Front Cover:

The front cover shows a photograph of three different waterslides of different heights. Which waterslide would you go fastest on?
# Unit 1: Gravity and Motion

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## Science Words to Know

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Section 1: Answering Questions

Questioning Phenomena

Think of the last time you tossed something up in the air. Chances are, you could predict exactly what would happen after you tossed it up. Before long, it would fall back to the ground. But did you ever wonder why objects fall back to the ground so predictably?

If you did, then you were thinking like a scientist. Asking questions is something that all scientists do. Scientists look for the causes of different phenomena they observe in the world around them. Broadly, science is the search for explanations about the natural world. Scientists use evidence to form conclusions that support those explanations. All knowledge learned from experiments is part of science.

Science is part of a larger cycle that includes engineering, math, and technology. This cycle is called the STEM cycle. Engineers apply scientific knowledge to create new technologies that solve problems. Math is a tool that both scientists and engineers use to capture results and communicate those results to others.

the STEM cycle

Scientists: answer questions
Can the energy in algae power vehicles instead of fossil fuels?

Engineers: solve problems
Vehicles that run on fossil fuels pollute the environment.

biologist testing green algae to see if it can be used as a fuel source

biofuel engineers test a container ship powered by green algae

Science, technology, engineering, and math are connected in the STEM cycle.
**Using a Scientific Process**

**Scientists** use a scientific process to guide them in developing a replicable experiment as they seek out answers to questions about the world around them. A process is a series of steps designed to meet a goal.

There are eight steps that scientists often follow to answer questions using data from experiments. These steps give scientists a logical pathway to move from a question toward an evidence-based conclusion.

**Step 1: Ask a question.**

The scientific process always begins with a question. Scientists look for the causes of different phenomena they observe in the world around them.

For example, Galileo Galilei was an Italian scholar in the 16th century who would become known as the father of scientific investigation and astronomy. He was fascinated by falling objects, and wondered whether different objects fall at different speeds.

One question he asked was: “Do heavier objects fall faster than lighter objects?”

**Step 2: Research the question.**

Every year the amount of scientific knowledge grows. Scientists use this existing knowledge to research their question. They want to find out what is already known about their question.
Step 3: Form a hypothesis.

After scientists have researched their question, they form a hypothesis. A hypothesis is a clear and concise statement that can be proved true or false. The hypothesis is the scientist’s prediction, based on what is known, about the answer to the question.

Three example hypotheses are:

- “Heavier objects fall faster than lighter objects.”
- “Heavier objects fall more slowly than lighter objects.”
- “Heavier objects fall at the same speed as lighter objects.”

Step 4: Write a summary of the experiment.

Scientists then write a summary of the experiment they will conduct to test their hypothesis. The summary should include the basics of the data to be collected, the variables that will be tested, and the parts of the experiment that will remain constant in each test or trial.

Step 5: List materials and procedure.

Scientists then list materials needed and the procedure they have created that they will follow. A procedure is like a recipe. Whenever you use a recipe, you are following a careful and precise procedure that someone else developed.

Scientists write down their materials and procedure so anyone can use the same materials and follow the same steps to get similar results. They also want to create a record of their thinking.
**Step 6: Draw a scientific diagram.**

They will also draw a scientific diagram. The diagram helps the scientists visualize how the different materials will interact in the experiment.

**Step 7: Carry out experiment to collect data.**

Scientists then conduct an experiment to test their hypothesis. An experiment is a specific procedure that tests if a hypothesis is true, false, or inconclusive.

Galileo conducted multiple experiments to test the hypothesis that heavier objects fall faster than lighter objects. Measuring the motion of a falling object is difficult. This is because objects fall to the ground so quickly.

Galileo realized that he needed to somehow slow down the motion of a falling object. He did this by rolling balls of different sizes down a wooden board that he inclined slightly from the ground. He thought that the balls would roll down the slope the same as if in a free fall, but more slowly.

The results of the experiment are data. Data are the measurements and observations gathered from an experiment.

