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About Alpha Publishing

believes that children and adults have the right to a quality education. Continuous learning is the best means of improving the lives of individuals and enhancing the standards and quality of our communities.

We cater for curricula aligned to international educational standards—Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) for both mathematics and English language arts. Our mission is to provide educational materials and courses across the Middle East and Africa that meet these international standards while also reflecting and incorporating the cultures and traditions of the region. Our dedicated publishing teams are mindful of the different types of learners who come from various national and cultural backgrounds.

Our publishing strategy is based on the motto: “We are in the Region, for the Region.” Coupled with the latest technology and innovative learning and teaching tools is the meticulous attention we pay to the delivery of globally recognized and culturally appropriate content. We integrate these things not only in our books, but also through eAlpha, our digital Learning Content Management System (LCMS).

At Alpha, we follow this set of principles that guides our publishing philosophy, strategy, and every aspect of our business operations:

**Life-Long Learning**
We constantly endeavor to infuse what we publish with global experience, expertise, and best educational practices. We do this bearing in mind our region’s current and future learning and teaching requirements.

**Innovative and Futuristic Focus**
We ensure that all of our products are based on cutting-edge research. We look to the future by teaching to all learning styles and abilities. We firmly believe that the future of our region will be determined by today’s student. By innovating our education to cater to each student, we are guaranteeing a positive future led by people who are informed and problem-solvers.

**Advancement of Technology**
Alpha Publishing places great importance on developing the technology needed to produce cutting-edge programs and courses for the educational transformation of the community.

**Results Oriented**
At Alpha, we know that enhancing teaching and learning outcomes is a key element for measurable impacts. Our online and offline assessments enable teachers and parents to easily gauge a student’s progress. The results of these formative and summative assessments will enable the learning experience to be adapted for any student.

**Excellence in Publishing**
We guarantee that what we publish is reliable and trustworthy, both globally and regionally. Our talented editors and writers have decades of experience producing the highest quality educational products around the world. Nothing but the best is acceptable at Alpha Publishing.

For more information please visit us at www.alphapublishing.com and www.ealpha.info.
Alpha Science is an integrated science program encompassing earth, life, and physical science as prescribed by NGSS. Alpha Science includes adequate rigor; inquiry learning; real-world context; career connections; integration of DCI, CCC, and SEP of NGSS; and opportunities for problem-solving, analytical thinking, making sense of phenomena, and designing solutions. Lessons and units fully integrate NGSS 3D design in student learning, teaching, and assessment. Lessons and units exemplify coherence; they fit together in a clear narrative thread that links multiple science domains with each lesson and unit, clearly building on the previous content. Support for the development of coherence will be provided in the Scope and Sequence as well as a comprehensive checklist, showing alignment based on the EQuIP Rubric for Science.

Alpha Science was written taking into account modesty and the religious beliefs and customs of students in the MENA region. The series is written for the region but has a world focus. This series incorporates a mixture of names and features from all regions of the world.

Lessons and chapters are clearly mapped and correlated to skills, DOK, rigor, and assessment boundaries, and they are aligned to CCSS mathematics and ELA standards.
**Teacher Guide**
The Teacher Guide provides assistance for the teacher in all phases of the teaching cycle and professional development.

**Student Book**
The Student Book is the main resource for students. It contains all the core lessons, learning opportunities, and assessments that students will complete during class and at home.

**Practice Book**
The Practice Book complements the Student Book; the Practice Book includes two pages for each lesson that provide extra inquiry-based learning opportunities and questions that reinforce what the students learn in class. Three types of approaches will appear throughout the Practice Book:
- An extension of the lesson with a reteach section in the beginning of the lesson page as it makes sense.
- A focus on the prominent Crosscutting Concept or Science and Engineering Practice of the lesson.
- A Performance Task Practice page that reinforces how all three pillars of instruction are addressed within a lesson and helps students build familiarity and prepare for Performance Task Assessments.

**Differentiated Anchor Activities**
The Differentiated Anchor Activities are engaging activities that encourage active learning and exploration while reinforcing foundational concepts. Each lesson has three levels of differentiated activities to meet the needs of students at differing levels of readiness for new material. Teacher support for implementation, materials lists, alignment, and procedures are included in the lesson planners.

**Exit Activities**
The Exit Activities provide a quick formative assessment for teachers. A short individual activity is completed by students in 3–5 minutes after the lesson instruction is complete. Teacher support for implementation procedures is included in the Lesson Planners.

**Digital Assessment Bank**
The Digital Assessment Bank provides teachers with a robust variety of assessment options. Items are a variety of test types—True/False, Matching, Completion, Multiple Choice, Short Answer, Multiple Response, and Open-Ended Items. Items are tagged with metadata to allow teachers to use ready-made assessments or to build their own using certain criteria. Metadata tags include NGSS Standard, Difficulty Level, Location Reference (Grade, Unit, Chapter, Lesson), Learning Objective (codes, not text), Topic, Keywords, and more.
Components of the Middle School Student Books and Teacher Guides

The Unit Introduction contains NGSS background information, the Big Idea of the unit, and Graphic Organizers to provide teacher support. The end of each unit has a Unit Review to fully integrate the chapters and lessons of each unit.

Each chapter opens with the Big Idea and a Reading Science feature. Each chapter also contains a Chapter Planner, Careers in Science or People in Science, a Chapter Wrap-up and Review, and a Teacher Dialogue feature that will build critical thinking skills. Each chapter ends with an extensive STEAM activity.

Lessons use the 5E instruction method—Engage, Explore, Explain, Elaborate, and Evaluate. Each part of instruction has scaffolded activities and instruction for students with substantial teacher support. Inquiry Learning features and activities are included to build skills and understanding. Each lesson contains a Home Activity. And once within each chapter, there is an Apply Math feature.

Alpha Middle School Science has many new features to support student learning.

The new quarter- or half-page features include:

- Teaching Connections—to draw a teacher’s attention to how the science content connects to another content area.
- History of Math, Technology, and Science—to draw history of math, technology, or science into the content being presented. It could also draw in a particular historical figure important to science, math, or technological advancement.
- Calculator Activity—to integrate the Casio FX-9860 into instruction.
- Technology Activity—to integrate and include, but is not limited to, spreadsheets and simulations.

New student and accompanying teacher margin features include:

- Engineering Connections
- Science and Math Connections
- Science and Art Connections
- Science and ELA Connections
- Careers in Math, Technology, and Science
- Timelines
- ESL/ELL Activities
- Science in Action
At Alpha Publishing, we are committed to continuously supporting teachers and schools using Alpha programs. We are fiercely dedicated to developing and promoting in the region the best in educational practices and methods to empower our talented educators. Alpha is proud and excited to offer a number of **FREE** trainings to our users, including:

- **Hot Start:** At the beginning of each academic year, we offer Service Training that provides an in-depth training and programs, pedagogies, features, teacher resources, student resources and how to access and utilize these on our online and offline Alpha CLMS platform.

- **Professional Development:** Alpha offers workshops that help teachers to learn the value of 21st Century Skills, reach students of different learning styles by using differentiating instruction based on the 8 Multiple Intelligences, develop classroom management skills, understand formative and summative assessments, and use the NGSS EQuIP rubric.

- **Ongoing Training:** Alpha commits to maintaining a lasting relationship with our program users. We offer continuing consultancy visits to follow up, provide solutions, garner feedback, and offer additional professional development.

- **Teacher’s Summit:** Alpha brings teachers together throughout many regions to collaborate and delve into the latest best practices in education.
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Big Idea

Stars in the night sky show patterns of movement. The Sun is one of many stars within the Milky Way galaxy. All stars produce radiant energy in the form of waves.

Did you know?

Though there are many stars in the Milky Way (as many as 300 billion!), there are fewer stars in our galaxy than there are trees on Earth.
FOCUS SKILL: SUMMARIZE A PRIMARY SOURCE

A primary source is first-hand information or data from witnesses or participants in events. In science, primary sources are documents that provide information about original research or written by the original researchers.

When you summarize a primary source, you retell the information in your own words. You also put the information in a shorter form than it was originally given. The text below is based on a press release from the National Aeronautics and Space Administration (NASA) in the United States. It tells about a recent discovery made by NASA astronomers. Because the writer works with NASA scientists, the press release is considered a primary source.

Astronomers Find First Evidence of Possible Moon Outside Our Solar System

NASA astronomers have made an exciting discovery. They found evidence of a new moon. It appears to orbit a planet outside our solar system. The discovery could be the first of its kind. It could be the first moon found in another solar system.

This possible moon is 8,000 light-years from Earth in the Cygnus constellation. It orbits a gas-giant planet that, in turn, orbits a star called Kepler-1625.

The team spent 40 hours observing the planet with the Hubble Space Telescope. They studied the light coming from the planet and the way that light changed over time. Scientists observed the planet before and during its transit across the face of the star. After the transit, they detected a second and much smaller decrease in the star's brightness 3.5 hours later. This small decrease may suggest a moon trailing the planet.

In addition to this dip in light, Hubble provided more evidence for the moon hypothesis. The data showed that the planet transit occurred more than an hour earlier than they had expected. This is consistent with a planet and a moon orbiting a common center of gravity. Such a planet might wobble from its expected location.

The researchers note this wobble could be caused by the gravity of a second planet in the system. While scientists have not detected a second planet in the system, it could still be there.

Adapted from NASA press release 18-081, October 3, 2018

Apply Focus Skill: Imagine you read this press release and want to share the information with your friend. Summarize the press release in your own words. Possible answer: Check students' summaries.
Have you ever seen a solar eclipse? During a solar eclipse, the Moon moves between Earth and the Sun. This causes the sky to go dark, even in the middle of the day. In ancient times, people thought this was a sign of bad things to come. Over time, astronomers recognized patterns in the timing of eclipses. These patterns allowed them to predict future eclipses.

The Sun is the star at the center of our solar system. It is not the only star in the sky. On a clear night, you can see countless stars across the dark sky. Do these stars stay in one place? Are they spread randomly across the sky, or do they make patterns? Just as patterns in solar eclipses allowed astronomers to predict future eclipses, patterns of motion in other objects in the night sky are predictable, too.

Stars follow more than one pattern of motion. Maybe you have noticed that a single star moves across the sky throughout the night. Stars rise and set just like the Sun and the Moon. Also, which stars you can see at night changes depending on what time of year you look at the sky. This is another pattern of motion.

Observing patterns in things that can be seen and measured is an important part of scientific discovery. Scientists use patterns to make predictions about future events.
Predicting Solar Eclipses

Ask a question. How are scientists able to predict the date of solar eclipses?

1. The table shows the dates and locations of five recorded and predicted solar eclipses over a period of about 60 years. At what location do you expect the next eclipse to occur? What is the pattern in the time between each eclipse?

   Location C. 18 years, 10 days.

<table>
<thead>
<tr>
<th>Eclipse</th>
<th>Location A</th>
<th>Location B</th>
<th>Location C</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>March 3, 2001</td>
<td></td>
<td></td>
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<td>March 13, 2019</td>
<td></td>
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<td>3</td>
<td></td>
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<td>March 23, 2037</td>
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<td>4</td>
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<td>April 2, 2055</td>
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<td>April 12, 2073</td>
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<tr>
<td>6</td>
<td></td>
<td></td>
<td>April 22, 2091</td>
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</tbody>
</table>

2. Predict. Imagine you are an astronomer in the year 2080. On what date and in what year do you expect the next solar eclipse to occur? Add your answer to the appropriate row and column in the table.

The Saros Cycle

Thales of Miletus was an ancient Greek philosopher who lived between 620 BCE and 546 BCE. Thales contributed to many areas of science. Some of his most important contributions were to astronomy. Thales studied ancient records of past eclipses and observed that they occurred in a pattern. He used this pattern to predict an eclipse that occurred on May 28, 585 BCE. According to records of the event, soldiers in a war at the time were so struck by the eclipse that they ceased fighting. A peace treaty was signed soon after the eclipse.

Thales of Miletus used historical data to begin to observe what scientists now call the Saros cycle. A **Saros cycle** is a series of eclipses that occur in an identical period of time. This period of time lasts approximately 18 years, 10 days, and 8 hours. After this period, the cycle repeats and identical eclipses occur. Because of Earth’s rotation, the 8-hour variation means the location of the eclipse changes each cycle.
Moving Lights in the Sky

You know that you can see bright objects moving in the night sky. On rare occasions these include comets and meteors. More commonly, these objects are nearby planets, the Moon, and stars.

As they orbit the Sun, Earth’s neighboring planets form patterns in the night sky. You can see some planets at night with the human eye. They look like bright stars. You need telescopes to see other planets.

In 1781 British astronomer Sir William Herschel used a telescope to make observations of stars too faint to be seen with the human eye. On March 17, he noted something that appeared to be a star but moved too quickly. At first he thought it was a comet. He and other astronomers followed its movement through the sky. They used the movements to calculate its orbit around the Sun. They discovered that it could not be a comet. William Herschel had discovered a new planet: Uranus.

Patterns of motion are repeated throughout the universe. Astronomers believe that many planets form in the clouds of dust surrounding stars, just like they did around the Sun. Because planets in other solar systems are so far away, scientists cannot observe them directly. Recently scientists have found planets orbiting other stars by looking at the patterns of light from the stars. When a planet passes between Earth and its star, it blocks some of the star’s light. This causes the otherwise constant rate of light from the star to change. A graph can be made that shows these changes in light. Scientists use the graphs to identify where there might be planets in other solar systems.

Apparent Motion of Stars

Like planets, stars also appear to move through the night sky. Unlike the Moon and the planets, this is caused by the motion of Earth, not by the motion of the stars themselves. As Earth rotates about its axis, you see different parts of the sky. This means that from your point of view, the stars appear to move across the night sky.

As Earth orbits the Sun, its position relative to the Sun and the background of stars changes. Also, different parts of the night sky are visible at different parts of the year. This creates two patterns of motion. One occurs daily, as stars rise and set. The other happens each year, as Earth orbits the Sun.

Do all star patterns change from month to month? Explain.

Possible answer: No, not all star patterns change from month to month. The stars that are “above” Earth in this image would look the same all year round.
Have you ever thought the arrangements of stars in the night sky look like particular shapes? If so, you are not alone. Humans have seen shapes by imagining connections between stars in the night sky since they first looked up at the night sky. People often connect myths and stories to the images they see in the stars.

Today most of the constellations people identify in the night sky come from the ancient Greeks. A **constellation** is a group of stars that people agree form some shape or pattern. The ancient Greeks named constellations based on stories from their mythology. To them, the stars took on shapes of characters and objects from these stories.

Sometimes people identify asterisms within a constellation. An **asterism** is a smaller, recognizable pattern within a constellation. A common example is the “Big Dipper.” The Big Dipper looks like a large spoon in the sky. These stars are a smaller part of the larger constellation Ursa Major.

Scientists still use the names the Greeks gave to constellations. The International Astronomical Union recognizes 88 constellations. Together these 88 constellations cover the whole celestial sphere. Scientists use these constellations as a way to map the sky. Astronomers often identify stars by the constellation in which the star lies.

