep astronauts safe. And later, on the return trip, it must withstand the turbulence and extreme heat of reentering the atmosphere. Finally, it is tossed about on the choppy surface of the ocean.

The Orion capsule provides an impressive gallery of different structures and functions in its engineering design.

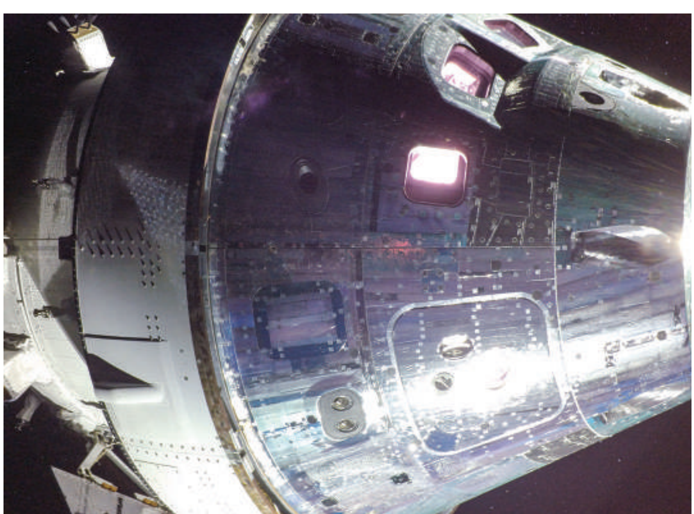
Pressure Vessel

The Orion capsule must be airtight and able to maintain its shape. The structure that allows the capsule to withstand pressure is called the pressure vessel. The pressure vessel is made of large pieces of aluminum alloy that are welded together. The alloy is strong enough for the pressure vessel to function yet not so heavy that it adds unnecessary weight to the spacecraft.

The capsule also must have an opening for astronauts to get in and out. Orion's hatch seals tightly with materials that won't let air pass between the vessel and its door. The material that seals the hatch must function in the cold of space as well as the heat of reentry through the atmosphere.

Backshell

On the outside of the pressure vessel is the backshell, which is made of insulating tiles that keep heat inside the capsule so the astronauts do not freeze in the cold of space. The tiles protect the crew from heat when the capsule reenters the atmosphere.



Heat Shield

When the Orion capsule returns to Earth, the astronauts activate thrusters to position the capsule so its bottom is facing Earth. The friction of the capsule flying through the atmosphere at 25,000 miles per hour causes that bottom surface to reach temperatures as high as 5,000ºF. To prevent the capsule from burning up, a special material called Avcoat is used to make the bottom into a heat shield. The heat shield is designed to burn and fly off the capsule bit by bit as the vessel descends through the atmosphere. This moves dangerous heat away from the capsule. A honeycomb-like surface, made of 320,000 cells, is filled by hand with Avcoat to complete the heat shield.

This heat shield was charred during a test flight of an Orion capsule.

Capsule Controls and Comfort

The four seats inside the Orion capsule are adjustable and comfortable. The controls are set up to be within reach and usable while astronauts are seated and in their suits.

Suits

Orion astronauts' suits control temperature and humidity. When the helmet is attached, they provide each astronaut with their own breathable atmosphere. The suit material is airtight and fire resistant. It is also brightly colored so the astronaut is visible on the ocean surface if they need to exit the capsule prior to being reached by ship.

The suit is also equipped with a life preserver for survival at sea. The suit includes gloves that have fingertips that work with touchscreens. All the materials are carefully selected to ensure the most lightweight but functional choice.

Parachutes

When the Orion capsule enters Earth's atmosphere at 25,000 miles per hour, friction with the air will slow it down to about 325 miles per hour. But it needs to slow down even more to reach a safe speed for landing in the ocean. The capsule has a system of parachutes that deploy in sequence. The lines that connect the parachutes to the capsule are extremely strong, and the parachutes are made of Kevlar and/or nylon. Again, these materials are as light as they can be and still be strong enough for the job.

1. **Altitude: 26,500 feet**
   Speed: 324 mph
   Three 7-foot Kevlar parachutes deploy and then release.
2. **Altitude: 25,000 feet**
   Speed: 307 mph
   Two 23-foot Kevlar/nylon parachutes deploy and then release.
3. **Altitude: 9,500 feet**
   Speed: 130 mph
   Three 11-foot Kevlar/nylon parachutes deploy and pull the main parachutes out, then release.
4. **Altitude: 9,000 feet**
   Speed: ~130 mph
   Three 116-foot Kevlar/nylon parachutes deploy and remain attached to the capsule as it descends to the sea surface.

1.

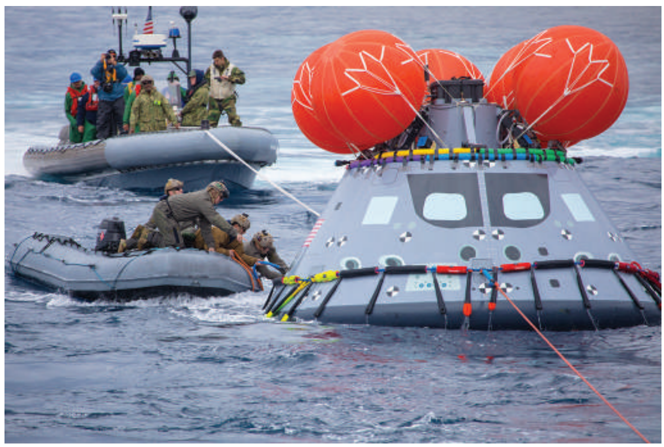
2.