Scientists use experiments to look for patterns in data that suggest a cause-and-effect relationship, where one event or thing is the result of the other. A pattern is something that happens in a regular and repeated way.
Scientists design experiments in a specific way, with variables and constants. A variable is something you change. It can be a factor, trait, or condition that can exist in differing amounts or types. There are independent and dependent variables in an experiment.

An independent variable is the variable changed by the scientist. To ensure a fair trial, an experiment should only have one independent variable. The scientist changes the independent variable to observe what happens. For example, in Galileo’s inclined plane experiment, the size of the balls was the independent variable.

The dependent variable is what happens as a result of the independent variable. In Galileo’s experiment, the dependent variable was the acceleration of the balls as they moved down the ramp. Simply put, accelerations are changes in an object’s motion. Whenever an object speeds up, slows down, or changes direction, it accelerates. Galileo wanted to see if changing the mass of the balls (independent variable) caused their acceleration (dependent variable) to change.

During the experiment, the height of Galileo’s ramp was constant. A constant is a quantity that remains the same in an experiment. Constants allow scientists to isolate one variable at a time to ensure the experiment results are valid. If Galileo changed the height of the ramp during his experiment, he wouldn’t know whether the results were because of the size of the balls or the height of the ramp.

**Step 8: Form a conclusion.**

After data have been collected, scientists form a conclusion. The conclusion uses data from the experiment as evidence to support whether the hypothesis is true, false, or inconclusive. After conducting numerous experiments, Galileo concluded that gravity causes all falling objects, regardless of size, to accelerate toward Earth at the same rate.
# The Scientific Process

<table>
<thead>
<tr>
<th>1</th>
<th>Question</th>
<th>End with a question mark and do not include words such as “I” or “because.”</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Research</td>
<td>Include a minimum of three facts relevant to the question.</td>
</tr>
<tr>
<td>3</td>
<td>Hypothesis</td>
<td>Write a concise statement that answers the question and can be proved true or false.</td>
</tr>
<tr>
<td>4</td>
<td>Summarize Experiment</td>
<td>Describe in 2-3 sentences the experiment you will do to test whether your hypothesis is true or false. Identify the independent and dependent variables, constants, and controls of the experiment. The independent variable is the variable changed. The dependent variable is what happens as a result of the independent variable. Constants of the experiment are conditions unchanged during each trial. A control in the experiment captures the effect of unknown variables.</td>
</tr>
<tr>
<td>5</td>
<td>Materials and Procedure</td>
<td>Vertically list all materials needed for your experiment with quantities. Next, vertically list the numbered steps of your procedure. Note safety precautions.</td>
</tr>
<tr>
<td>6</td>
<td>Scientific Diagram</td>
<td>Draw a diagram of the experiment set-up that is at least the size of your hand. Title it and include labels for all materials on the materials list.</td>
</tr>
<tr>
<td>7</td>
<td>Data</td>
<td>Follow your test procedure and gather data (both observations and numbers) to determine whether the hypothesis is true, false or inconclusive. Use proper units, title data tables, and tape into lab notebooks.</td>
</tr>
</tbody>
</table>
| 8 | Conclusion | Use the data collected in the experiment to explain why the hypothesis is true, false, or inconclusive. Every conclusion must contain a minimum of 3 elements:  
1. Restate your hypothesis.  
2. Make a claim (true/false/inconclusive).  
3. Use key points of data as evidence to support and explain your claim. |
### Section 1 Review

<table>
<thead>
<tr>
<th>Multiple Choice</th>
<th>Critical Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MC1.</strong> What is an independent variable in an experiment?</td>
<td><strong>CT1.</strong> Why do scientists form hypotheses?</td>
</tr>
<tr>
<td>A. what you change in an experiment</td>
<td><strong>CT2.</strong> Why is it important to leave all opinions out of hypotheses?</td>
</tr>
<tr>
<td>B. what stays the same in an experiment</td>
<td><strong>CT3.</strong> Why are scientists so careful in how they set up experiments, making sure to write down everything clearly and specifically in their laboratory notebook?</td>
</tr>
<tr>
<td>C. the various hypotheses you could come up with</td>
<td><strong>CT4.</strong> Do scientists ever intentionally conduct experiments that don’t produce data? Why or why not?</td>
</tr>
<tr>
<td>D. the data gathered in the experiment</td>
<td><strong>CT5.</strong> Why is the sentence in italics below not a proper conclusion?</td>
</tr>
<tr>
<td></td>
<td><em>I think that candy tastes delicious.</em></td>
</tr>
</tbody>
</table>