Tonight, look up at the sky and find stars that appear to make a shape. Sketch a picture and name your constellation. **Check students’ sketches for shapes found in stars connected by lines.**

▲ People use constellations as reference frames. They divide the sky into sections that observers on Earth can use when making observations in the night sky.

▲ The “Big Dipper” is an asterism within the constellation Ursa Major.
The seasonal pattern of motion of stars means that different constellations are visible at different times of year. Constellations along Earth's plane of orbit change with the seasons. The section of the sky you see in the summer is different from the section of the sky you see in the winter. For example, in the Northern Hemisphere the constellation Orion is only visible in the winter.

Not all constellations are affected by this pattern of motion. Some circumpolar stars are “above” or “below” Earth's plane of orbit in space. Circumpolar stars and constellations move in close circles around the North Star and never set. They are visible all year round. Ursa Major is one constellation in the Northern Hemisphere that can be seen in the summer and the winter.

This table shows the rise and set times for Aldebaran, a star in the constellation Taurus.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Rise time</th>
<th>Set time</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 16, 2018</td>
<td>9:51 p.m.</td>
<td>9:58 a.m.</td>
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<tr>
<td>November 20, 2018</td>
<td>9:36 p.m.</td>
<td>9:42 a.m.</td>
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<td>November 24, 2018</td>
<td>9:20 p.m.</td>
<td>9:27 a.m.</td>
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<td>November 28, 2018</td>
<td>9:04 p.m.</td>
<td>9:11 a.m.</td>
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<td>December 2, 2018</td>
<td>8:49 p.m.</td>
<td>8:55 a.m.</td>
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<td>December 6, 2018</td>
<td>8:33 p.m.</td>
<td>8:40 a.m.</td>
</tr>
<tr>
<td>December 10, 2018</td>
<td>8:17 p.m.</td>
<td>8:24 a.m.</td>
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</tbody>
</table>

Possible answer: The set time is always 12 hours and 7 minutes after the rise time; every 4 days, the rise and set times are 16 minutes earlier.

As Earth rotates about its axis, the stars in the sky appear to move. Each star traces a circle centered about the North Star. The North Star, or Polaris, sits directly above Earth's axis and does not move in the sky. Stars close to the North Star are always visible. Stars farther away rise and set and are only visible for short periods.

Imagine you are looking at the stars on a clear night. You find a constellation you particularly like near the horizon. Over the course of the night, it gets higher in the sky, then begins to set, and finally disappears over the horizon. A week later you return at the same time to see your favorite constellation. To your surprise, it has already reached its peak in the sky! Why is that?

As Earth orbits the Sun, our location on Earth's surface points to different places in the night sky. This causes different motion of the stars, separate from the motion caused by Earth's rotation. Because of this motion, stars rise about four minutes earlier every night. This also means the sky at night during the summer looks very different from the sky at night during the winter.
You may wonder, “If the stars move across the sky, how did ancient Greeks see the same constellations I see?” Over the course of a night, the stars move as a single mass. Their positions relative to one another are always the same. All the stars in the Milky Way, including the Sun, orbit around the center of the galaxy. This means that the Sun and the other stars are in the same reference frame. These stars move together at mostly the same rate. Because of this, from the perspective of Earth, it looks like all the stars move together at the same rate over the course of each night. And you see the same constellations that the Greeks saw 2,000 years ago.

However, within their own regions of the galaxy, all stars have their own motion, too. This motion is separate from the motion around the center of the Milky Way. Over time, these slight changes lead to the proper motion of stars. **Proper motion** is the apparent motion of nearer stars across the sky against the background of more distant stars. Proper motion occurs on large time scales and accounts for the shifting of stars in a constellation over 50,000 years.

You know that the apparent motion of stars through the sky each night is due to Earth’s rotation. You also know that Earth’s orbit around the Sun causes the apparent motion of the stars from season to season. Though it looks like the stars are moving, both of these changes are caused by Earth’s motion, not the actual motion of the stars. Proper motion is how you see the stars’ true motion.

Proper motion occurs on large timescales because stars are very far away. The star with the fastest proper motion is called Barnard’s Star. Relative to the other stars in its region of the Milky Way, Barnard’s Star moves at an incredible 110 kilometers per second. As seen from Earth, this motion appears much smaller. If you stretch out your arm and extend your pinky, it would take Barnard’s Star 350 years to cross the width of your pinky in the sky relative to the other stars.

Other long-term motion causes changes in the night sky. Currently, Earth’s axis in the Northern Hemisphere points toward the star Polaris, the North Star. The orientation of Earth’s axis slowly shifts and appears to trace out a circle in the sky. This motion is called precession. This process takes approximately 26,000 years. This means that far in the future, Polaris will no longer be the North Star.

Even rarer still, the night sky changes as a result of the life cycle of stars. Stars appear and die over periods of billions of years. Because not all stars are created at the same time, you may see stars now that are near the end of their lifetime. As they get older, their appearance changes or they may disappear. Like precession and proper motion, it is unlikely you will see these changes in your lifetime.
**Finding Other Planets**

**Ask a question.** Light curves are graphs made from the brightness of light measured from one specific star over a period of time. How can you use patterns in light curves to learn about other solar systems?

1. Think about patterns in the solar system. Imagine you are on another planet in a different solar system, observing the Sun. How might you observe some of these solar system patterns from this point of view? Remember that at that distance, you will not be able to see individual planets with a telescope.

   Possible answer: Distant observers of the solar system may be able to detect planets without directly seeing them. If one planet passes between the Sun and the observer, the pattern of light from the Sun will change.

2. **Explain** Below are light curves from two stars in the Milky Way. Time in days is shown on the x-axis, and relative brightness is shown on the y-axis. Which curve do you think shows a star with one planet orbiting it? Why?

   Possible answer: I think graph A shows a star with a planet orbiting it because that graph shows a light curve with a clear and significant periodic change in the amount of light. The light from the planet in graph B is relatively constant.

3. Imagine scientists use a light curve to determine a star has two planets orbiting it: one smaller planet and one more massive planet. What do you think the light curve for this planet looks like? Sketch the light curve.

4. **Conclude** Is using light curves a good method for finding planets outside the solar system? Why or why not? Discuss your thoughts.

   Possible answer: One possible issue with light curves is that there is a large room for error. Other objects between the star and the observer may cause a change in light similar to a star with a planet. Another issue is that it requires the planet to be orbiting such that it passes between Earth and the star. If a planet orbits a star but never passes between the star and the observer, it won’t show up in the light curve.

Accept all sketches that show a light curve with two sets of periodic spikes, one set notably longer than the other.
1. **Vocabulary** Use the vocabulary terms to complete the paragraph.

Stars can be identified by the ______ constellation ______ in which they are found. A smaller pattern of stars within this region is called a(n) ______ asterism ______. The stars appear not to move relative to each other because their ______ proper motion ______ is very small. The cycle of eclipses that repeats approximately every 18 years is called the ______ Saros cycle ______.

2. **Identify** Circle the patterns that are caused by the rotation of Earth.

- rising and setting of constellations
- proper motion of stars
- the phases of the Moon
- planets moving over the course of a night
- seeing different stars in different seasons

3. **Explain** Why do the stars rise and set each night but do so at different times each day?

Stars appear to rise and set each night because Earth spins on its axis. The time a certain star rises changes each night because Earth is also orbiting the Sun.

3. **Analysis** While there are some constellations only visible in the Northern or Southern Hemisphere, some constellations are visible in both. Why do you think that is?

As Earth rotates, stars closest to the North Star remain in the Northern Hemisphere. Stars further from the North Star rise and set, moving into the part of the sky visible from the Southern Hemisphere.
Dancing Stars

You have learned that nearly all the stars move across the sky every night. They also change position from one night to the next. Both of these motions follow patterns. Both patterns can be used to predict future motion of the stars. You can observe the stars over a few sequential nights to predict how the night sky will change in a few weeks.

1. **Ask a question.** Think about the night sky. Think about the ways stars move in the sky. Your goal is to predict how some constellations will change during one night. You will also predict how the night sky will change in a few weeks. Ask two questions about what you need to know about star motion in order to make these predictions.

   Possible answer: How long do I need to observe one constellation to predict its motion for the rest of the night? Do I need to observe more than one constellation to predict how the night sky will change in a few weeks?

2. **Make a plan.** Write down information about the types of observations you will make on your first night. Write down the observations you will need in order to make your long-term prediction.

   Possible answer: On my first night, I will record my observation location and the time of my first observation. I will draw the position of a few constellations in the sky. I will choose one constellation to watch for that night. I will draw a new picture of that constellation’s position in the night sky 20 minutes after my first picture. I will do this every 20 minutes for two hours. This will show me how the constellation moves through the sky over the course of one night.

   The next night, I will return to the same place at the same time as the first night. I will draw one picture of the same constellations. I will repeat this process for five nights. This will show me how the constellations move through the sky over a period of days.
3. **Record your observations.** Record your observations of the stars for the first night and for any later nights. Include drawings as part of your observations.

Accept all drawings that show detailed observations over the course of multiple nights.

4. **Make your prediction.** Sketch a picture of the sky the way you think it will appear one week, two weeks, and three weeks from tonight.

Accept all sketches that show a reasonable amount of critical thinking applied to the changes in the night sky over time.

5. **Check your prediction.** Return to the same observation location at the same time in one, two, and three weeks to observe and sketch the night sky. Keep a journal and check to see whether your predictions were correct. After three weeks, evaluate your predictions. How do your predictions compare to your actual observations of the night sky? What are the limitations of your predictions?

Possible answer: I was able to figure out the motion of the stars after a few nights. My predictions were mostly correct, but they were not exact. Some of the timings of my predictions were off. I predicted that some stars would disappear behind the horizon but they did not. One limitation of my predictions was I could not predict what stars would rise after my observations. There were stars below the horizon when I observed the sky that rose after my observation. It would be difficult for me to predict the parts of the sky that were not visible during my observation.
Gravity and Structure in the Universe

LESSON 2

You live on planet Earth. This planet has one moon and orbits the Sun. Earth, the Moon, the Sun, and seven other planets make up our solar system. Our solar system is just one such system in a large collection of stars called a galaxy. This galaxy is called the Milky Way.

What lies outside our galaxy? More galaxies! Many, many more galaxies. In fact, scientists estimate that there are about 200 billion galaxies in the universe. To put that into perspective, that is more than 25 times the number of people on planet Earth.

How can scientists learn about different galaxies if there are so many? They look for patterns. Scientists observe properties in one part of the universe and apply those properties to other parts. They also know that laws of physics that apply on Earth, such as gravity, also apply in other parts of the universe.

How can you estimate the number of dots? How can working with a smaller portion of the image help you make your better estimate?

Possible answer: I can divide the image into smaller sections and count the dots in one section. Then I can multiply that number by the number of sections to estimate the total.

The Hubble Deep Field is an image taken of about one 24-millionth of the sky. This image of a very small section of the sky includes nearly 3,000 galaxies.
Lesson 2  Gravity and Structure in the Universe

DIRECTED PRACTICE

Shape of a Galaxy

Ask a question. Galaxies usually form spiral shapes. Why?

1. **Predict**  Describe what you think will happen when you pour the sand into the tub of water. Describe how you think the sand will change when you start to stir the water.

   Possible answer: When I pour the sand into the water, it will sink to the bottom. When I stir the water, the sand will stay on the bottom but will move in a circle.

2. **Observe**  Pour the colored sand into the water. Place the spoon into the water and slowly begin to stir the water in a circle. Slowly increase the speed of your stirring. Be careful not to let any water spill over the edge of the tub. Stop stirring and pull the spoon out of the water. Continue to watch the sand. Describe how the sand reacted when you started to stir, when you stirred faster, and when you stopped stirring.

   Possible answer: When I began to stir the water, the sand started to move around the bottom of the tub. As I stirred faster, the sand spread out into a disk shape and lifted off the bottom. It continued to spin in a circle. When I stopped stirring, it slowed down and eventually came back to a pile in the middle.

3. **Conclude**  How do you think the sand in water relates to the shape of galaxies? Did the shape of the sand look similar to any pictures you have seen of space? Discuss your ideas with your classmates.

   Possible answer: When I pour the sand into the water, it will sink to the bottom. When I stir the water, the sand will stay on the bottom but will move in a circle.

A Structured Universe

You may have noticed that many systems in the universe look similar. Moons orbit planets. Planets orbit stars. Even stars orbit around a central point in the galaxy. It is no coincidence that all these systems look so similar.

The reason systems in the universe have similar structures is the same reason a baseball falls to the ground when you throw it but a satellite orbits Earth. All these interactions are affected by gravity. Gravity is the force all objects with mass exert on other objects with mass. The greater the mass, the greater the effect of gravity.

Gravity affects the orbits of human-made satellites in the same way it affects the orbit of Earth’s satellite, the Moon.

Earth formed as gravity pulled together elements orbiting the Sun when the solar system was young. Gravity holds Earth in orbit around the Sun. Gravity holds all the stars you can see in the sky together in the Milky Way galaxy.
A galaxy is a collection of stars, interstellar gas, dust, and the remnants of stars that are all bound together by gravity. A smaller galaxy may contain about 100 million stars. The largest galaxies contain as many as 100 trillion stars! Each star orbits around the same point at the center of the galaxy.

Measuring about 100,000 light-years in diameter, the Milky Way is a medium-sized galaxy. Its nearest galactic neighbor is the Andromeda galaxy. Andromeda is 2.5 million light-years away. On a very clear night in the Northern Hemisphere, you can sometimes see Andromeda in the sky even without a telescope. Both the Milky Way and the Andromeda are spiral galaxies. A spiral galaxy is a galaxy that contains a bulge, a disk, and a halo. Spiral galaxies are one of three types of galaxies.

The bulge of a spiral galaxy is the bright, spherical structure found at the center. The bulge contains mostly older stars. The disk includes the areas outside the bulge. The disk forms spiral arms and contains mostly dust, gas, and younger stars. The Sun is located in one of the arms of the Milky Way, about halfway from the center.

A less-dense, spherical halo of stars surrounds the disk. Because the stars are more spread out, this region is less bright than the bulge and the disk. As a result, images of spiral galaxies often show only the bulge and the disk. Scientists further classify spiral galaxies according to the shape of their arms. For example, they look at whether it has tightly wound arms. They also look to see if the arms emerge directly from the bulge or from the sides.

Label the different sections of the spiral galaxy.

In 1887 Isaac Roberts, an amateur Welsh astronomer, took the first photograph of the Andromeda galaxy. At that time, scientists believed Andromeda was a nebula, or cloud of gas, within our own galaxy. In the early twentieth century, an astronomer named Heber Curtis calculated the distance to Andromeda and found it could not exist within the Milky Way.
Another type of galaxy is an elliptical galaxy. An **elliptical galaxy** is a galaxy shaped like an elongated sphere. It is a bright mass of stars. The stars are brightest near the center and less bright near the edges. All the stars in a spiral galaxy move in generally the same circular direction. This is not true in an elliptical galaxy.