3.

4.

At-Sea Retrieval

Following Orion's splashdown in the ocean, the capsule becomes a life raft. The capsule floats inflate to turn the capsule upright. The flexible deflated float fabric is tightly packed away during the entire space mission. Inflated, the waterproof, airtight, brightly colored floats also function as visual targets for the ship that will retrieve the capsule.



Main Science Idea

Designing engineering solutions requires knowing how materials behave and choosing the right materials for each necessary function.

Things Get Disorderly

Chapter 18

As you walk along a mountain trail, you can observe all of Earth's spheres at once. You breathe in and out into the atmosphere. Living representatives of the biosphere rustle and chirp all around you. You cross the land of the rocky geosphere and streams of the hydrosphere. Maybe you experience some of the hydrosphere as rainfall, too.

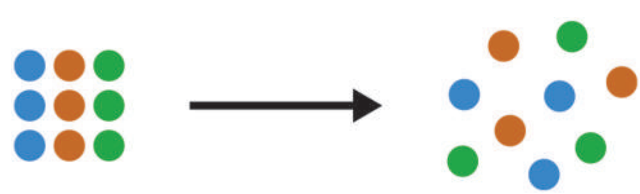
You know that all these complex systems are dynamic—constantly changing. Some of the changes occur swiftly, and others, such as the formation of mountains or the erosion of valleys, happen very slowly. But have you ever stopped to wonder *why* everything around us is constantly changing?

It has to do with a concept in science called entropy. Entropy is the tendency of things in the universe to become more random—that is, LESS ordered. Matter and energy tend to spread out and become less organized.

Let's think on a smaller scale and look at a simple example.

In a glass containing ice and water, the ice will absorb thermal energy (heat) from the warmer water around it. That causes the ice to melt, adding more liquid water to the glass. In time, all the water in the glass will be the same temperature. In a little more time, the water and the glass itself will be at the same temperature as the air in the room as the thermal energy is evenly distributed throughout the system, which includes the ice, the water, and the surrounding air (as well as the furniture, room, and building it's in). That's entropy.

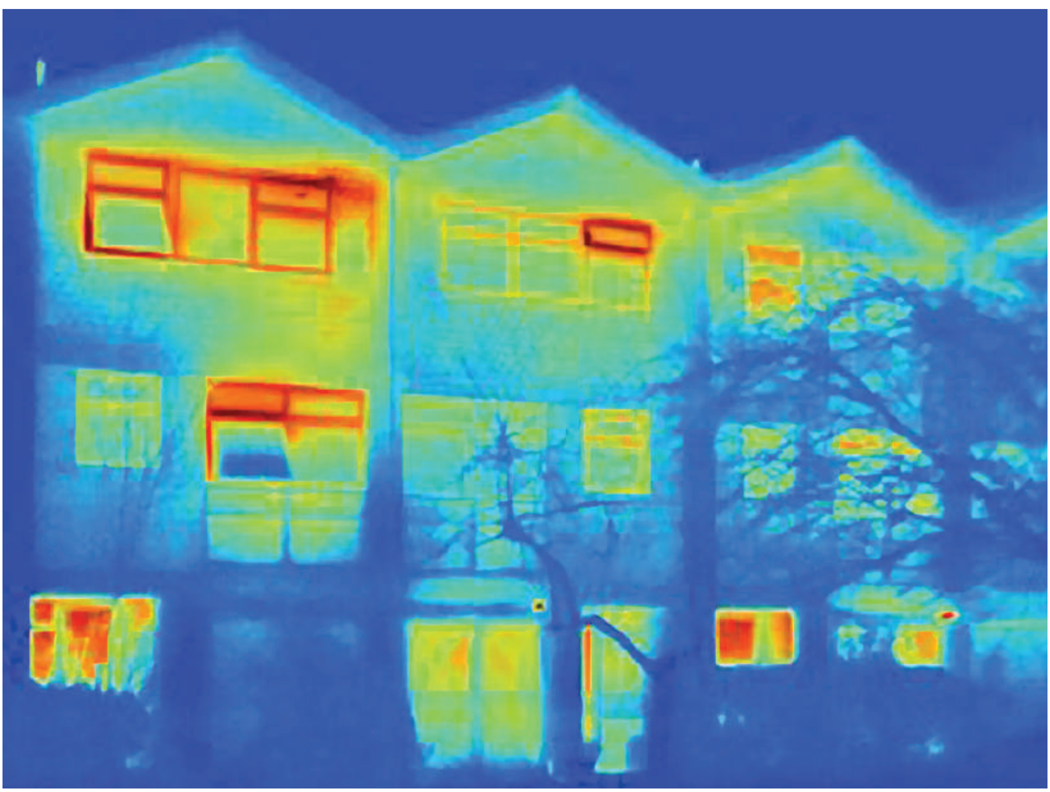
Matter wants to spread out randomly, too. For example, consider the glasses containing water and food coloring. In time, even without stirring the liquids, the food coloring will evenly distribute throughout the water in these glasses.