**MC2.** Which of the following is not a hypothesis?  
A. All birds fly south in the winter.  
B. I think fish are delicious.  
C. Corn is heavier than rice.  
D. Metals always sink.
Section 2: Energy and Motion

A 61-Meter Drop

In April 2018, an amusement park in Ohio called Cedar Point began testing its newest roller coaster. This roller coaster is called Steel Vengeance. A ride on Steel Vengeance will last about 2 minutes and 30 seconds. It will reach speeds of up to 119 kilometers per hour (74 miles per hour). The first drop is a 90-degree drop of 61 meters (200 feet).

The height of ice slides, waterslides, and roller coasters is key to how all of these rides work. The taller the ride, the faster you can go. This is because of gravity—the force of attraction between all matter (everything that has mass and takes up space). Gravity pulls objects together.

It’s gravity that keeps us and all objects on Earth from floating off into the atmosphere, and that pulls all objects thrown up in the air back to the ground. In fact, an informal motto for national roller coaster day, held every August 16, is, “May the force of gravity be with you.”
Understanding Gravity

All matter has gravity, from rocks to plants, animals, and stars. However, the force of attraction depends on the mass of the two objects. **Mass** is the measure of the amount of matter that makes up an object or substance. It is measured in grams (g). The more massive an object is, the more its gravity will pull on other objects.

Earth’s gravity pulls on all objects on or near Earth’s surface because Earth is so massive. Earth’s gravity pulls all objects near Earth’s surface downward. Gravity keeps you from floating off into space. Earth’s gravity is also what pulls you back to the ground from the top of a waterslide.

Weight and Mass

The gravitational force exerted on an object by a planet or moon is called **weight**. It is measured in newtons (N). Here on Earth, weight is calculated by multiplying the object’s mass by the acceleration of gravity. The acceleration due to gravity is nearly identical everywhere on Earth (9.8 m/s²).

Non-scientists often think that an object’s weight is the same as its mass. The two are related because an object’s weight depends on its mass. However, weight also depends on the force of gravity. On other planets and the moon, which have noticeably different gravities, an object’s weight would change dramatically. For example, the moon is less massive than Earth. Because of this, its gravity is weaker than Earth’s, so an object’s weight would drop by 83 percent on the moon compared to on Earth. The object’s mass, on the other hand, would remain the same wherever it was.
The Force of Gravity

Gravity is an attractive force. A force is a push or pull that acts on an object, changing its speed, direction, or shape. Attractive forces pull objects together. Opposing forces push objects apart.

Forces are acting everywhere in the universe all the time. Even if you are standing still, you have many forces acting on you. Earth’s gravity exerts a force on all objects on and near its surface, pulling everything on Earth’s surface toward the center of Earth.

Gravitational Fields

Because gravity is an attractive force, objects don’t need to come into contact with one another to exert a force on each other. Instead, objects have gravitational fields. A gravitational field is the area around one object where another object will feel the gravitational force of the first object.

For example, Earth is so massive that its gravitational field extends beyond the atmosphere, pulling on all objects within it, including the moon.

This gravitational field causes patterns in movement. Remember that a pattern is something that happens in a regular and repeated way. Every time you release a pen in the air, the pen will fall back to Earth’s surface because the pen is within Earth’s gravitational field.
Forms of Energy

As an object moves within Earth’s gravitational field, it forms a system. A **system** is a set of connected, interacting parts that form a more complex whole. If you hold a pen in the air, you, the pen, and the ground form an energy system.

The energy of the system will increase or decrease depending on the height you hold the pen above the ground. **Energy** is the ability to do work. **Work** is any change in position, speed, or state of matter due to force. Examples of work include heating an object or moving an object.

Energy can either be stored or in motion. Energy that is stored is called **potential energy**. The energy of motion is called **kinetic energy**.