Spiral galaxies and elliptical galaxies differ in other ways, too. The stars in an elliptical galaxy tend to be older than those in a spiral galaxy. Elliptical galaxies are less common than spiral galaxies. Elliptical galaxies can vary greatly in size. The smallest elliptical galaxies are one-tenth the size of the Milky Way. The largest elliptical galaxies are some of the largest galaxies in the universe.

The third type of galaxy is an irregular galaxy. An **irregular galaxy** is a galaxy that does not have the clearly defined shape and symmetry of a spiral galaxy or an elliptical galaxy. They are usually much smaller than the other types of galaxies, too. Scientists classify irregular galaxies by how much structure they have. Many irregular galaxies were once spiral or elliptical galaxies. These galaxies have deformed, changing from spiral or elliptical in shape to irregular. This change in shape might be the result of uneven gravitational force or a collision with another galaxy.
Science is exciting because there are always new questions to be answered. Galaxy formation is one of the frontiers of modern astronomy. This means a lot of current research focuses on answering questions about how galaxies form. It is difficult for scientists to learn how galaxies form because the process happens over billions of years. Also, most galaxy formation occurred in the early universe.

In the early universe, there was gas and very little structure. There were no stars or planets. Small disturbances in the gas interrupted this uniformity. Because of gravity, matter attracted other nearby matter. This resulted in “clumps” of matter throughout the universe. Eventually the force of gravity became so great that stars formed within these clumps. Over time, small clusters of stars filled the universe. Again through the force of gravity, these clusters of stars pulled on other clusters. The clusters merged, forming galaxies.

Have you ever spun around holding an object tied to a string? The string extends and the object spins in a circle around you. A similar pattern of motion occurs as objects spin around each other in space. This is why most galaxies form round shapes.

What happens to galaxies after they form can affect the type of galaxy they become. Galaxies that do not interact with other galaxies are often spiral galaxies. These galaxies have a lot of gas in their arms where new stars are forming. Galaxies that merge with other galaxies tend to become elliptical galaxies. These galaxies contain very few areas for new stars to form.

Even today the Milky Way continues to develop and change. Its closest neighbor, the Andromeda Galaxy, is moving even closer. In approximately 4 billion years, the two galaxies will collide. They will form one larger galaxy. The stars in a galaxy are spread so far apart that it is unlikely any two stars will collide during the merger.

**Home Activity**

What questions do you think scientists ask when they want to learn new things about the universe? Skim news articles or websites to find a topic related to galaxy formation that scientists are studying today. Read about the research being conducted. Write a short report summarizing what you learned about this research. What question do you think scientists asked to lead them to this research?
**Math Skill: Use Ratios to Analyze Relationships**

The force of gravity is the result of the interaction of two or more masses at a certain distance apart. Gravity is directly proportional to the mass of an object. For example, an object with twice the mass will exert twice the gravitational force. As two objects move farther apart, they exert a weaker force of gravity on one another. Gravity is inversely proportional to the square of the distance. So, an object that is twice the distance away will exert one-fourth the gravitational force.

Imagine a star with the same mass as the Sun. Also imagine a planet with twice Earth’s mass orbiting this star at the same distance Earth orbits the Sun. If $G$ is the force of gravity on Earth and $r$ is the distance between Earth and the Sun, the force of gravity on this planet is:

$$G_2 = \frac{M_2}{r^2} = \frac{(2ME)}{r^2} = 2 \frac{M_E}{r^2} = 2G$$

Now imagine a planet with the same mass as Earth orbits this star but at three times the distance of Earth. The force of gravity on this planet is:

$$G_3 = \frac{M_E}{r_3^2} = \frac{M_E}{(3r)^2} = \frac{1}{9} \frac{M_E}{r^2} = \frac{1}{9}G$$

**Calculate** Complete the table. Use proportions to complete the missing information. Assume all planets in the table orbit stars the mass of the Sun. Distances are given in astronomical units, or AU. AU is defined as the distance between Earth and the Sun. Mass is given in Earth masses, $M$.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass ($M$)</th>
<th>Distance from star (AU)</th>
<th>Gravitational force (relative to Earth-Sun system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R772</td>
<td>8</td>
<td>4</td>
<td>0.5</td>
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<td>Earth</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Saturn</td>
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<td>10</td>
<td>1</td>
</tr>
<tr>
<td>X</td>
<td>18</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>G206</td>
<td>50</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Stella</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Jupiter</td>
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<td>5</td>
<td>12</td>
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</tbody>
</table>
Guided Practice

**Galaxies Coming Together**

**Ask a Question.** How does gravity impact galaxy formation at different stages?

1. **Explain** Summarize the steps of galaxy formation. Start with the early universe and describe both elliptical and spiral galaxies. Identify the role gravity plays at each step.

   Possible answer:

   1. Gas is spread throughout the universe. Very little gravitational interaction occurs because matter is uniform.
   2. Small disturbances cause the matter to form clumps. Matter forms clumps because as matter moves closer to other matter, gravity causes the matter to pull more strongly on each other.
   3. Enough matter comes together to cause stars to form. The force of gravity provides the energy needed to start star formation.
   4. Stars attract other nearby stars through the force of gravity, forming early galaxies.
   5. Galaxies that develop in isolation tend to form spiral galaxies. Gravity causes the spiral shape of these galaxies and places the stars in orbit around the bulge.
   6. Galaxies that merge with other galaxies tend to form elliptical galaxies. Gravity leads to these mergers, just like the matter clumps in step 2.

2. Design a flowchart that shows the steps of galaxy formation. Include branches where more than one path is possible. Include sketches and descriptions of what is happening, including the ways gravity plays a role in each step.

   Accept flowcharts that creatively include all details given in question 1 and identify the role of gravity at each step.
1. Vocabulary Use vocabulary terms. Identify the type of galaxy shown in each image.

- irregular galaxy
- spiral galaxy
- elliptical galaxy

2. Describe Your friend has never seen a picture of a galaxy. He knows there are three types of galaxies. How would you describe a spiral galaxy without showing him a picture?

   Possible answer: A spiral galaxy has a bright bulge in the center. A disk of stars surrounds the bulge. It looks like a pinwheel in the sky. A halo around the disk is less bright.

3. Conclude An astronomer discovers a new irregular galaxy. She observes many younger stars and gases that may lead to new star formation. What conclusions can she draw about this galaxy's past based on these observations?

   Possible answer: Irregular galaxies are often elliptical or spiral galaxies that were somehow deformed. Because this galaxy contains young stars, it was likely a spiral galaxy before it became an irregular galaxy. Elliptical galaxies contain older stars.
Home Sweet Home

The Milky Way galaxy is home to our solar system. Because we are inside the Milky Way, we cannot see our own galaxy from the outside. However, we can use what we know about other spiral galaxies to model our own galaxy.

1. **Ask a question.** Think about how you can model the Milky Way galaxy. What do you already know that will help you build your model? What additional information do you need to know to build the model? What questions might building a model help you to answer?
   
   Possible answer: I already know a spiral galaxy has a bulge, a disk, and a halo. Where in the Milky Way is our solar system located? How many spiral arms does our galaxy have?

2. **Make a plan.** How will you build your model? Make a list of materials you will need and explain the steps you will use to build your model.
   
   Possible answer: I will research more about the Milky Way to learn how many arms the galaxy has and where the solar system is located within those arms. I will build a simple model, using a paper plate to represent the halo around the galaxy. I will glue tightly packed cotton balls to the center of the plate to represent the bulge. I will make the disk out of loosely packed cotton balls. I will use a pin to mark the location of our solar system.
3. Explain the uses of your model. What questions can your model answer?

Possible answer: My model shows the three-dimensional shape of the Milky Way. A three-dimensional representation of a galaxy provides more detail than a two-dimensional image. My model can answer the question, Where in the Milky Way is our solar system located?

4. Draw a conclusion. What are the limitations of your model? How could you improve your model to reduce those limitations?

Possible answer: There are billions of stars in the Milky Way, so individual stars are not shown. While it would be impossible to include all the stars, I could make an insert for my model that shows the stars in a smaller area, such as the stars closest to our solar system.
Essential Question
How can you model the reflection, absorption, and transmission of light by different materials?

Warm Up
In what ways do you use light?

Vocabulary
absorption
diffraction
intensity
reflection
refraction
signal
transmission

The Speed of Light
When you turn on a lamp, you can see the light right away. It seems like this happens without any motion taking place. But light has a speed. In fact, the speed of light is the fastest speed in the universe. Nothing can go faster than light. This means when light is viewed on a small scale, like the size of a room, it looks like it travels in an instant. But in space, it takes light time to get from place to place.

If you have ever looked at pictures of objects in space, you have looked back into time. If an object is 100 light-years away, the light from the object took 100 years to get to you. This means that what you see is what the object looked like 100 years ago!

The people in this photo are far away. How could you get a better idea of what these people look like without getting closer to them?

Possible answer: If I used binoculars or a telescope, I could see these people better even from far away.
Guiding Light

**Ask a question.** How can you use mirrors to guide light around an object?

1. **Predict** Place the laser pointer at one end of a table. Stand the index card at the other end of the table directly across from the laser pointer. Place the piece of cardboard between the two so that it blocks the laser pointer’s path. How many mirrors will it take to redirect the light around the cardboard and to the index card? Check students’ answers. It is possible to redirect the laser with only two mirrors, though students may think they will need more.

2. Set up the small mirrors so that when you turn on the laser pointer, the light shines on the index card. Try to use as few mirrors as possible. How many mirrors did you use? Could you have used fewer? How do you know?

   Possible answer: I used three mirrors. I don’t think I could have used fewer. It took two mirrors to get the light around the corner and a third mirror to get the light back to the target.

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**MATERIALS**

- cardboard
- index card
- laser pointer
- small mirrors

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**Light Waves, Radio Waves, X-Rays, and More**

Microwaves and radio waves, just like the light waves from a lightbulb, are a type of electromagnetic radiation. Like all waves, electromagnetic waves transfer energy. In a microwave, this energy transfer cooks your food. In an X-ray machine, this energy transfer is used to see inside your body.

Light waves have the same properties as other waves. You can measure the wavelength, amplitude, and frequency of light. These wave properties correspond to different characteristics of different forms of light. The amplitude of light corresponds to its brightness. Wavelength and frequency correspond to the different types of electromagnetic waves. For example, light waves have a much higher frequency than radio waves.

Electromagnetic radiation can transfer information. Radio waves broadcast information many miles away. Electromagnetic waves travel from celestial objects into space and down to Earth. Astronomers use tools to capture these waves. They use the information they collect to learn about objects millions of light-years away.
Electromagnetic waves have the same properties as other waves. An electromagnetic wave has crests, troughs, and amplitude. In an electromagnetic wave, the amplitude relates to the wave's intensity. **Intensity** is a measure of the amount of energy the wave carries. A light wave with a high amplitude is much brighter than a light wave with a low amplitude.

The wavelength of an electromagnetic wave tells what type of electromagnetic wave it is. X-rays have a very short wavelength, with the largest X-rays having a wavelength of only 1 nanometer. (That is very small; consider there are 1 billion nanometers in 1 meter.) The longest electromagnetic waves are radio waves. Radio waves can have wavelengths as long as 1 kilometer or more.

Because electromagnetic waves all move at a fixed speed, it can be useful to talk about a wave’s frequency. Frequency is the number of cycles a wave makes per second. Frequency is inversely proportional to wavelength. Waves with a large wavelength have a very low frequency, and vice versa. Visible light has a frequency between 430 and 750 terahertz. One hertz is a unit equal to one cycle per second.

Other waves you have heard about, such as water and sound waves, are mechanical waves. This means they need a medium through which to move. Waves in the ocean move through water. Sound waves move through the air. But what about light waves? Many years ago, scientists thought there must be some medium through which light moves. However, now scientists know that electromagnetic waves are not mechanical waves. Light travels from stars, through space, to Earth. Because space is a vacuum, there is no medium carrying light in space.

**Visible Light Spectrum**

![Visible Light Spectrum Diagram]

Different wavelengths of visible light appear as different colors.
Reflection, Refraction, and Absorption

People use light in different ways. How light or other electromagnetic radiation is used depends on how the radiation interacts with matter. When radiation interacts with matter, it can reflect, refract, or absorb. Mirrors show a reflection because their surfaces reflect electromagnetic radiation. Glasses help people see by refracting electromagnetic radiation. Microwaves cook food because food absorbs electromagnetic radiation.

When an electromagnetic wave strikes matter, one form of interaction is absorption. **Absorption** occurs when a wave enters a new medium and the medium’s molecules vibrate. The object absorbs the incoming light. Because light carries energy, this causes the energy of the object to increase. This is how a microwave heats your food. The microwaves carry enough energy to raise the temperature of matter. This is also why sunlight feels warm on your skin. Your skin absorbs some of the sunlight. Sunscreen helps to prevent your skin from absorbing radiation that can be harmful.

Another form of interaction between electromagnetic radiation and matter is reflection. **Reflection** occurs when light bounces off an object. The law of reflection says that light will leave the object at the same angle it struck the object. At any given moment, all objects are both absorbing and reflecting light. You see different colors because of the way objects reflect and absorb light.

Though all objects reflect light, not all objects produce smooth reflections. You can see an image of yourself in a mirror but not in a wooden table. Non-reflective objects produce diffuse reflection. Because the microscopic surface is very rough, light is reflected in many different directions. Smooth surfaces such as glass reflect light in a single direction. This produces a clear image.

A third method of interaction between radiation and matter is transmission. **Transmission** occurs when light moves through an object. Both glass and water allow light to pass through them. However, an object looks different when seen through water than when seen through glass. This is because of refraction. **Refraction** occurs when light moves from one medium to another and the path of light bends. This can cause the resulting image on the other side to change. Lenses in eyeglasses, microscopes, and telescopes use refraction to improve the quality of an image.

You have probably seen a straw in a glass of water. The image of the straw underwater does not match up with the image of the straw above the water. Draw a picture of a straw in water and show the path of light from the straw to your eye. How does this explain what you see? **Accept all student drawings that show an understanding of refraction changing the direction of the path of light.**
Capturing Light

Scientists must understand the ways radiation interacts with matter in order to interpret electromagnetic signals. A **signal** is something—such as a wave—sent to relay information. At all times, an endless stream of electromagnetic radiation reaches Earth from objects in space.

Atmospheric opacity is the measure of how much light of a certain wavelength is absorbed by Earth's atmosphere. The symbol on the x-axis between nanometer and millimeter is micrometer. There are 1 million micrometers in a meter.

Scientists use reflection and refraction telescopes to magnify images of stars light-years away. Refraction telescopes use lenses to focus visible light into an eyepiece. They tend to be long and skinny. Reflection telescopes use a large mirror to reflect visible light to a single point. They use lenses to refract the light and focus it into an eyepiece or a camera.