In an orderly arrangement of particles, entropy will eventually, naturally result in a random arrangement.

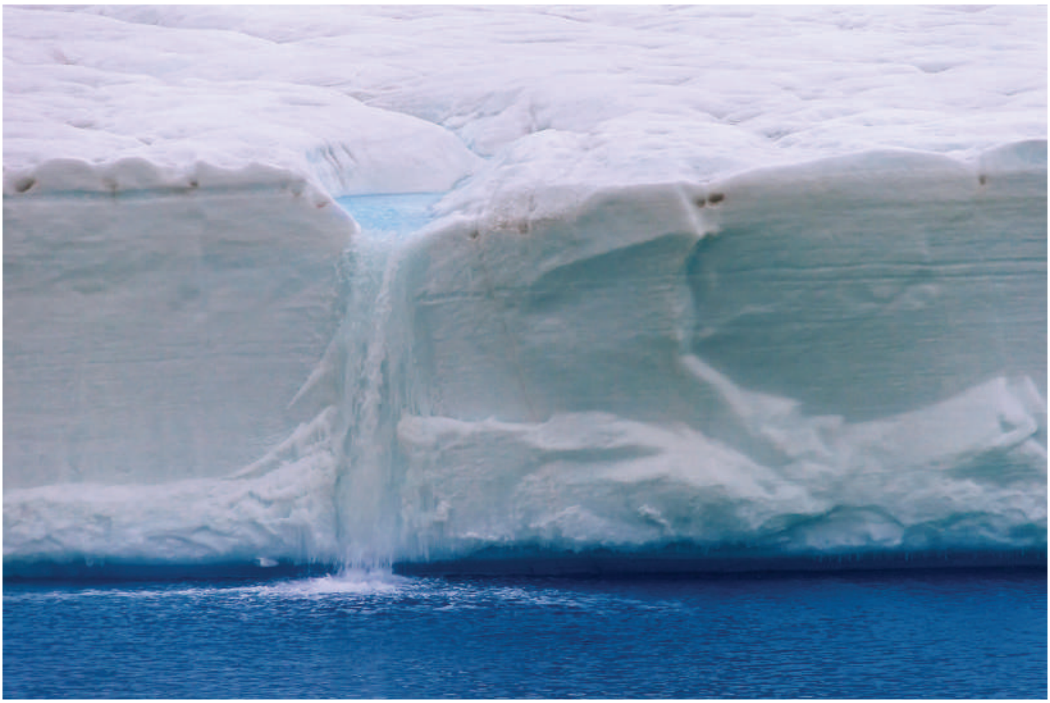
Here's another thermal energy example. When a furnace has to warm a home again and again throughout a cold day, it's because the thermal energy the furnace adds to the interior is always making its way through the materials of the home and out into the cold air surrounding the home. A home is a designed system. We want that system to work in an orderly way and maintain a stable temperature. But to keep a room either stably warm or stably cool requires a regular input of additional energy.

Whenever we look at any orderly system, we can think of entropy and consider how conditions in that system will naturally change and, eventually, cause the system to no longer function in the same way.



A thermal image shows where heat escapes buildings.

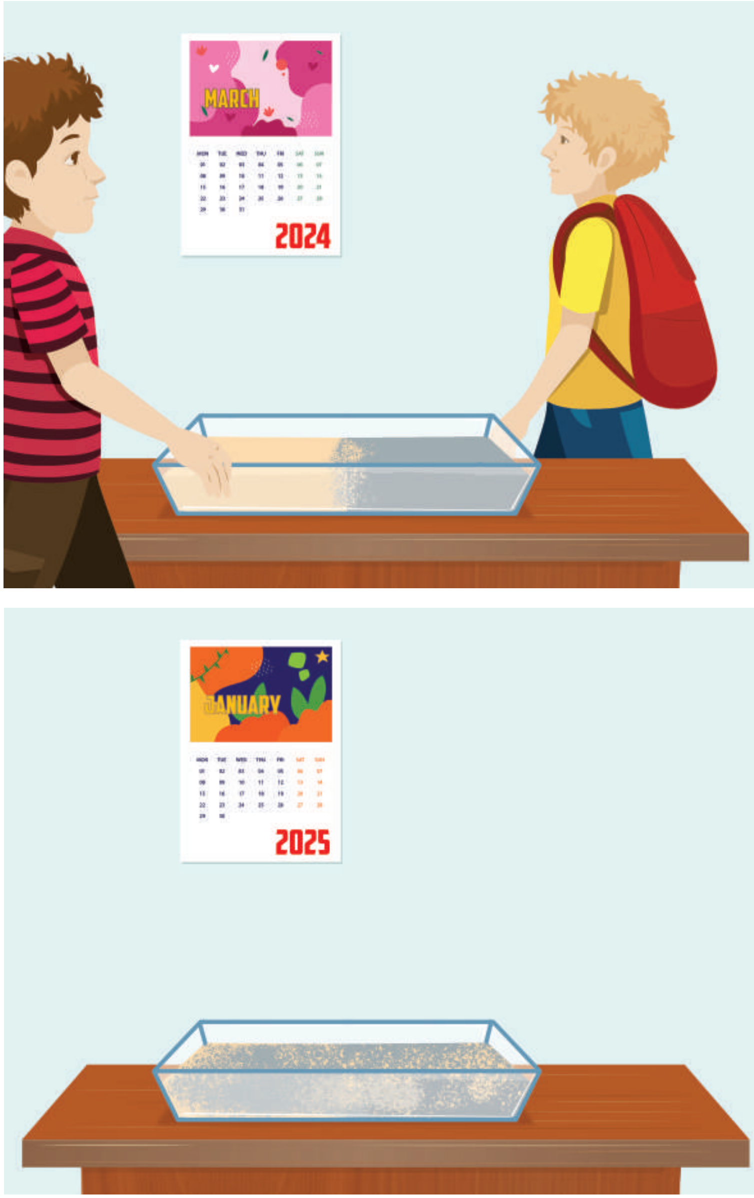
Think also of fresh water entering ocean water from melting ice. The water where the melted ice pours directly into the ocean is less salty than the surrounding ocean water. Fresh water added to ocean water disperses throughout the ocean. Over time, things become uniform.