**Forms of Energy**

Energy is never created or destroyed, but it can change from one form to another. When you hold a pen above ground, a form potential energy called gravitational potential energy is stored in the system. **Gravitational potential energy** is the energy stored in an object as a result of its vertical position or height above the ground.

If you drop the pen and it falls to the ground, the gravitational potential energy changes into kinetic energy.

Any object in motion has kinetic energy. A dog running across a field has kinetic energy because it is in motion. A ringing doorbell has the kinetic energy of sound.
Energy Systems

Energy can transfer into or out of systems or objects when a force is applied.

For example, imagine that you lift a ball above the ground. You, the ball, and the ground make up an energy system. Your lifting provides a force that transfers energy to the ball. This force is necessary to overcome the downward pull of Earth’s gravity. The energy system gains gravitational potential energy because of the ball’s position above the ground.

The higher you hold the ball, the more gravitational potential energy there is stored in the energy system. This is a cause-and-effect relationship. The height of the ball causes the amount of energy stored in the system to change (the effect).

When you drop the ball, that potential energy transforms into kinetic energy as the ball moves to the ground. In a perfect system, the total amount of energy is conserved as it transforms from one form to another. That means that however much potential energy there was stored in the energy system, that same amount of energy will transform into kinetic energy as the ball falls to the ground.
However, in the real world, some of that energy is transferred out of the system. For example, friction transfers energy out of a system. Friction is a force that slows motion when two objects rub against each other. Friction slows motion because it causes some of the energy of the moving object to change into heat. Friction is why your hands feel hot after you rub them together.

Drag, also called air resistance, is another force that transfers energy out of a system. Drag is similar to friction, but it occurs between a solid substance and a fluid such as air. As the ball falls to the ground, it experiences drag as it moves through the air. The force of drag causes some of the ball’s energy to transfer out of the system. It’s important to point out that energy didn’t disappear. Instead, it transferred out of the system.

These same concepts can be applied to a roller coaster. Think about the roller coaster as a system. The roller coaster system is made up of Earth, the track, and the roller coaster cars. The cars are pulled to the top of the first hill, usually with a long chain that runs underneath the tracks. The chain provides the force that moves the roller coaster cars away from the ground. This force transfers energy to the roller coaster system. As the cars climb up the hill, the system gains gravitational potential energy.

As the cars climb up the hill, the system gains gravitational potential energy.
Read the following article¹, and then answer the questions below.

Have you ever looked closely at a roller coaster? Did you realize it doesn’t have an engine? Have you ever stopped to wonder how a roller coaster operates at such high speeds without one? As the roller coaster rises higher and higher into the air, its potential energy keeps growing until it reaches its maximum potential energy at the crest of a hill.

When a roller coaster reaches the top of the first big hill, gravity takes over, causing the roller coaster to fall down at a constant rate of 9.8 meters per second squared. All that stored potential energy changes to kinetic energy.

Roller coaster rides are so exciting (or terrifying!) for some people because of the other forces at work on your body during the ride. The forces of gravity and acceleration that move the roller coaster along the track also affect your body in the same ways. For example, when you go around a sharp curve or a loop-the-loop, special forces of acceleration push you in different directions. Not only do these forces keep you in your seat, but they also are responsible for the exhilarating feelings you get that some people call a “rush.”

Some people also love the weightless feeling you get briefly at the top of a loop-the-loop. That feeling you get is caused by two forces countering one another: gravity is pulling you toward the ground at the same time as inertia is pulling you toward the top of the loop.

If you want to ride the world’s fastest roller coaster, you’ll need to catch a flight to Ferrari World in Abu Dhabi, which is part of the United Arab Emirates. There you can ride the Formula Rossa, which reaches an amazing top speed of 149.1 miles per hour. The ride is so intense that passengers must wear goggles to protect their eyes!

**Questions:**

1. What is the central idea in this article?
2. What details does the author use to support the article’s main idea?
3. In two sentences, summarize the article, leaving out all opinions or judgments.