Visible light is not the only way scientists can observe the universe. Celestial objects emit radiation in frequencies across the electromagnetic spectrum. With the right tools, scientists can measure this radiation. This helps them learn new things about objects they have observed in the visible spectrum. It can also allow scientists to “see” new objects that do not emit any visible light.

Infrared and ultraviolet radiation is close to visible light on the electromagnetic spectrum. In fact, most visible light telescopes can be used to detect infrared radiation, too. Infrared and ultraviolet images often look similar to visible light images of the same object. Radio waves and X-rays are different from visible light and require different equipment. Much of the research done on galaxy mergers is done in the radio spectrum.

Different types of electromagnetic waves affect observation in ways beyond the types of tools needed. Visible light and infrared light can easily pass through Earth's atmosphere. However, the atmosphere absorbs ultraviolet light at many frequencies. The atmosphere also absorbs X-rays at nearly all frequencies. Because of this, tools for ultraviolet or X-ray observation must be placed at high elevations.
Interpreting Signals from Space

You know that electromagnetic signals travel through space, enter the atmosphere, and then are observed with tools like telescopes. But how are these signals produced in the first place? Just like the Sun, other stars in the sky produce their own light. Nuclear processes in the cores of stars produce large amounts of energy. This energy is released as radiation.

All objects release some amount of electromagnetic radiation. This is called black body radiation. The intensity and wavelength of the radiation depends on the temperature of the object. Objects with higher temperatures release radiation with more energy and at a higher frequency. This is why metals glow when they are heated to very high temperatures.

Humans release radiation, too. However, you cannot see people glow. The average human body temperature emits radiation with a wavelength of about 10 micrometers. These wavelengths are too long to be seen with the human eye. Thermal cameras can detect infrared radiation, though. Thermal cameras can even see human bodies through certain types of barriers because of the radiation that living things emit.

Scientists can learn about stars by the kind of the radiation they emit. A star containing a lot of helium will emit different radiation than a star containing a lot of oxygen. Scientists use diffraction to look for the presence or absence of certain wavelengths of light in a signal from a star. Diffraction occurs when light goes through a prism and different wavelengths refract by different amounts. Scientists use this process to learn about the elements that make up a star’s structure.

Scientists can learn a lot about a star from its radiation. The wavelength of light emitted by a star also depends on its temperature. A hotter star has more energy than a cooler star, so it emits radiation of a higher frequency. This means hot stars appear blue and cool stars appear red.

Home Activity

Think about the path light takes when you look at a star through a telescope. Draw a picture of this path. Be sure to include the different ways light is reflected, refracted, and absorbed up until the point that it hits your eye. Show your drawing to a friend or a family member. Have him or her point out any parts of the drawing that are unclear.
Reading the Stars

Ask a question. A diffraction grating is a tool that splits light into its spectrum. Light of different wavelength is diffracted at different angles, so the different colors that make up a single source of light become visible.

1. Look at one source of light in your classroom through the diffraction grating. Describe what you see.
   Possible answer: When I looked at the lights in our classroom, I saw a single purple line, some blank space, then a wider blue line, smaller blank space, a wide green line, then even smaller blank space, and finally a region that was yellow and red of varying brightness.

2. Predict Select a different source of light in your classroom to observe, but do not use the diffraction grating yet. Do you think the spectrum from this light source will look similar to or different from the first light source?
   Possible answer: I think the computer will have the same spectrum as the lightbulb because both lights are produced with electricity.

3. Observe Use the diffraction grating to observe multiple light sources around your school. Make a sketch of each spectrum you observe. Be sure to note the different colors you see. How are the spectra similar and how are they different?
   Possible answer: Different lights show different colors. The spacing between the colors is also different for different lights. Some lights had very similar colors and spacing, but most were different.

4. Conclude What do you think the different spectra you observe tell you about the chemical makeup of the different light sources? How is this similar to the way astronomers use diffraction to analyze a star’s structure?
   Possible answer: I think the light sources with different spectra use different materials to produce the light. Scientists can use these spectra to determine what elements make up different stars by comparing their spectra to known spectra.
Lesson Review

1. **Vocabulary** Use vocabulary terms from the lesson to complete the sentences.

   The amplitude of an electromagnetic wave corresponds to the wave’s ________________ intensity ________________.

   The process by which light moves through an object is called ________________ transmission ________________.

   When radiation strikes an object, ________________ absorption ________________ causes the energy of the object to increase. ________________ Reflection ________________ contributes to the color of the object we see. ________________ Refraction ________________ occurs when light moves from one medium to another.

2. **Compare** Place the following types of radiation in order from highest energy to lowest energy: gamma rays, radio waves, visible light, ultraviolet radiation, X-rays, infrared.

   Gamma rays, X-rays, ultraviolet radiation, visible light, infrared, radio waves

3. **Explain** Many large telescopes are located at the tops of mountains. One of the most efficient telescopes, the Hubble Space Telescope, is in orbit in space. Why would scientists want to place telescopes in these remote locations?

   Possible answer: Even though visible light can pass through the atmosphere, the light still interacts with the atmosphere. This affects the quality of the image a telescope takes. At high elevations there is less atmosphere, so the images will be clearer. In space, the Hubble Space Telescope is above the atmosphere, so there is very little for the light to interact with before it reaches the telescope.

4. **Infer** Reflecting telescopes tend to be much larger than refracting telescopes. Why do you think this allows them to produce clearer images of objects in space?

   Possible answer: Reflecting telescopes use large mirrors to collect large amounts of light. More light allows for more information to be collected. This means the images will be clearer.
Hear It on the Radio

Radio waves are used to send signals across large distances. Most radio stations are split up into two categories: AM and FM. The M in both of these stands for “modulation.” AM radio waves vary in amplitude in order to transmit information. FM radio waves vary in frequency. The variations in the signal are picked up by an antenna and translated into whatever information the station sends out to the world.

1. **Ask a question.** Think about different ways a wave’s amplitude or frequency can interact with objects. How might these interactions affect radio waves? Think of a question to ask about the ways AM and FM radio may differ.
   
   Possible questions: Which of the two types of radio waves travels farther? Which is better at getting inside concrete structures?

2. **Make a plan.** Design an experiment. List the steps you will take to answer your question. Write the steps in the order you will complete them.

   Possible answer: Tune a car radio to an AM station. Tune a music player inside the car to an FM station.
   
   Move in one direction until I lose a signal.
   
   Note which signal is lost first.
   
   Find a large concrete structure, such as a parking garage.
   
   Tune a portable radio to an AM station.
   
   Walk to the middle of the garage, and then underground, until I lose a signal.
   
   Switch to an FM station.
   
   If it still has a signal, go deeper until I lose the signal.
   
   Otherwise, walk out of the structure until I regain the signal.
3. **Record your observations.**

   Possible answer: In my first experiment, the FM station was lost a long time before the AM station. In the second experiment, I lost the AM station fairly quickly when I entered the parking garage. However, when I switched to an FM station, the signal was still there and strong.

4. **Draw a conclusion.** Summarize what you learned from your investigation. What did your investigation tell you about the different types of radio waves? Explain.

   Possible answer: I learned that AM and FM waves have different properties. AM radio waves can travel across longer distances because the FM radio station was lost long before the AM station. FM radio waves are better at going through solid objects because the FM radio station worked inside the parking garage but the AM station did not.
First Malaysian Astronaut

Sheikh Muszaphar Shukor Al Masrie is the first Malaysian astronaut. He is also an orthopedic surgeon. In 2006, the Malaysian government selected Sheikh Muszaphar as one of three finalists for the Malaysian Angkasawan spaceflight program. This program, a joint venture with the Russian Federation, selected a Malaysian to send to space. The Malaysian government started the program as a way to get younger Malaysians excited about math and science. While aboard the International Space Station (ISS), Sheikh Muszaphar performed experiments on the growth of different cancer cells in space.

The ISS has housed scientists from countries around the world since November 2000. The ISS allows scientists to conduct research in many different fields. Because astronauts live on the station, they can study the long-term effects of low-gravity environments on the human body. The ISS may also be used as a staging base for future human exploration deeper into space.

How might Sheikh Muszaphar’s research on the ISS benefit scientists on Earth?
Possible answer: Research on the ISS may benefit scientists on Earth because there may be conditions they can simulate in space that are difficult to research in a laboratory. This may allow scientists to answer questions they were unable to answer in laboratories on Earth.

If your country had a competition to select someone to go to space, would you want to enter? Why or why not?
Possible answer: Yes, I would want to enter this competition. I think going to space would be an exciting opportunity to learn more about outer space, which is a type of science that interests me.
2.1 Motion in the Night Sky

- Earth’s rotation and orbit cause patterns of motion of the stars in the sky. These patterns change from night to night, as well as over the course of a year.
- Patterns of motion caused by the motion of the stars themselves are only visible over very long timescales of around tens of thousands of years.
- For centuries humans have identified patterns of stars in the sky called constellations. Scientists use constellations to divide the sky into distinct regions.

2.2 Gravity and Structure in the Universe

- Gravity controls the motion of the stars in the Milky Way galaxy just as it controls the motion of the planets in the solar system and the Moon around Earth.
- Scientists divide galaxies into three categories—spiral, elliptical, and irregular—based on their shape and how they were formed.
- Many galaxies were formed in the early universe as gravity pulled together gas to make stars, then stars to make galaxies.
- Galaxies that form in isolation tend to be spiral galaxies and have regions with active star formation. Galaxies that form from galaxy mergers tend to be elliptical galaxies and have little star formation.

2.3 Light from Space

- Light has many properties of other waves, with amplitude corresponding to intensity and wavelength corresponding to frequency and color.
- Scientists use tools to reflect, refract, and absorb light and other forms of electromagnetic radiation from space to study celestial objects.
- Stars emit different wavelengths of light depending on their temperature and chemical makeup.
Chapter 2
Stars and Light

Chapter Review

1. Vocabulary Complete each sentence with the correct term.

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<th>absorption</th>
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A Objects in a microwave heat up because of absorption.

B The image of a straw underwater appears to break at the surface because of refraction.

C Scientists use diffraction to analyze a star’s light and determine its chemical makeup.

D A pattern of stars in the sky about which people tell stories is a constellation.

2. Describe Give a brief description of each type of galaxy.

Spiral galaxy: a spherical, bright, central region called a bulge surrounded by a disk that forms spiral arms; a halo surrounds the disk.

Elliptical galaxy: a roughly spherical collection of stars that is bright at the center and less bright as you move outward.

Irregular galaxy: a collection of stars with no symmetry.

3. Calculate Venus is about \( \frac{3}{4} \) the mass of Earth and about \( \frac{3}{4} \) the distance from the Sun as Earth. How strong is the pull of the Sun’s gravity on Venus relative to Earth?

\[ \frac{4}{3} \]

4. Identify Imagine you are an astronaut on another planet that has one moon. You arrive during a solar eclipse in 2021. There are solar eclipses again in 2024, 2027, and 2030. It is now 2031. When do you expect the next solar eclipse to occur? How do you know?

2033. Past eclipses happened every three years and the last eclipse happened in 2030.
5. **Explain**  When you made observations of the night sky over multiple nights, you went outside at the same time every night. Why was it also important to view the sky from the same location?

Possible answer: The view of the sky changes depending on a person’s location on Earth. This changes the most from the Northern Hemisphere to the Southern Hemisphere. The sky can also look different at the same time within the same hemisphere.

6. **Infer**  How does a change in position on Earth from east to west affect your view of the sky? Is this the same as the change from north to south?

Possible answer: If you look at the sky at 10PM in the east and then look at the sky when it is 10PM in the west, it will look the same. But if you change position from east to west very quickly, the sky will look different. This is because of Earth’s rotation. This difference in what you see due to a change in position from east to west is not the same as the difference in what you see due to a change in position from north to south.

7. **Explain**  Why is it useful to divide the sky into regions based on constellations? Could scientists use a coordinate system to track locations in the sky?

Possible answer: It is useful to divide the sky into regions based on constellations because it allows scientists to locate where in the sky a star is found, even as the stars move through the sky. It would be difficult to use a coordinate system on the sky because the sky is not flat. Also, the sky changes over time. The constellation moves with the stars, so a star’s position in a constellation does not change as the stars move across the sky.
In this chapter you learned about patterns in the night sky. You also read about how observing these patterns can help people make predictions. Telescopes are a common tool used to make observations of the night sky. Telescopes are an important achievement in optical engineering.

Have you ever looked through a telescope? What sorts of things did you see? If not, what things would you expect to see with a telescope? Telescopes can be used to observe things on Earth as well as in space.

Many different design considerations go into making a telescope. The most efficient tool is designed specifically for the task at hand. What sort of telescope would you want to use to track the motion of planets in the sky? Could you use the same telescope to track the motions of stars and galaxies?
Your Task

A converging lens is a refracting lens that causes light to focus to a single point. A magnifying glass is one example of a converging, or convex, lens. You will use converging lenses to build your own telescope. You can use the telescope in a classroom setting to calculate the telescope's magnification. Then you can take the telescope out at night and use it to make your own observations of the night sky. You will need to model your design and decide what observations of the sky you want to make.

Identify the Problem

1. What is your task in this activity?
   
   Possible answer: I will design a telescope that can be used to observe the night sky.

2. What tools will you need for this activity?
   
   Possible answer: I will need multiple lenses, something to construct the body of my telescope, and something to hold the parts together, such as tape and glue.

3. What are your design constraints?
   
   Possible answer: I can only use lenses to construct my telescope. I know that reflecting telescopes also use mirrors, but I will be making a refracting telescope.

Research

4. What are the different parts you need to include in your telescope?
   
   Possible answer: My telescope needs to have a larger lens and an eyepiece. It also needs to have a body. The body or the eyepiece must be able to move in some way so I can focus the image.

5. What factors go into determining a telescope's magnification?
   
   Possible answer: The magnification of a telescope is related to the ratio of the focal length of the two lenses.

6. What observations of the night sky would you like to make once your telescope is complete?
   
   Accept all answers that show desired observations motivated by scientific inquiry.
Develop Multiple Models

7. One design for your telescope uses a single cardboard mailing tube with a large lens at one end and a smaller lens at the other for an eyepiece. Explain what other materials you would need, how you might construct such a telescope, how you would attach the eyepiece to the tube, and the advantages of this design.

Possible answer: I would apply glue to the edges of the larger lens and fit it on one end of the mailing tube. I would use another piece of cardboard in a funnel shape to create an eyepiece, with the lens on the smaller end and the cardboard tube attached to the larger end. One advantage of this design is it requires few materials.

8. Another design for your telescope uses two different-sized tubes made with manila folders. A large lens is fitted at one end and a smaller lens is fitted at the end of the other-sized tube for an eyepiece. Explain what other materials you would need, how you might construct such a telescope, how you would attach the eyepiece to the tubes, and the advantages of this design.