A backyard firepit is an example of entropy. It starts as a tidy arrangement of unchanging wood. As the wood burns, heat, ash, and smoke spread out. Over time, the fire goes out, and everything there becomes the same temperature. Wind scatters the ash.

Entropy is an abstract concept, but we can use a concrete model to visualize it. Suppose you have a sealed, clear, plastic box on a table in your classroom. The bottom of the box contains black sand on one side and white sand on the other. There is no physical barrier dividing the two colors of sand. The box gets bumped from time to time as students walk around the table. White sand shifts onto the black side; black sand shifts onto the white side. Over the course of the school year, random movements cause the distinction between the black and white sand to disappear. The two colors of grains are all mixed together, and the sand now just looks gray.

No random movements are going to bump all the black sand back to one side and the white back to the other. According to the concept of entropy, things never get more orderly on their own. They just get more disorderly and random until they are uniform.



The uniform appearance of the sand in the box is a sign of disorder, and increased entropy, in the system.

Main Science Idea

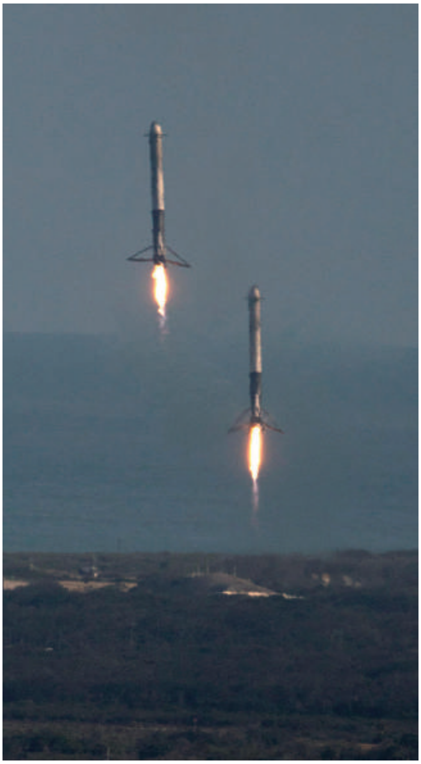
Entropy is the idea that matter and energy tend to become evenly distributed and inactive over time. Eventually, entropy changes all systems so they don't work in the same way.

Optimizing a Solution

Chapter 19

Space exploration demands a lot of energy, research, testing, and equipment. Many components get destroyed or left to drift in orbit because reusing or retrieving them isn't possible or cost-effective. In the early 2000s, the company SpaceX began developing a type of rocket that would be partly reusable from one mission to the next. That was a first in rocket science.