Possible answer: I would tape the two manila folders into two tube shapes, making one smaller than the other so that it can fit inside the larger tube. I would apply glue to the edges of the larger lens and fit it on one end of one manila folder. I would use another piece of folder in a funnel shape to create an eyepiece, with the lens on the smaller end and the manila tube attached to the larger end. One advantage of this design is that the distance between the two lenses can be adjusted so that the image in the telescope can be focused.

9. A third design for your telescope uses two different-sized cardboard mailing tubes. A large lens is fitted at one end and a smaller lens is fitted at the end of the other-sized tube for an eyepiece. Explain what other materials you would need, how you might construct such a telescope, and the advantages of this design.

Possible answer: I would place the smaller mailing tube inside the larger one, making sure it could slide up and down. I would apply glue to the edges of the larger lens and fit it on one end of the larger tube. I would use another piece of cardboard in a funnel shape to create an eyepiece, with the lens on the smaller end and the smaller mailing tube attached to the larger end. One advantage of this design is that the distance between the two lenses can be adjusted so that the image in the telescope can be focused. The cardboard mailing tubes are also a stronger material than manila folders.

10. Evaluate the three designs. Which do you think would make the most effective telescope? Which do you think would be easiest to build? Consider these factors, as well as any others you can think of, and select the design you want to build.

Accept all reasonable answers and explanations based on logical reasoning.
**Build and Test Your Model**

11. How will you test your telescope to calculate its magnification? List your steps below.

   Possible answer: I can set up a board with equally spaced lines. I will stand across the room from the board. I will look through my telescope with one eye and look at the lines with my other, unaided eye and note how many lines I see. I can then calculate the magnification using the focal lengths of the lens and see how these numbers compare.

12. Using the tools you listed in your design, construct your telescope. Then follow the steps you listed in the previous question to calculate your telescope’s magnification. Include both your data and your final results below.

   Accept all answers that show thorough data collection and analysis.

13. Evaluate your telescope design. Are there changes you could make to improve your design? Are these changes necessary to make your observations?

   Possible answer: Some light gets in between the two different-sized tubes and messes up my image. I could improve my design by finding a slightly larger inner tube that allows less light through. These changes are not necessary to make my observations because there will be less environmental light when observing the sky at night than in the classroom.
Use Your Model in the Field

14. How will you use your telescope to make observations? Can you make observations over the course of one night? Will you need to make observations over multiple nights? If you make observations over multiple nights, what factors will you need to consider?

Accept all answers that show observation patterns and methods effectively tailored to what the student has chosen to observe.

15. Take your telescope outside and begin to make your observations. Use the space provided below and on the next page for taking notes and making sketches of your observations.

Accept all accurate and detailed sketches and field notes.
Evaluate Your Model Further

16. Now that you have used your telescope for observations, evaluate your design further. Did you notice things about your design that you did not consider in the classroom? How might you improve your telescope design now?

Possible answer: I discovered that my telescope design was less sturdy than I expected after multiple observations. If I were to use my telescope again, I could improve the design by using stronger materials or finding a more effective way of holding the pieces together.
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<td>Lesson 2 Mutations</td>
<td>MS-LS3-1</td>
<td>LS3.B</td>
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<td>Developing and Using Models</td>
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<td>Lesson 3 Pedigree Charts</td>
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<td><strong>Chapter 7 Populations: Change Over Time</strong></td>
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<td>Lesson 1 Natural Selection</td>
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<td>Lesson 2 Genetic Changes in Populations</td>
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<td>Obtaining, Evaluating, and Communicating Information</td>
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<td><strong>Chapter 8 Environmental Adaptation and Change</strong></td>
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<tr>
<td>Lesson 1 Adaptations and Environments</td>
<td>MS-LS4-6</td>
<td>LS4.C</td>
<td>Cause and Effect: Mechanism and Explanation</td>
<td>Using Mathematics and Computational Thinking</td>
</tr>
<tr>
<td>Lesson 2 Adaptations to Changing Environments</td>
<td>MS-LS2-4</td>
<td>LS2.C</td>
<td>Stability and Change</td>
<td>Engaging in Argument from Evidence</td>
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<td>Lesson 3 Catastrophic Changes</td>
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<td><strong>Chapter 9 Biodiversity</strong></td>
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<tr>
<td>Lesson 1 The Importance of Plant Biodiversity</td>
<td>MS-LS2-5</td>
<td>LS4.D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lesson 2 The Importance of Animal Biodiversity</td>
<td>MS-LS2-5</td>
<td>LS4.D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lesson 3 Maintaining Biodiversity</td>
<td>MS-LS2-5</td>
<td>LS2.D</td>
<td>Stability and Change</td>
<td>Engaging in Argument from Evidence</td>
</tr>
<tr>
<td><strong>Chapter 10 Environmental Change</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lesson 1 Human Impacts on Ecosystems</td>
<td>MS-ESS3-3</td>
<td>ESS3.C</td>
<td>Cause and Effect: Mechanism and Explanation</td>
<td>Constructing Explanations and Designing Solutions</td>
</tr>
<tr>
<td>Lesson 2 Populations and Resources</td>
<td>MS-ESS3-3, MS-ESS3-4</td>
<td>ESS3.C</td>
<td>Cause and Effect: Mechanism and Explanation</td>
<td>Engaging in Argument from Evidence</td>
</tr>
<tr>
<td>Lesson 3 Global Climate Change</td>
<td>MS-ESS3-5</td>
<td>ESS3.D</td>
<td>Stability and Change</td>
<td>Asking Questions and Defining Problem</td>
</tr>
</tbody>
</table>
First discovered in Germany in 1860, *Archaeopteryx* is one of the oldest known fossils with feathers. *Archaeopteryx* lived 150 million years ago in the age of dinosaurs. *Archaeopteryx* had characteristics of both birds and dinosaurs. In addition to feathers, it had teeth, a long bony tail, and claws on its wings.
FOCUS SKILL: MAIN IDEA AND DETAILS

Identifying important information can help you understand text passages about science topics. To pinpoint important information, first identify the **main idea**. The main idea is the central point of a reading passage. It is not always stated directly in the text. Next, look for details. **Details** support the main idea.

An Incomplete Record

Fossils tell about the history of life on Earth. There are not fossils for all species that have ever existed, though. There are likely many species that were never fossilized or that humans have not yet found. The fossil record provides glimpses at certain forms of life at certain points in time.

Fossil formation occurs only rarely. Special conditions must be met for fossils to form. For example, some fossils form when sediment buries organisms soon after they die. This happens under volcanic ash and under mud from flooded rivers. Volcanic eruptions and floods do not happen every day.

Not all body parts form fossils. Usually the hard structures, such as bones, teeth, and shells, are preserved. Other parts will more likely break down before forming fossils. Species without hard body parts are unlikely to leave a trace.

Many old fossils lie deep beneath the ground. The movement of tectonic plates may lift fossil-containing rocks to the surface. This exposes the rocks to erosion. Over time, erosion uncovers the fossils. Then fossils can be found near Earth’s surface. Fossils deep inside Earth are less likely to be discovered.

Apply Focus Skill: Read the text above. Then fill in the graphic organizer with the main idea and details.

Main Idea
Possible answer: Fossils give incomplete evidence for a history of life on Earth.

Possible answer: Certain conditions must be met for fossils to form.

Possible answer: Not all kinds of organisms or parts of organisms form fossils.

Possible answer: Fossils deep beneath the ground are less likely to be discovered than those at the surface.
Warm Up
What clues about the past can you get from a fossil?

Vocabulary
biodiversity
chordate
cyanobacteria
microfossil
paleontologist

Essential Question
How are fossils used to learn about the history of life on Earth?

Pictures of the Past
To the untrained eye, fossils might look like ordinary rocks. But to a trained scientist, they are much more than that. They paint a picture of past organisms and environments that often look different from current organisms and environments. The more fossils scientists find, the clearer the picture becomes.

When a Moroccan fossil collector showed scientist Nizar Ibrahim a box of fossils, Ibrahim knew one of them was special. Years later he would realize just how special it was. In 2014 the fossil collector led Ibrahim and his team to the site where the fossil was found. It was in the middle of the Moroccan Sahara desert. The team unearthed several more fossils. The fossils came from a dinosaur called Spinosaurus. They were about 100 million years old.

*Spinosaurus* was a large predatory dinosaur. The first *Spinosaurus* fossils were discovered by Ernst Stromer in Egypt in 1912, but the fossils were destroyed during World War II. Since that time, *Spinosaurus* had eluded scientists.

Ibrahim and his team dug up many *Spinosaurus* bones. With the help of Stromer’s original drawings of his discovery, they used the bones to reconstruct its skeleton. The skull was shaped like a crocodile’s, with sharp, cone-shaped teeth. Its back had a structure like a sail on top of it. Its hip bones were narrow. The bones in its feet were shaped like paddles. The scientists made an incredible conclusion: *Spinosaurus* could swim. This would be the first dinosaur known to live in water.

In the paragraph above, underline the sentences giving evidence that *Spinosaurus* lived in water.

*Spinosaurus* was an enormous predatory dinosaur. It lived in North Africa’s prehistoric rivers and swamps.
Lesson 1  Evidence from the Fossil Record

DIRECTED PRACTICE

Interpreting the Fossil Record

Ask a question. What can you learn from fossils in rock layers?

The diagram shows fossils found in rock layers at a dig site. Use the diagram your teacher supplies to answer the questions.

1. Sequence Which fossils are oldest? Which are youngest? Put the fossil types in order.

<table>
<thead>
<tr>
<th>Oldest</th>
<th></th>
<th>Youngest</th>
</tr>
</thead>
<tbody>
<tr>
<td>ammonite</td>
<td>clam</td>
<td>dinosaur</td>
</tr>
<tr>
<td>trilobite</td>
<td>fish</td>
<td>plant</td>
</tr>
</tbody>
</table>

2. Analyze How has life at the dig site changed over time? How do you know?

   Possible answer: Life has changed from simpler organisms like trilobites and ammonites to more complex organisms like plants, birds, and mammals. I know because the fossils in the older rock layers are different from the fossils in the younger rock layers.

3. Infer How might the environment have changed between layers B and D? Use fossil evidence from the diagram to support your answer.

   Possible answer: The environment changed from aquatic to terrestrial. The fossil record shows a change from aquatic life-forms to terrestrial life-forms.

Fossils Give Clues

Scientists like Nizar Ibrahim are paleontologists. A paleontologist is a scientist who studies fossils to learn what past organisms looked like and how they lived. Fossils also provide evidence about how living things and environments have changed.

When paleontologists find a fossil, they note the location of the fossil site. They may remove the fossil for further study. This requires slow and careful work. Paleontologists observe the rock layer in which a fossil occurs. They may take samples or record notes about it. They may record information about rock layers above or below the fossil, too. The location and layer of rock in which the fossil was found allow paleontologists to determine the age of the fossil.

What tools might a paleontologist use to study fossils at a fossil site?

Accept all reasonable responses. Possible answers: hammer, shovel, digging machine, chisel, paintbrush, ruler, magnifying lens.
Recall that the set of all fossils together is called the fossil record. To determine the age of fossils, paleontologists refer to superposition and index fossils, and they use radioactive dating. Then they order the fossils by age to reconstruct the history of life on Earth.

Scientists noticed that different types of fossils appear in different strata. Major changes in fossils occur at specific rock strata around the world. Scientists used this evidence to mark boundaries between major segments in geologic time.

The oldest fossils are microfossils. Microfossils are fossils that are too small to be seen without a microscope. Microfossils first appeared in the Archean Era more than 3,500 million years ago (mya). These fossils document Earth’s earliest known living things. There is evidence that life began earlier than this. The first organisms probably did not leave behind fossils, though.

Near the end of the Archean, fossils of simple cells became more common. These fossils resembled modern bacteria called cyanobacteria. Cyanobacteria are bacteria that perform photosynthesis. Earth’s first oxygen most likely came from unicellular organisms like these.

During the Proterozoic Era, cyanobacteria became more common. Fossils of more complex cells began to appear in the fossil record. Multicellular organisms appeared, too. These included algae and the first animals.

- **When did cyanobacteria first emerge?**
  Cyanobacteria emerged near the end of the Archean Era, more than 2,500 million years ago.

- **How did the complexity of organisms change during the Proterozoic Era?**
  Possible answer: More complex cells and multicellular organisms, including algae and the first animals, appeared in the fossil record.
The term **diversity** means “variety.” When paleontologists study fossils, they learn about changes in biodiversity. **Biodiversity** is the variety of living things on Earth or in a particular habitat or ecosystem.

The Precambrian Era did not have much biodiversity. At the beginning of the Paleozoic Era, about 542 MYA, this changed. In a relatively short period of time—about 50 million years—a large number of new species emerged. Because of the rapid emergence of so many species, this period is called the Cambrian explosion. In the Cambrian explosion, the ancestors of almost all modern animal groups emerged.

**How could you measure biodiversity?**

**Possible answer:** by counting the number of different species or the number of groups of organisms in an area

Most animals that lived during the Cambrian were invertebrates, or animals without backbones. Near the end of this period, chordates appeared. **Chordates** are animals that have a flexible support rod called a notochord. All vertebrates, animals with backbones, are chordates.

A variety of vertebrate chordates emerged during the Paleozoic and Mesozoic. The diagram on this page shows the successive appearance of fish, amphibians, reptiles, mammals, and birds in the fossil record. Notice that each later group of organisms shows some characteristics from the previous group plus additional characteristics. The organisms get more complex over time. For example, all the animals that appear after chordates have backbones.
The fossil record indicates an overall increase in the complexity of organisms. It also shows a transition from aquatic to terrestrial life-forms over time. Life on land is relatively recent. During Precambrian time, all life was aquatic. The first terrestrial life appeared in the fossil record during the Paleozoic Era.

The fossil record also provides evidence that biodiversity has increased over Earth's long history. Yet most fossils are the remains of extinct species. Increases in biodiversity have had five major setbacks. The ends of the Ordovician, Devonian, Permian, Triassic, and Cretaceous periods were marked by mass extinctions.

Volcanic eruption, climate change, and asteroid impacts can contribute to mass extinctions. During a mass extinction, biodiversity decreases. The largest mass extinction in Earth's history took place at the end of the Permian Period. It is estimated that 90 percent of Earth's species died out in a short period of time.

The most recent mass extinction occurred at the end of the Cretaceous Period. This event marked the end of the age of dinosaurs in the Mesozoic. The disappearance of the dinosaurs may have allowed for the rise of mammals in the Cenozoic Era.

What can cause a mass extinction?
Possible answer: an asteroid impact, volcanic eruptions, climate change

Home Activity
Draw several ancient organisms from the fossil record on separate pieces of paper. Use the pages of a thick book to model rock strata. Place the pieces of paper in the book at the appropriate locations to represent the fossil organisms. Using the model, explain to a friend or family member how paleontologists use fossils to reconstruct the history of life.
Math Skill: Construct Functions

Marine fossils such as trilobites are found in the Bright Angel Shale of the Grand Canyon in the United States. This rock layer was formed during the middle of the Cambrian Period. It is about 100 meters thick.