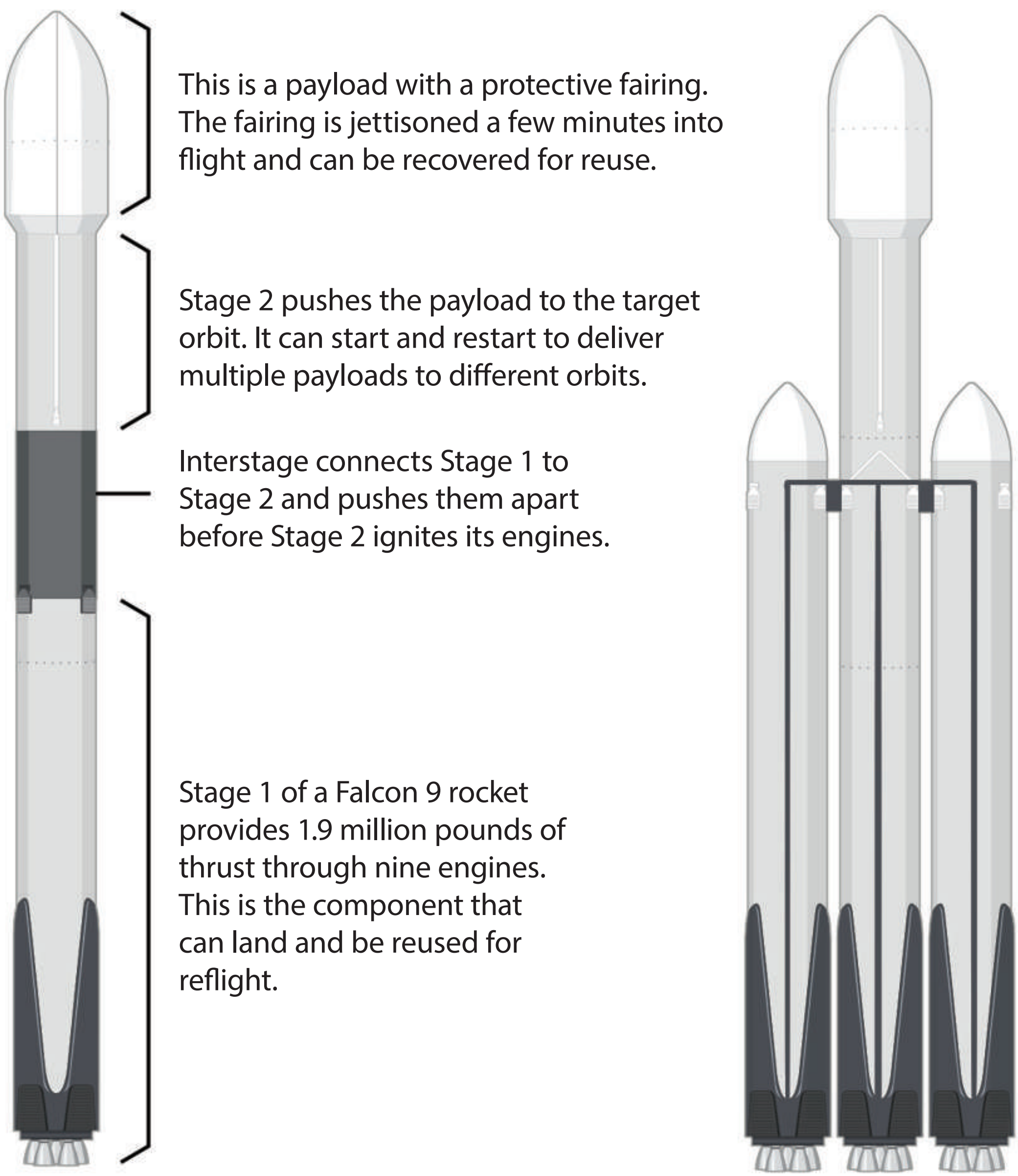
Launch



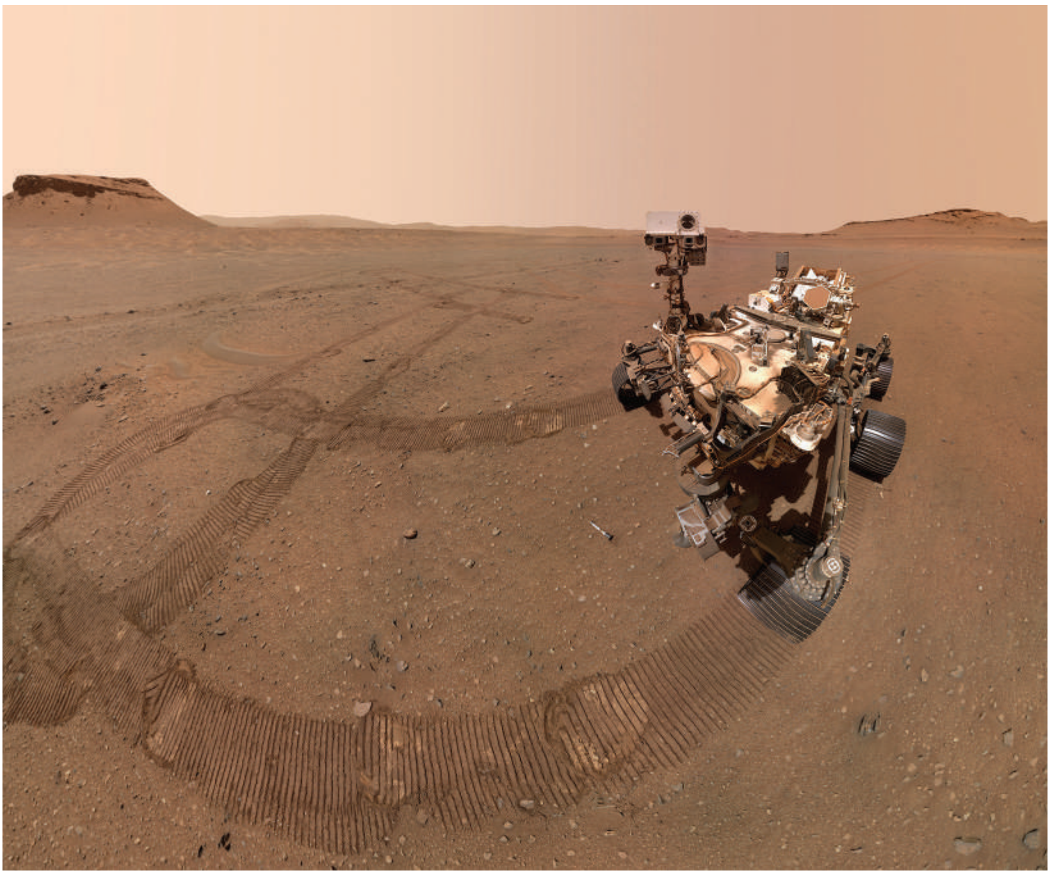
Boosters landing

SpaceX managed to save and reuse rocket boosters, the most expensive components in a rocket launch. The company optimized the design of an essential tool for exploring space and delivering satellites to Earth's orbit.

Optimizing saves money. SpaceX Falcon rockets have accomplished over 270 launches, over 220 controlled booster landings, and over 220 reflights of previously launched rocket boosters.



Another hard and expensive space mission is exploration of Mars by a series of rovers. The Mars 2020 mission by NASA sent a rover called Perseverance to travel across the surface of Mars collecting images, data, and samples. Perseverance can send daily images and data to Earth. The samples it stores will eventually be brought back to Earth in a series of handoffs between different automated spacecraft.



The Perseverance rover is equipped with cameras. One is mounted on a robotic arm that can be used to take selfies.

The photo shown here is actually made of many different digital images that are stitched together by software here on Earth. Having the rover do the fieldwork while scientists on Earth use other processes to analyze and interpret data is one way to optimize the Mars 2020 investigation.

Similar missions to Mars might be optimized by training rovers' computer systems to know what they are looking at as they explore unknown territory on the "red planet."

Think about how your mind and eyes work together if you are looking for a specific food in the refrigerator or a puzzle piece to complete a puzzle. Your mind has an image that it wants your eyes to find. This is called a search image. If you have seen many things and remember what they look like, your mind can generate thousands of search images. In that way, the trained human mind is optimized to find things.

Now, think about a Mars rover, which is programmed to recognize some things, but it cannot recognize or make sense of nearly as many things as a human mind can. Instead, the rover sends images back to Earth, and then NASA tells the rover what to do next. This is less optimal because Mars is millions of miles from Earth and those back-and-forth signals take time.

To optimize rover performance, NASA is attempting to program the next generation of Mars rovers to recognize what they see, more like a human would, and then perform the next correct task based on recognition and prior information. NASA is tapping the collective knowledge of humans to write that computer programming.

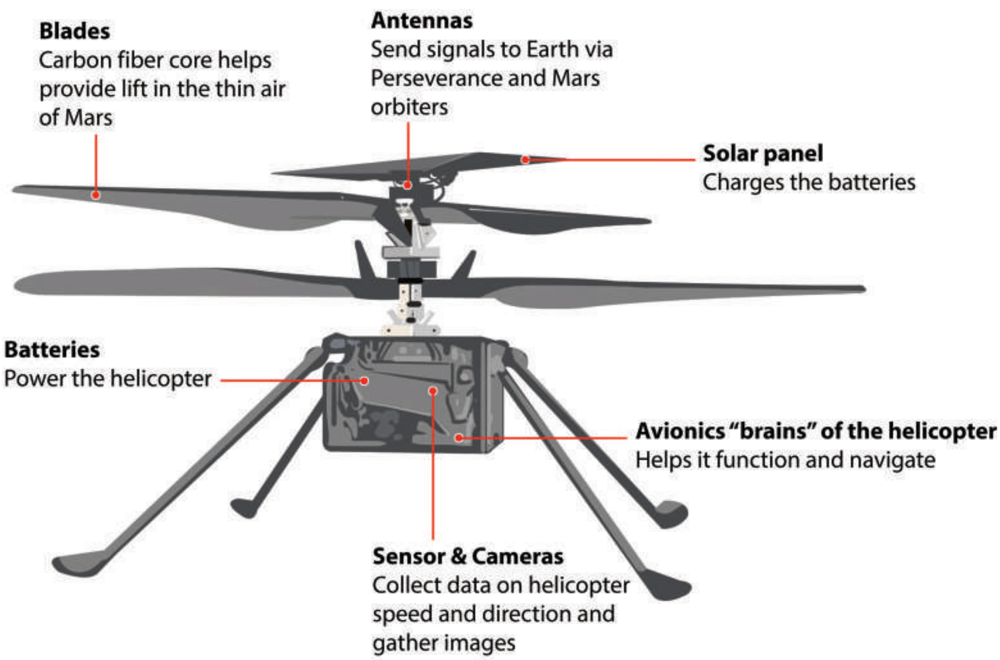
Making a planetary rover work more autonomously—more on its own—optimizes its design.

Joining Perseverance on Mars was a small helicopter called Ingenuity. It first took flight on Mars on April 19, 2021, and it performed seventy-two flights by its final mission in January 2024. Ingenuity was like drones that people use to explore and photograph Earth's surface, only it operated millions of miles from the nearest human.

Ingenuity's engineers needed to meet some key challenges with their design.