Suppose you and a group of paleontologists found several fossils at different depths within this layer of rock. The table lists the depths at which the fossils were found. The ages of some of the fossils are known. It is your job to estimate the ages of the remaining fossils.

<table>
<thead>
<tr>
<th>Fossil</th>
<th>Depth (meters)</th>
<th>Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>505 million (505,000,000)</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>507 million (507,000,000)</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>508 million (508,000,000)</td>
</tr>
<tr>
<td>D</td>
<td>70</td>
<td>512 million (512,000,000)</td>
</tr>
<tr>
<td>E</td>
<td>80</td>
<td>513 million (513,000,000)</td>
</tr>
<tr>
<td>F</td>
<td>100</td>
<td>515 million (515,000,000)</td>
</tr>
</tbody>
</table>

1. Use words to describe how the age of these fossils is related to the depth at which they are found. What is the rate of change?
   
   Possible answer: Age increases with depth. For every 1 m of depth, the age of the rock increases by 100,000 years starting at 505 million years old.

2. Use the data to write a function that represents how age changes with depth. Use the variable $A$ to represent the age of the fossil and $D$ to represent the depth.
   
   Possible answer: $A = (100,000 \times D) + 505,000,000$

3. Use the function you wrote to solve for the missing ages. Add them to the table.

4. Use the function to determine the depth at which you would expect to find a 507,500,000-year-old fossil.
   
   $507,500,000 = (100,000 \times D) + 505,000,000$
   
   $2,500,000 = 100,000 \times D$
   
   $\frac{2,500,000}{100,000} = D$
   
   $D = 25$ meters
A genus is a grouping of similar species. The graph shows how the number of marine genera (singular: genus) has changed over time.

**Ask a question.** How has marine biodiversity changed over time?

1. **Identify**  Draw arrows on the graph to note each of the five major mass extinctions.

2. **Infer** How might scientists have determined the number of marine genera over Earth’s history?

   Possible answer: by grouping and counting similar fossil types in rock layers that were once covered by seawater.

3. **Analyze** What patterns does the graph show?

   The graph shows an overall increase in the number of marine genera over the past 550 million years. The graph shows five mass extinctions in which marine genera decreased significantly. After each mass extinction, the number of marine genera increased and then the biodiversity ultimately exceeded all previous levels.

4. **Predict** Make a prediction about marine biodiversity in the future.

   Explain your prediction.

   Possible answer: Climate change will lead to warmer ocean temperatures. Some species may adapt to warmer sea water, but others may not. If people do not develop new technologies to reduce global warming, there might be a sixth major extinction in which marine biodiversity will decrease.
Lesson Review

1. **Vocabulary** Use the vocabulary terms from the lesson to complete the sentences.

   A scientist who studies fossils to learn about past life-forms is a(n) [paleontologist](#).

   The oldest fossils in the fossil record are [microfossils](#). Unicellular photosynthetic organisms called [cyanobacteria](#) added oxygen to the atmosphere. In the Cambrian Period, there was a rapid increase in [biodiversity](#).

2. **Identify** Circle the best answer.

   (a) The sudden disappearance of many species from the fossil record is evidence that [a mass extinction event took place](#).

   biodiversity has increased
   fossil complexity increased
   the organisms never existed

   (b) What pattern does the fossil record show over many hundreds of millions of years?

   decreasing complexity of living things
   increasing complexity of living things
   increasing environmental stability
   decreasing number of species on land

3. **Summarize** How has life on Earth changed over time?

   Possible answer: Life has become more complex and more diverse over time. First, only unicellular organisms existed. More life-forms emerged in later eras. These included more complex life-forms such as reptiles and mammals. Life has also transitioned from only aquatic organisms to both aquatic and terrestrial species.

4. **Apply** You discover a new fossil. How does the location it was found help you learn more about it and where it fits in the history of life?

   Possible answer: The age of the rock in which it was found would help me determine how old it is. The age of the fossil will give me clues about what type of organism it might be because different groups of living things emerged at different times.

5. **Analyze** The diagram shows fossils in rock layers. Use the diagram to explain both how living things and the environment have changed over time.

   Possible answer: The lowest and oldest layer has only marine invertebrates. This suggests that the environment was covered by a sea long ago. More recently, marine vertebrates emerged, including fish. The more recent rock layers include vertebrates that lived on land.
Fossil Evidence

Many of the different types of organisms that have existed throughout history are represented by fossils. Some fossil organisms appear very different from organisms living today. Others appear similar to living organisms. Think about the fossils you have read about and observed. Then decide on a question you would like to explore in more detail.

1. **Ask a question.** Choose a group of fossil organisms to research. Examples of fossil groups include trilobites, dinosaurs, flowering plants, and mammals. Ask a question about the group of organisms. The question should be one you can answer by doing research, making observations, or both.
   
   Possible question: What kinds of dinosaurs lived in Africa?

2. **Make a plan.** What information do you need to answer your question? How will you access the information? Use the space below to plan your investigation. Discuss how you will ensure that you have multiple high-quality sources of information. Explain how you will summarize your findings.
   
   Possible answer: I will need access to a library or a computer with internet access. I will need access to fossil images, too. I will search for at least three government or educational resources on this topic. I will take notes on African dinosaurs, including the types of dinosaurs that lived there and when and how they lived. I will compile the most important information in a table.
3. **Communicate.** Summarize your findings in the space below.

<table>
<thead>
<tr>
<th>Dinosaur</th>
<th>Classification</th>
<th>Where, when, and how it lived</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mansourasaurus shahinae</td>
<td>sauropod (titanosaur): large, long-necked dinosaurs</td>
<td>fossil found in Egypt; lived during the Cretaceous period (100–66 million years ago); herbivore</td>
<td>related to brachiosaurids, another group of large, plant-eating dinosaurs</td>
</tr>
</tbody>
</table>

Accept all reasonable responses.

Accept all reasonable responses.

4. **Draw a conclusion.** What is the answer to your question? Use information from your research to support your conclusion.

Possible answer: Most of the major dinosaur groups lived in Africa during the age of dinosaurs. Although the fossil record is not very complete, sauropods (such as Mansourasaurus), theropods (such as Spinosaurus), and “bird-hipped” dinosaur fossils (such as Lycorhinus) have all been found.

5. **Ask a new question.** What new question or questions occurred to you as you conducted your research?

How do Africa's dinosaur fossils compare to those from South America?
Essential Question
How does comparing structures help explain how organisms are related?

Warm Up
What do lizards have in common with birds and snakes?

Vocabulary
clade
common ancestor
comparative anatomy
derived character
homologous structure
phylogenetic tree
shared character
vestigial structure

Missing Feet?

The word *tetrapod* means “four feet,” but there are many examples of tetrapods that do not have four feet. The tetrapods are a broad animal group. Most tetrapods move by pushing their feet against the ground.

The first tetrapods swam in shallow seas. They used their feet as flippers. Tetrapods emerged on land about 400 million years ago. The diversity of tetrapods has increased greatly since then.

Birds are tetrapods. They walk on two feet, but they also have a pair of wings. Each wing contains bones that resemble those in a lizard’s front legs. Birds have scales on their legs and feet. Their scales are similar to those on lizards and snakes.

Snakes do not have legs, but they are also tetrapods. Fossils have been found of snakes with legs. Some modern snake species have tiny hip and leg bones.

Fill in the graphic organizer to support the claim that snakes and birds are tetrapods.

<table>
<thead>
<tr>
<th>Claim</th>
<th>Evidence</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snakes and birds are tetrapods.</td>
<td>The bone structure in bird wings is like the bone structure in the front legs of lizards. Some snakes have hip bones and leg bones like lizards (but smaller). Fossils of snakes with legs have been found.</td>
<td>Possible answer: Species can be classified based on these similar body structures.</td>
</tr>
</tbody>
</table>
Comparing Wings

Ask a question. Closely related organisms have many structural similarities. Insects, birds, and bats have wings. Which winged animals are more closely related?

1. Compare  What similarities and differences do you observe in the wings?
   Possible answer: Wing 1 and Wing 2 have bones, including a humerus bone. Wing 1 has a claw and is covered with skin. Wing 2 is covered with feathers instead of skin. Wing 3 has no bones—its skeleton is on the outside of its body. Wing 3 is divided into a front and back wing, unlike the other wings.

2. Classify  Draw a line to match the species with its wing type. Explain your choices.

   - **Wing 1**  Peregrine falcon
   - **Wing 2**  Green-striped white butterfly
   - **Wing 3**  Egyptian fruit bat

   Wing 1 goes with the bat because it has skin, like other mammals. Wing 2 goes with the falcon because it has feathers, like other birds. Wing 3 goes with the green-striped white butterfly because its body shape and wings look like those of a butterfly.

3. Conclude  The wings represent animals from three major groups: mammals, birds, and insects. Which two groups are most closely related? Explain.

From the Sea to Land

There are three major groups of terrestrial animals—mollusks (including snails), arthropods (including insects), and tetrapod vertebrates. Organisms within each group share a most recent common ancestor. This common ancestor is the set of organisms from which all members of a group descended. Organisms that share a common ancestor are related. Those that share a more recent common ancestor are more closely related.

Fossils suggest that the common ancestor of tetrapods was an aquatic, fishlike organism. It had fleshy fins that gave rise to legs, feet, and the other types of tetrapod limbs.

▲ The common ancestor of tetrapods had leglike fins.
Comparative Anatomy

The fossil record is one line of evidence that helps scientists classify organisms and determine relatedness. Comparative anatomy is another line of evidence for relatedness. Comparative anatomy is the study of the similarities and differences of structures within and between groups of organisms. For example, vertebrates have a series of small bones that form a backbone. Arthropods, including insects, spiders, and crustaceans, have an outer skeleton. Members of these two groups can be identified because they have those shared characters. A shared character is a characteristic shared by members of a group. Organisms with more shared characters are more closely related.

Homologous Structures

After tetrapods colonized land, they diverged, or grew apart, from their common ancestor. Eventually they became new species. Some of their shared structures began to change and serve different purposes in the new species. The forelimbs, or front limbs, of amphibians, mammals, and birds became legs, arms, fins, and wings. The forelimbs are homologous structures. Homologous structures are structures that were inherited from the same body part of a common ancestor. They look different and are often used differently by the descendants.

The pictures show the forelimbs of a horse, a whale, a frog, and a bird. Despite having a different look and function, the same set of bones is present in each structure.

In which animals are the radius and ulna bones fused, or joined together? How might this help these animals survive in their environments?

Possible answer: The radius and ulna are fused in the horse and the whale. This might help them by strengthening their legs and fins for pushing against the ground or water to generate movement.

In which animals are the phalanges fused? How might this help the animals survive in their environment?

Possible answer: Phalanges are fused in the horse and the bird. This might protect them against breakage from the ground’s impact (when running) or the wind’s force (when flying).
Homologous structures can be used to determine how organisms have changed over time. For example, the first mammals appeared in the fossil record 200 million years ago. These mammals lived on land. The first whales appeared in the fossil record 50 million years ago. These mammals lived in Earth's oceans. Scientists wondered about the relatives of whales. Did they share a common ancestor with a mammal that lived on land?

The discovery of several fossil skeletons helped answer these questions. The fossils suggested that whales had a common ancestor with small, hoofed land mammals. These animals did not look like modern whales at all. However, their ear structure was very similar to that found in modern whales. The unique ear structure is found only among the descendants of this most recent common ancestor. The fossil record shows a gradual movement of these descendants from land to water.

Vestigial Structures

Not all homologous structures have an obvious function. Boa constrictors and pythons have pelvic bones and hind limbs. They do not use these structures. Like other snakes, they move using their scales and their flexible body. Pelvic bones and hind limbs are vestigial structures in these snakes. A **vestigial structure** is one that serves no apparent purpose but was inherited from a common ancestor. The structures were functional in the ancestor.

> How are vestigial structures evidence that organisms have changed over time?

Possible answer: Organisms that have vestigial structures have a common ancestor in which the structure was functional. The organism has changed over time and no longer needs the structure, but it is still present.

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**Engineering Connections**

Plant and animal structures are often well-suited to the functions they perform. Engineers sometimes look to plants and animals for ideas when designing solutions to human problems. This is called biomimicry. Birds have inspired many designs for things that move. Engineers have long designed airplanes shaped like birds. This makes them more aerodynamic, or efficient at flying through air. Birds have inspired train engineers, too. Kingfishers are birds that can dive into water without making a splash. This is how they catch prey. A bullet train in Japan was modeled after the beak of a kingfisher. The train can move very rapidly and is able to enter and exit tunnels with little sound.
Homologous structures, fossils, and other evidence can be used to construct a phylogenetic tree. A **phylogenetic tree** is a diagram that shows common ancestors and the relatedness of their descendants. A phylogenetic tree is like a family tree for species or groups of organisms.

A phylogenetic tree can take different shapes. Most commonly, a common ancestor is at the base of the tree. Traveling up the tree represents traveling from the past toward the present. As a group changes over time, its line branches, or splits. These changes are represented by forks that create new branches. The branches represent descendants from the common ancestor. Tracing a branch from its tip to the base allows you to see the ancestors of the organisms represented by each branch.

Each branch point represents a clade. A **clade** is a group that contains a most recent common ancestor and its descendants. Clades can be large or small. They can be nested within each other.

**Draw a circle to represent the common ancestor of B and C.**

**Which letters represent the two most closely related organisms? How do you know?**

B and C; these organisms share the most recent common ancestor.

**How many clades are represented in the phylogenetic tree of A, B, and C? How do you know?**

Two; the phylogenetic tree shows two common ancestors to the three descendants.

**How many times did wing forelimbs arise in this phylogenetic tree? Of the animals shown, which is most closely related to the bird?**

Two; the crocodile
To sort out clades and assemble phylogenetic trees, scientists use shared derived characters. A **derived character** is a characteristic of a group that is different from the previous groups. These have emerged as organisms have changed over time. They are shared only by the descendants of the organism in which the character emerged. They are the defining characteristics of a clade. In contrast, an ancestral character is one that arose before a group of organisms branched off from common ancestors.

By studying patterns of derived characters in organisms, scientists can make inferences about their path of descent from a common ancestor. Examine the phylogenetic tree of vertebrates. The derived characters are shared by the groups of animals that descended from the ancestor in which the character first appeared. The groups that split off before the character appeared do not have that character.

Notice that the branches of phylogenetic trees do not always represent single species. They can represent groups of species, as shown below.

**Home Activity**

Make a family tree with the help of your family. What evidence did you use? How is a family tree similar to and different from a phylogenetic tree? Explain your answers to family members.

- Which animal groups have four limbs? amphibians; primates; rodents and rabbits; crocodiles; dinosaurs and birds
- Which animal groups have hair? primates; rodents and rabbits
**GUIDED PRACTICE**

**Classify Organisms**

**Ask a question.** How can you classify organisms by their structures?

1. **Observe** Study the photos. Make a list of shared characters that could be used to group the organisms. Think about the structures discussed in the lesson.