- **Mars's atmosphere is thinner, meaning there's less air for the blades of the helicopter to interact with and provide lift.**
- **There was no way for the batteries to be changed or recharged.**
- **Images recorded by Ingenuity's cameras needed to be transmitted to Earth.**

The antennas, solar panel, batteries, special carbon-fiber blades, and other features helped optimize Ingenuity to successfully survey Mars from above.



Main Science Idea

To optimize something means to revise and improve it so it can achieve its best possible performance.

The Information Age

Chapter 20

Stone Age: From 2.5 million to about 5,000 years ago

For millions of years, humans existed without the help of tools made of metal. There were no electrical components, plastics, or many of the things that now dominate today's technology. Humans and their ancestors used stone knives, spears, axes, and hammers to hunt animals. People also used bone to make tools as well as musical instruments. Stone Age arrowheads are still found today in forests and other habitats all over the world. Examining these tools helps anthropologists learn how humans lived thousands of years ago.

Bronze and Iron Ages: From about 5,000 to about 2,000 years ago

The Stone Age was followed by the Bronze Age and then the Iron Age. Humans extracted metals from the ground and made tools from them. People also made jewelry, coins, and artwork. The metal objects contributed to the development of different civilizations.

Renaissance: From the 1300s to the 1700s CE

After a long period called the Dark Ages, in which technology did not advance very much, the Renaissance period brought new ways of thinking. Technologies advanced, including telescopes and other devices that had lenses. People took interest in looking more closely at very small things or zooming in on faraway objects, including distant planets and stars. The first printing presses were developed, too, which allowed knowledge to be recorded, shared, and distributed more widely.

Industrial Age: From about 1850 through the 1950s and beyond

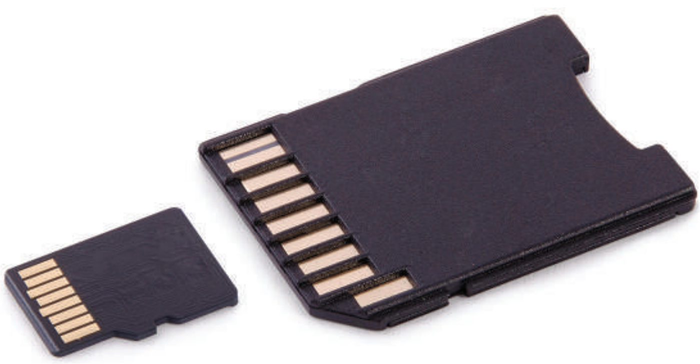
Beginning around 1850, the Industrial Age was marked by advancements in large-scale manufacturing of tools, vehicles, and other goods, especially machinery that could do work that humans couldn't do by hand or couldn't do as quickly. Food production also became more mechanized, from the designs of fishing gear to farm equipment.

Advances in manufacturing, food production, and materials science, as well as other technological developments that defined the Industrial Age, are still underway.

Information Age: Now!

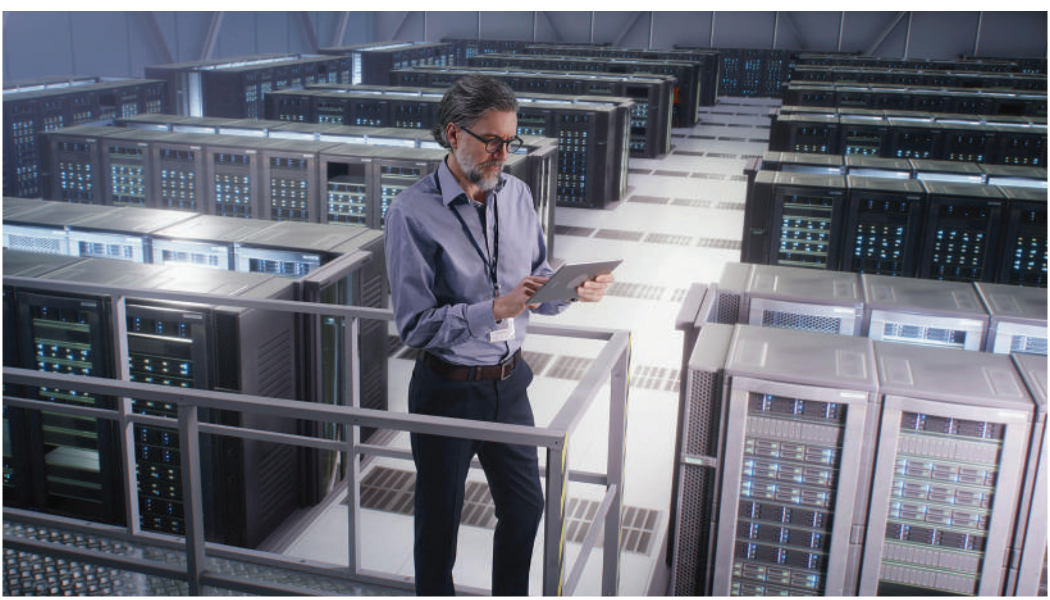
Thanks to major advances in how information is stored and shared, the age you are living in now is called the Information Age. Information technology began as printed products, such as books, and grew to include digital information technologies such as mobile phones, computers, servers, and more.