   Accept all reasonable responses. Possible answers: an outer skeleton, fins, four legs, fur, wings, a tail

2. **Classify** In the first row, identify the four shared characters you will use to classify the organisms. List each organism that belongs in one or more of the four groups.

   - **Shared character:** Outer skeleton
   - **Shared character:** Feathers
   - **Shared character:** Wings
   - **Shared character:** Tail

   Answers will vary.

3. **How can classifying organisms help you make predictions about them?**

   Possible answer: Knowing what group an organism belongs to allows you to make inferences about it.

4. **Explain** Does your classification system tell you anything about the ancestors of the organisms? Explain.

   Possible answer: No. I did not use shared, derived characters to classify the organisms.

5. **Draw Conclusions** How could you design a classification system that tells more about the ancestors and relatives of an organism?

   Possible answer: I could group the organisms into clades using a phylogenetic tree. This would mean classifying by derived characters.
Lesson Review

1. **Vocabulary** Use vocabulary terms from the lesson to complete the sentences.

   A diagram that shows the relatedness of organisms through common ancestors is called a(n) ________ **phylogenetic tree**. The diagram groups similar organisms into ____ **clades**. A defining characteristic of all the organisms in a clade, different from the previous group, is called a(n) ________ **derived character**.

2. **Identify** Circle the correct answer.

   (a) Homologous structures ________.  
       - have a common function  
       - are evidence of a common ancestor  
       - look the same externally  
       - are evidence of different ancestors

   (b) What evidence did scientists use to infer that whales descended from hoofed land mammals?  
       - **homologous ear bones**  
       - vestigial fins  
       - a phylogenetic tree  
       - fin fossils

3. **Explain** Give an example of homologous structures in an animal group. Describe why they are homologous.

   Possible answer: the hind limbs of a whale and the hind limbs of a horse; both form from the same bones, but they are used for different purposes.

4. **Analyze** Examine the photo of *Archaeopteryx*. *Archaeopteryx* lived about 150 million years ago. Use evidence from the photo to make an argument about its relationship with other animal groups.

   Possible answer: *Archaeopteryx* is most closely related to birds and dinosaurs. It has characteristics of both. It has feathers like a bird, but claws, teeth, and the skeletal features of dinosaurs and other reptiles. It also appeared in the fossil record at the same time as birds.
Make a Phylogenetic Tree

Many of the organisms that lived long ago looked very different from organisms living today. The structural similarities and differences between fossils and living organisms can be used to infer relatedness.

1. **Ask a question.** Choose an extinct organism you would like to know more about. Think of a question you would like to investigate about how it is related to living organisms. Choose a question that can be answered by comparing structural similarities and differences. Keep in mind that you will need to present your findings in a phylogenetic tree.

   Possible answer: Where does the woolly mammoth fit in the vertebrate phylogenetic tree?

2. **Make a plan.** List the steps you will follow to answer your question. Write the steps in the order you will complete them.

   Possible answer:
   1) I will examine wooly mammoth skeleton photos and images.
   2) I will read information about wooly mammoth skeletons.
   3) I will research and list living animals that have characteristics similar to wooly mammoths.
   4) I will research shared derived characters of wooly mammoths and related animal groups.
   5) I will attempt to create a phylogenetic tree with the available information.
   6) I will research phylogenetic trees of wooly mammoths and living animals that have wooly mammoth–like characteristics.
   7) I will check my phylogenetic tree against other research.
3. **List the sources you use.** What sources did you use to find information for your investigation? List them.

Students should list reliable sources, including encyclopedias; scientific books and publications; and the websites of government agencies, universities, and reputable publications.

4. **Communicate.** Draw your phylogenetic tree.

Answers will vary. Possible answer:

5. **Draw a conclusion.** Summarize your findings. What is the answer to your question?

Possible answer: Based on skeletal structure, I think wooly mammoths are most closely related to living elephants. Living elephants have hair and lack two openings behind the eye. The woolly mammoth, like living elephants, is most closely related to rodents and rabbits on this phylogenetic tree.
What do chickens, frogs, and mice have in common? If you said a backbone, you are correct. If you said a tail and gill slits you are also correct! In their early stages these animals have fishlike structures. In fact, all vertebrates have these features before they are born or hatched from an egg. In fish, the gill slits develop into gills. In land vertebrates, the gill slits become other structures.

Are gill slits and tails homologous structures in vertebrates? Explain.

Possible answer: Yes. The presence of these similar structures early in development suggests that these different animals descended from a common ancestor.

The photos on this page all show the same kind of organism as it grows and changes. Can you name it?

frog
Which Animal Is Which?

Ask a question. The pictures show a reptile, a fish, and a bird before being born or hatched. How do the early stages of these animals compare?

1. Observe  What structures of the animals can you recognize?
   Picture 1:
   Possible answer: tail, gill slits, forelimb beginning to grow

   Picture 2:
   Possible answer: tail, gill slits, one of the paired forelimbs and one of the paired hind limbs beginning to grow

   Picture 3:
   Possible answer: tail, gill slits, one of the paired forelimbs beginning to grow

2. Identify  Can you tell which animal is which? Explain.
   Possible answer: No. The animals look too similar at this stage. I think one is a fish because it has only one limb pair and because the tail is different. I cannot tell which picture shows the bird and which shows the reptile because the pictures look almost the same.

3. Conclude  How do the early stages of vertebrate animals compare?
   Possible answer: In their early stages of development, these animals look very similar and they are difficult to identify.

From Egg to Frog

A frog lays eggs. The eggs are fertilized. A tadpole grows legs and becomes an adult frog. The development of frogs consists of a series of distinct stages from egg to adult. Development is the predictable series of changes in the size, shape, and function of an organism during its lifetime. Patterns in development provide evidence about ancestry.
About two centuries ago scientists began to study the development of vertebrate embryos. An *embryo* is a young organism that has not been born or hatched. Scientists noticed that the embryos of vertebrate species were difficult to tell apart—especially in their early stages. In 1828 Karl Ernst von Baer argued that closely related species have similar patterns of embryonic development. He noticed structures in embryos that were not present in the adult forms of the organism.

Ernst Haeckel added to these observations in the late 1800s. He believed embryos progressed through the adult stages of their ancestors as they developed. He also believed that organisms changed over time by adding stages onto the end of their development. As scientists made more observations, Haeckel’s ideas were disproved. Later studies showed that embryos did not go through their ancestors’ adult stages of development. However, researchers noted that embryos had homologies with their ancestors. A homology is a structural similarity. In the early stages of development, embryos have homologies with ancestral groups.

Recall from Lesson 1 that all vertebrates have a chordate ancestor. The embryo diagram shows homologies shared by vertebrates and their chordate ancestors. Vertebrates and invertebrate chordates have four features in common during early development. One is the presence of a tail. A notochord and a nerve cord run the length of the back. Finally, gill slits are near the head. In aquatic animals, gill slits become gills. A gill slit is also known as a pharyngeal pouch. It sits between the mouth and throat. The presence of pharyngeal pouches in land-dwelling vertebrates is evidence that their ancestors lived in the sea.

**Identify the four structures in the diagram.**

1. Nerve cord
2. Gill slits (pharyngeal pouches)
3. Notochord
4. Tail

**What does embryology suggest about the ancestors of horses?**

That they descended from a five-fingered ancestor.

Embryology, the study of embryos, reveals many examples of how ancestral groups have changed over time. Horse embryos go through a stage in which their limbs have five fingers. They later develop hooves. Baleen whales, which sift their food rather than bite it, go through a stage when they start to develop teeth. They lose those tooth buds before birth, however.
As vertebrate embryos progress into the later stages of development, they begin to look more like adults. Compare the early and late stages of a chicken’s development with the embryo of a mouse on the previous page. Both have tails early on. Only at the later stages does the chicken’s beak become visible. The feathers form just before hatching.

Ancestral chordate homologies change or disappear during development. The nerve cord becomes the brain and spinal cord. The notochord is replaced by vertebrae. The pharyngeal pouches form a group of structures around the mouth and sinus cavities.

There are two groups of modern whales: toothed and baleen. Which is the ancestral character? How do you know?

Some invertebrates develop through metamorphosis. Metamorphosis is a series of different body forms. Butterflies undergo a metamorphosis. So do most other insects. As with embryology, the study of metamorphosis can explain relatedness among animal groups.

Name a chordate that undergoes metamorphosis.
Possible answer: frog

Careers in Math, Technology, and Science

Developmental biologists study how organisms grow and develop. Many developmental biologists work in the lab doing research. One important area of research relates to cancer. Cancer cells are cells that develop and reproduce abnormally. A developmental biologist might research how or why cells become cancerous. Other developmental biologists study embryos, looking for homologies or to advance medical knowledge. Agriculture benefits from research in developmental biology. Understanding the complex life cycles of insect pests helps protect crops.
Evidence of Common Ancestry

Some derived characters are present during specific stages of development. Notochords are present only in the very early stages of vertebrate development. Tunicates, also called sea squirts, undergo a metamorphosis. The young, larval form loses its notochord as an adult. Lancelets are the third chordate group. They develop notochords early and keep them as adults. By studying all stages of development, the shared characters in these groups become apparent.

Classification by Levels

Today, scientists use shared, derived characters in classifying organisms. This is called phylogenetic classification. **Phylogenetic classification** is a classification system in which organisms are grouped into clades based on common ancestors.

One of the first classification systems was developed more than two centuries ago by Carolus Linnaeus. His system is called Linnaean classification. **Linnaean classification** is a classification system that groups organisms based on shared characteristics—but not necessarily shared, derived characters. Organisms are grouped into seven levels, each containing smaller and smaller groups. The levels are kingdom, phylum, class, order, family, genus, and species. Kingdoms are the largest group. They contain the greatest diversity and number of species.

Although phylogenetic classification gives a clearer picture of how organisms are related than the Linnaean system, both are still used.
Today, most scientists recognize six kingdoms: animals, plants, fungi, archaea, bacteria, and protists. Most kingdoms are divided into phyla (singular, phylum). Plants are divided into divisions instead of phyla, however. Phyla (or divisions) are divided into classes. The largest class of animals is the insects, with about 900,000 named species. Classes are divided into orders, orders into families, families into genera, and genera into species. As the groups get smaller, the organisms in the group have more shared characters. For example, the kingdom animalia contains all animals from tunicates to oryxes. The genus Oryx consists of the Arabian oryx, the scimitar oryx, the East African oryx, and the gemsbok.

Linnaeus used a two-part naming system called binomial nomenclature. In binomial nomenclature, each species has a two-part name that consists of the genus and species. This system is still in use today. The two-part name is called the scientific name. The scientific name of the Arabian oryx in the picture below is Oryx leucoryx. This can be abbreviated as O. leucoryx.

Scientific names help scientists avoid confusion. For example, the Egyptian fruit bat’s scientific name is Rousettus aegyptiacus. Other parts of the world have large fruit bats, too. Scientists use binomial nomenclature to communicate clearly which species they are referring to.

How does the Linnaean classification system use patterns?

Accept all reasonable responses. Possible answer: The Linnaean system uses patterns of similarities in characteristics to classify organisms into smaller and smaller groups.

<table>
<thead>
<tr>
<th>Level</th>
<th>Linnaean classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingdom</td>
<td>Animalia</td>
</tr>
<tr>
<td>Phylum</td>
<td>Chordata</td>
</tr>
<tr>
<td>Class</td>
<td>Mammalia</td>
</tr>
<tr>
<td>Order</td>
<td>Artiodactyla</td>
</tr>
<tr>
<td>Family</td>
<td>Bovidae</td>
</tr>
<tr>
<td>Genus</td>
<td>Oryx</td>
</tr>
<tr>
<td>Species</td>
<td>Oryx leucoryx</td>
</tr>
</tbody>
</table>

The order Artiodactyla includes most of the large land mammals. It contains animals with divided hoofs, such as sheep, goats, camels, cows, giraffes, and antelopes.

Arabian oryx, O. leucoryx

Home Activity

Take photos or collect pictures of common organisms. With the help of family members, identify the organisms by their common names. Do any of the organisms have more than one common name? If possible, identify the organisms by their scientific names. Explain to your family how scientific names reduce confusion about the names of organisms.
GUIDED PRACTICE

Observe Development

The images show the inside of a developing mouse embryo at different stages of development. Study the images and answer the questions below.

Ask a question. What evidence about ancestry can you gather by observing the embryonic development of a mouse?

1. Observe What do you observe about the four features?

<table>
<thead>
<tr>
<th>Feature</th>
<th>12 days old</th>
<th>14 days old</th>
<th>20 days old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notochord/vertebral column</td>
<td>partial notochord; beginning to form vertebral column</td>
<td>vertebrae forming</td>
<td>vertebrae formed with partially enclosed nerve cord</td>
</tr>
<tr>
<td>Nerve cord</td>
<td>looks like a long, thin tube</td>
<td>long and thin; looks like a long, thin tube</td>
<td>brain forming at the head end</td>
</tr>
<tr>
<td>Gill slits (pharyngeal pouches)</td>
<td>absent or not observable</td>
<td>present</td>
<td>absent</td>
</tr>
<tr>
<td>Length</td>
<td>about 5 mm</td>
<td>about 10 mm</td>
<td>about 15 mm</td>
</tr>
</tbody>
</table>

2. Observe Do you see any evidence that the vertebral column is forming around the nerve cord? Explain.

Possible answer: Yes; between 12 and 14 days old, the vertebral column is getting more fully formed and appears to be moving closer toward the nerve cord. At 20 days old, the vertebral column is wrapping around the nerve cord just below the brain.

3. Compare Describe how the shape of the embryo changes as it develops.

Possible answer: It is very curled up at Day 12. It becomes less curled up as it continues to develop. It also gets longer.

4. Identify When does the organism begin to resemble the adult form?

Possible answer: The mouse does not begin to resemble its adult form until Day 20. Before that it is difficult to tell what it is.

5. Draw Conclusions What evidence do you have from your observations that a mouse is a vertebrate chordate?

Possible answer: The embryo has gill slits/pharyngeal pouches. The nerve cord changes to form a brain. The vertebral column develops around the nerve cord.
Lesson Review

1. **Vocabulary** Use vocabulary terms from the lesson to complete the sentences.

   An unborn or unhatched organism is a(n) ____________ _____________. As embryos proceed through ____________ they often show homologies. These homologies give scientists clues about their ancestry and are used to classify organisms. The Linnaean classification system names organisms using a two-part naming system called ____________.

2. **Compare** Number the levels of the Linnaean classification system from 1 to 7 with 1 being the largest and most inclusive and 7 being the smallest and least inclusive.

   6. genus
   3. class
   4. order
   7. species
   2. phylum
   5. family
   1. kingdom

3. **Explain** What does the presence of gill slits in the early embryos of chickens and turtles suggest about their ancestry?

   Possible answers: They have a common ancestor with each other. They have a common ancestor with fish.

4. **Infer** During embryonic development, whale embryos have hair and hind legs. What can you infer about their ancestry based on this observation?

   Possible answer: The ancestors of whales had hind limbs and hair. These ancestors were likely tetrapod mammals and lived on land.

5. **Evaluate** What do you think happens when scientists discover new information about the relatedness of organisms?

   Possible answer: Classification systems and phylogenetic trees change as new information is discovered. The way the organism is classified and/or the phylogenetic tree will be revised based on the new information.
Comparing Development

You have learned that patterns of embryonic development are evidence of descent from a common ancestor. Closely related organisms look very similar in the early stages of development. In this activity, you will use embryonic similarities to determine relatedness in different vertebrates.

1. **Ask a question.** Study the picture of embryonic development in fish, amphibians, reptiles, and birds. Ask a question about the relatedness of the animals that you can answer by analyzing the pictures of their embryonic development.
   Possible answer: Which animal is most closely related to the bird?

2. **Make a plan.** What will you look for to help you identify relationships? How will you organize your data?

   Possible answer: I will look for the presence of four limbs, a tail, and gill slits. I will also compare the overall shape of the embryo during development. The animal with the most similarities should be most closely related.

<table>
<thead>
<tr>
<th>Embryo observations</th>
<th>Fish</th>
<th>Amphibian</th>
<th>Reptile</th>
<th>Bird</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four limbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gills or gill slits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall shape first stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall shape second stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall shape third stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. **Describe the process you will use to answer your question.**
   Give details about how you will analyze the data you collect about the pictures.
   Possible answer: I will fill in the table with observations of the characteristic listed. Then I will determine which animal has the most in common with birds. I can infer that the animal with the most developmental similarities is most closely related.

4. **Record your observations.** What did you observe? Were you able to get the information you need from the embryo images? Record your observations in a data table.

<table>
<thead>
<tr>
<th>Embryo observations</th>
<th>Fish</th>
<th>Amphibian</th>
<th>Reptile</th>
<th>Bird</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four limbs</td>
<td>no</td>
<td>all stages</td>
<td>all stages</td>
<td>all stages</td>
</tr>
<tr>
<td>Tail</td>
<td>all stages</td>
<td>all stages</td>
<td>all stages</td>
<td>reduced in the third stage</td>
</tr>
<tr>
<td>Gills or gill slits</td>
<td>all stages</td>
<td>all stages</td>
<td>all stages</td>
<td>First and second stage only</td>
</tr>
<tr>
<td>Overall shape first stage</td>
<td>similar to bird</td>
<td>similar to bird</td>
<td>similar to bird</td>
<td>—</td>
</tr>
<tr>
<td>Overall shape second stage</td>
<td>different from bird</td>
<td>different from bird</td>
<td>similar to bird</td>
<td>—</td>
</tr>
<tr>
<td>Overall shape third stage</td>
<td>different from bird</td>
<td>different from bird</td>
<td>similar to bird</td>
<td>—</td>
</tr>
</tbody>
</table>

5. **Draw a conclusion.** Did the data you collected from the images provide evidence of relatedness? Were you able to answer your question? If not, what other information do you need? What can you infer about the relatedness of the organisms?
   Possible answer: Yes. I was able to infer that the reptile is most closely related to the bird. Analysis of the overall shape of the reptile and the bird throughout the development was very similar. The other three characteristics I looked for were almost the same in the other animals, so I was not able to draw a conclusion based on those.
Nizar Ibrahim is a German-Moroccan paleontologist. He is best known for his discovery of a *Spinosaurus* skeleton in Morocco. Ibrahim has made other discoveries, too. He discovered a large flying dinosaur named *Alanqua saharica*. These dinosaur fossils are unlike any others in the world. Ibrahim has also discovered prehistoric fish, crocodile, and turtle fossils in the Moroccan Sahara Desert. The fossils give additional clues about the past environment. The area where *Spinosaurus* was found was once a tropical river ecosystem. *Spinosaurus* lived among several other large, meat-eating dinosaurs. Ibrahim’s discoveries help people understand the river ecosystem that occurred long ago in North Africa.

Ibrahim wants to document the biodiversity of African dinosaurs. Much of what people currently know about dinosaurs comes from fossil discoveries in Europe and North America. Those areas have been explored more extensively than Africa. By studying Mesozoic Era fossils in Africa, Ibrahim hopes to have a more accurate view of the fossil record.

In addition to studying dinosaurs, Ibrahim wants to improve scientific research. He wants to promote a better understanding of science in Morocco and around the world. He believes this can happen by inspiring the next generation of explorers and scientists. He creates museum exhibits using a variety of media to engage public interest in paleontology.

**What evidence suggests the Moroccan Sahara Desert was a river ecosystem during the Mesozoic Era?**

Possible answer: Nizar Ibrahim discovered Mesozoic-Era fish, crocodile, and turtle fossils there. These are all animals that would be expected to live in a river ecosystem. *Spinosaurus* was an aquatic, predatory dinosaur. It would have required a water environment in which to live and feed.

**How have Ibrahim’s discoveries changed ideas about dinosaur biodiversity during the Mesozoic Era?**

Possible answer: Dinosaurs from North Africa are now better represented in the fossil record. Descriptions of dinosaur biodiversity now include more North African species, including *Spinosaurus* and *Alanqua saharica*. These dinosaurs are unique—they were not found in Europe or North America.
3.1 Evidence from the Fossil Record

- The fossil record can be used to reconstruct the history of life.
- Fossils document the increasing complexity of life on Earth over the past 3,500 million years.
- Fossils show a trend of increasing biodiversity since the emergence of the first life-forms.
- Despite the long-term trend of increasing biodiversity, there have been five major mass extinctions—events that were marked by a significant decrease in biodiversity.

3.2 Comparing Structures

- Structural similarities among organisms, both living and extinct, suggest evidence of relatedness and common ancestry.
- Structural similarities that were inherited from a common ancestor are homologous.
- Some homologous structures are vestigial, meaning that they are no longer functional.
- Phylogenetic trees show the relatedness of species and groups of species. Phylogenetic trees are created using homologous structures, derived characters, and other evidence about ancestry.

3.3 Comparing Development

- Developmental patterns provide evidence about ancestry. Closely related species and groups of species share similar patterns of growth and development.
- Different vertebrate groups have similar patterns of early embryonic development.
- Vertebrate embryos sometimes show features in early development that the Linnaean classification system uses a binomial method to name species. Species are classified using a taxonomic hierarchy based on shared characteristics.
Chapter Review

1. Vocabulary Complete each sentence with the correct term.

<table>
<thead>
<tr>
<th>binomial nomenclature</th>
<th>biodiversity</th>
<th>development</th>
</tr>
</thead>
<tbody>
<tr>
<td>embryo</td>
<td>homologous structure</td>
<td>mass extinction</td>
</tr>
<tr>
<td>paleontologist</td>
<td>phylogenetic tree</td>
<td>vestigial structure</td>
</tr>
</tbody>
</table>

A  A scientist who studies fossils to learn about extinct organisms is a(n) ___________ **paleontologist** ___________.

B  The fossil record shows an increase in ___________ **biodiversity** ___________ over Earth’s long history.

C  The limb pairs of reptiles, birds, and mammals are an example of a(n) ___________ **homologous structure** ___________.

D  Patterns in the growth and ___________ **development** ___________ of an organism can be used to infer its relatedness to other organisms.

E  The weakly developed pelvic bones of a snake are an example of a(n) ___________ **vestigial structure** ___________.

2. Identify  Circle each item that provides evidence that life has changed over time.

A  the fossil record
B  homologous structures
C  vestigial structures
D  developmental patterns

3. Explain  How do scientists know how and when ancient organisms lived?

Possible answer: They examine the age and location of rocks in which fossils were found. They compare fossil structures with similar structures on modern species and observe how modern organisms use the structures.

4. Apply  Dolphins look a lot like fish. How could you determine how closely related they are?

Sample answer: You could look for homologies. Both have a backbone; however, dolphins do not have gills like fish. Dolphins have lungs. Their fin structures are more like limbs. This suggests that dolphins are more closely related to other tetrapod mammals than fish.
5. **Summarize** What patterns help scientists evaluate the relatedness of species?

   Possible answer: Evidence about relatedness comes from patterns in structures and development. Related species have similar structures that develop in similar ways. Patterns of change in the fossil record also offer clues about relatedness.

6. **Compare and Contrast** How are the phylogenetic and Linnaean classification systems similar and different?

   Possible answer: The Linnaean system assigns organisms to smaller and smaller groups based on shared characteristics. The groups are less and less inclusive. As a result they have more and more similar organisms. Phylogenetic classification uses evidence about an organism’s ancestry to classify it into clades. Like in the Linnaean system, clades are nested and organisms are classified into smaller and smaller groups that have more and more similarities.

7. **Explain** What patterns in development support the argument that fish and chickens have a common ancestor?

   Possible answer: Fish and chicken embryos both have gill slits early in development. In fish, the gill slits develop into gills. In chickens, the gill slits disappear during development.

8. **Evaluate** The diagram shows a whale skeleton.

   What evidence from the picture suggests that whales have a common ancestor with rabbits? What additional evidence would you expect if you were to compare the development of whale and rabbit embryos?

   Possible answer: The skeleton shows front limb bones, including the humerus, and partial hind limb bones (pelvic bones). These are homologous structures that whales share with rabbits. If I were to compare the development of whale and rabbit embryos, I would expect that both would have gill slits, hair, and legs at some stage of development, although whales would lose the hair and legs later. This evidence suggests that the ancestors of both whales and rabbits were mammals that lived on land.
Nizar Ibrahim and his team members wanted to visualize *Spinosaurus*. They wanted to show what a living *Spinosaurus* might have looked like. To do this, they pieced together data from several sources. They used a special X-ray called a CAT scan (or CT scan) on each of their fossils. They used Ernst Stromer’s drawings for comparison. They used fossils from relatives of *Spinosaurus* to fill in any missing details.

Ibrahim and his team worked with artists and animators. They used a three-dimensional printer to create a life-sized skeleton model. They produced animations to show the dinosaur in action. Their *Spinosaurus* exhibits have been displayed in museums around the world.

Museum exhibits are designed to capture visitors’ attention and tell a story. The story might include how the fossils were found. The story might include the age of the fossils. It might include what the fossils tell about the organisms’ features and behaviors. Art, design, and technology are used to help develop an exhibit. The exhibit might include fossils, drawings, animations, and skeleton models. Some museum exhibits include life-sized, moving models.
Your Task

Your task is to create a museum exhibit for the fossil shown in the photo. This fossil was recently found in rock that was determined to be 155 million years old. It measures 5.5 meters in length. It was found with fossil ammonites and squidlike invertebrates. Its teeth appeared to have originally been pointed and conical, but they were very worn.

Use what you learned in the chapter to make inferences about the organism. You will need to determine what it looked like, what its environment was like, and how it lived. Your inferences should be based on evidence. Then you will create an exhibit for a museum that brings the dinosaur to life. The exhibit should be interesting and inspire visitors to learn more about the dinosaur. You will use materials found at home or in your classroom to construct a three-dimensional model of the museum exhibit.

Identify the Problem

1. What is your task? Describe the criteria and constraints.
   Possible answer: I must design a three-dimensional museum exhibit for the fossil shown. The criteria are that the exhibit must bring the dinosaur to life. It needs to be interesting and inspire visitors to learn more about it. It will need to show what the dinosaur looked like, what its environment was like, and how it lived. The constraints are that the inferences made about the organism must be based on evidence.

2. How will you learn about the organism?
   Possible answer: I will look back at the information about the fossil record from 155 million years ago and see what types of organisms were living. I will study the skeleton and see what its structure suggests it might be related to. I will analyze the information about the other fossils it was found with to see what type of environment it would have lived in.
Research

3. What animals with skeletons lived 155 million years ago? What period was this? What types of animals were common?
   Possible answer: Fish, amphibians, reptiles, and mammals lived 150 million years ago. This was the Jurassic, the age of the dinosaurs.

4. Study the dinosaur skeleton. What types of living or extinct organisms does it resemble? Use evidence from the skeleton to infer what type of animal it was.
   Possible answer: The skeleton has four limbs and a tail. The front limbs are wide and look like they might have been used for swimming. It reminds me of a cross between a dolphin and a crocodile. I think it was a reptile because it was found during a time when they were very common.

5. What do the ammonites and squidlike creatures found near the skeleton tell about the environment in which it lived?
   Possible answer: They are evidence that it lived in a marine environment.

6. What can you infer about the diet of the organism based on the worn teeth?
   Possible answer: The organism ate hard foods that wore down its teeth. It was likely a predator. It might have eaten organisms with shells or bony skeletons.

7. What inferences can you make about how the animal lived? Use evidence to support your arguments.
   Possible answer: The shape of the limbs suggests it was aquatic. The teeth suggest it was a predator.
Design Your Exhibit

8. Make a sketch of what you think the organism looked like in its environment.

   Answers will vary but should reflect the shape of the skeleton fossil shown. Students should show the organisms in an aquatic environment.

9. What will your exhibit show?

   Possible answer: The exhibit will show a life-sized replica of the skeleton. It will show a video of what the organisms looked like and how it lived in its environment. Real fossils will be shown and visitors will learn about where and how they were found.

10. How will you use art and technology to bring the organism to life in a museum exhibit?

    Possible answer: An animated video will show the organism in its environment. It will show how it swam and hunted.
11. Use materials at home or in your classroom to build a model of your museum exhibit. Make a labeled diagram of your model.

Check student drawings. They should label the different parts of the museum exhibit.

12. Describe a visitor’s experience as he or she walks through the exhibit.

Answers will vary. Possible answer: Visitors first see some of the actual fossils and learn about where they were found. Then they see the life-sized three-dimensional skeleton model. Finally, they watch a movie about how the organism lived and see the environment in which it lived.
Evaluate Your Design

13. Take a group of classmates through your exhibit. Using your exhibit model, explain to a group of classmates what they will see and learn.

14. Was your exhibit able to keep your classmates’ attention? Did they ask questions and want to learn more? Was your exhibit successful?
   Answers will vary. Possible answer: Yes, my exhibit kept my classmates’ attention. They asked questions and wanted to learn more about the ancient reptile.

15. Seek feedback from your classmates. What did they like about the exhibit? What would have made their experience better?
   Answers will vary. Possible answer: They liked the life-sized skeleton and the three-dimensional animation. They had a hard time following how I learned about the dinosaur. I can redesign the exhibit to better tell the story about how I took what I learned about the fossil discovery and translated it to a three-dimensional movie.

   Answers will vary. Possible answer: I could use more technology to make the organism more life-like instead of showing the skeleton.

Answers will vary but should show that students have taken their classmates’ feedback into account in their improved design.
Print and Online Components on eAlpha Platform:
  • Student Book
  • Teacher Guide
  • Practice Book

Online Components on eAlpha Platform:
  • Assessments
  • Lesson Plans
  • Differentiated Anchor Activities
  • Exit Activities