Inside a computer are microchips, processors, and digital storage devices. They produce and store information as tiny electrical signals. Signals can be combined into code, usually long series of ones and zeros, that result in images such as text, photos, videos, and animation appearing on an electronic screen. These products are stored and shared as computer files. The most powerful of all modern computers, a quantum computer that can make sense of complex data with astounding speed.



Tiny digital storage devices can hold enough digital information to match what is found in entire libraries, photo catalogs, music collections, and other forms of analog storage. Digital devices have gotten smaller in size but have larger capacity to store files.

Digital information can be sent along wires as electrical signals. Signals can also be sent as packets of light through fiber-optic cables. Many signals end up converted into radio signals transmitted wirelessly through the air by tall towers. Likewise, towers receive radio signals from mobile devices and convert them to electrical signals.



To help store and transmit the huge amounts of digital data that exist today, engineers build and manage large computer server farms. Servers store and transmit data through the internet, a network that connects computer devices all over the world. Many of the computer files that people use are stored only on servers, not on their own devices. This "elsewhere but accessible" storage is often called "the cloud."

The Future of the Information Age

The "tech" industry is the collected activity of companies that find ways to use digital technology and the internet. The tech industry changes the way businesses work and creates new business opportunities.

Some tech businesses connect people looking to take a vacation with homeowners who want to rent out their homes. A vacationer can use an application, or "app," to see photos of a property, find restaurants, and more. There is an app for almost everything, and they are flexible and convenient!

Different tech solutions help vacationers keep an eye on their homes while they are away. Video cameras and sensors allow homeowners to monitor their homes from afar. There are even refrigerators that track when important groceries inside are running low. Virtually anything can be monitored and controlled from a smartphone.

Another sector of the tech industry that is taking off—literally—is drone technology. Drones can be deployed to take photos or videos of properties that are for sale, sports events, weddings, wildlife, and much more. Many drones can be operated from mobile devices. Some drones are being used to deliver packages—from food to lifesaving medicine—to remote locations.

Tech changes fast and is always learning. For example, you might think the tech industry could learn *about* biology but not *from* biology. Think again! DNA, the molecule that contains information for building cells and organisms, is being investigated as a form of storage for the same type of code used in computers. Why use DNA as a model for preserving digital files? Because DNA is so small and can store so much information. One estimate suggests that all the digital information produced by human activity in a year could be stored in a DNA molecule the size of a table-tennis ball.

Main Science Idea

Most current, modern technology is built to store and transfer digital information. This is an area of human activity that is developing fast.

Glossary

A

age, n. a period of time defined by a technology

analogy, n. a model that explains one idea by comparing it to something else

area, n. amount of space within the a certain space

astronomical unit, n. unit of length equal to the average distance between the Earth and the Sun

C

causation, n. one event causes another event to occur

constraints, n. limits on the designed solution to a problem

constructive critique, n. feedback that aims to help people improve their behavior or performance

correlation, n. a description of the relationship between two or more variables

criteria, n. the conditions that a solution must meet to be judged as successful

D

data, n. information that is observed or measured and recorded

difference, n. instances of things being unlike or distinguishable from another

E

efficiency, n. the degree of producing desired results

energy, n. the capacity to do work or cause change

entropy, n. the idea that matter and energy tend to become evenly distributed and inactive over time

evidence, n. a detail that supports a claim or helps prove an idea is true

explanation, n. the stated reason for something or about how something happens

F

feedback, n. reactions to a product or a performance used as a basis for improvement

formula, n. a mathematical rule that uses letters or names to represent amounts that can be changed

function, n. the action or purpose for which a thing works

G

geologic time scale, n. a timeline that divides Earth's history into time units

goals, n. the result or end that a person wants to happen

graph, n. a diagram that organizes and displays data in a way that reveals patterns and makes the data easier to understand

I

indirect, adj. a type of relationship in which two variables affect each other through a third variable

information, n. knowledge or facts that is given or received

investigation, n. an instance of investigating

L

light year, n. the distance that light travels in one Earth year

M

method, n. the way scientists gather information, observations, and the tools and steps used

model, n. a representation of something that can help people learn about the real thing

N

notes, n. records of what you have learned or heard

O

objective, n. based on facts and evidence

optimize, v. to revise and improve it to its best possible performance

outline, n. a plan for a presentation or paper

P

pattern, n. a reliable system of traits or a set of repeating details

prediction, n. a declaration in advance of what one thinks will happen

prehistory, n. the period of time before written history

presentation, n. a way for a speaker to convey information to an audience

R

rubric, n. a scoring guide that addresses the criteria and constraints

S

scale, n. the size of a picture, plan, map, or model compared to the real thing

scientific, adj. the study of the natural world through observation and experimentation

similarity, n. things that are shared or similar between two things

solution, n. a process, action, or device that fixes a problem

stability, n. the tendency of something to remain undisrupted

structure, n. the way in which something is made and the parts it is made of

subjective, adj. based on personal feelings, tastes, or opinions

system, n. a set of parts that work together and affect each other

T

team, n. a group of people who work together to achieve a common goal

teamwork, n. working together as a group

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Daniel H. Franck

Subject Matter Expert

Terri L. Woods, PhD
Associate Professor (ret.)
Department of Geology
East Carolina University
Greenville, NC

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