¹ Adapted from http://wonderopolis.org/wonder/how-do-roller-coasters-work/
# Section 2 Review

<table>
<thead>
<tr>
<th><strong>Multiple Choice</strong></th>
<th><strong>Critical Thinking</strong></th>
</tr>
</thead>
</table>
| **MC3.** You throw a ball up in the air. What causes the ball to fall back to the ground?  
  A. variable  
  B. acceleration  
  C. gravity | **CT6.** Your friend Mary doesn’t believe that all objects have gravity. Mary believes this because objects such as pencils, cars, and people don’t attract each other with their gravity. How would you explain why we can’t observe the effects of the gravity of any of these objects? |
| **MC4.** Which of the following best describes the relationship between mass and gravity?  
  A. More massive objects have more gravity.  
  B. Less massive objects have more gravity.  
  C. There is no relationship between mass and gravity. | **CT7.** A roller coaster is an example of an energy system, as is a person. What is another example of an energy system? |
| **MC5.** Which of the following best explains why roller coaster cars lose energy as they move over the track?  
  A. Energy is transferred into the roller coaster system.  
  B. Energy is transferred out of the roller coaster system.  
  C. Some energy is destroyed as the roller coaster cars move. | **CT8.** Why does friction make your hands feel warm after you rub them together? How is this an example of energy being transferred? |
Section 3: Energy Transfer in Collisions

The Game of Billiards

The game of pool, also called pocket billiards, has a history that dates back to the 15th century in northern Europe. It evolved from a game similar to croquet that was played outside, where a mallet is used to hit balls through hoops. This is why the cloth of the table today is green. It was intended to mimic the color of grass. The game was also the first sport to have a world championship.

If you were to watch a game of billiards, you would see energy transfer and energy conservation happening with almost every turn. There are different kinds of billiards, but the scientific principles remain the same in all of them.

Playing Billiards

At the beginning of the game, solid and striped balls are grouped together, leaving out the cue ball, which is the white ball. Someone then “breaks,” which means that person uses a cue stick to hit the white cue ball toward the group of colored balls. The cue ball is supposed to “break up” the group of solid and striped balls.

You can think about the game of billiards as a system consisting of the balls and the table. The outside force of a person hitting the cue ball causes energy to transfer from the cue stick to the cue ball and then to the other balls. In a perfect system, the same amount of energy put into the cue ball is going to be conserved and transferred to the other balls because of the conservation of energy. In the real world, some energy transfers out of the system because of friction caused by the white cue ball moving across the table, and drag as it moves through the air.
Transferring Energy

Whenever two objects come into contact with each other, both objects exert a force on each other. For example, when the cue ball hits another ball, the force of the collision transfers some of the cue ball’s kinetic energy into the second ball.

This transfer of energy changes the motion of the billiard balls. This is why the solid and striped balls begin to move after a break—the white cue ball has transferred kinetic energy that causes the other balls to move. If the cue ball is hit with a smaller force, it will have less energy to transfer to the other balls. If it is hit with a greater force, it will have more energy to transfer to the other balls.

Motion after Energy Transfer

The motion of the white cue ball after it hits another ball depends on how exactly it hits the other ball. For example, the cue ball will stop moving if it travels in a straight line and hits the other ball exactly in the middle of the other ball. This is because of energy conservation. All of the energy from the white cue ball is transferred to the other ball.

However, you’ll often notice in a game of billiards that the cue ball keeps moving after hitting another ball. This is because the cue ball did not hit the other ball exactly in its middle. As a result, not all of the cue ball’s energy is transferred to the other ball, so the cue ball keeps moving before friction eventually causes it to stop.
Section 3 Review

<table>
<thead>
<tr>
<th>Multiple Choice</th>
<th>Critical Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MC6.</strong> Pedro plays tennis. Which of the following statements describes the outcome of the energy transfer that takes place when Pedro hits the tennis ball with his racquet?</td>
<td><strong>CT9.</strong> In a baseball game, the hitter swings a bat at the ball. Why does the hitter usually want to hit the ball with a lot of force?</td>
</tr>
<tr>
<td>A. Pedro’s racquet transfers energy to the ball, causing the ball to move forward.</td>
<td><strong>CT10.</strong> In the example above, of the baseball player hitting a ball with a bat, why is there a loud noise when the bat makes contact with the ball?</td>
</tr>
<tr>
<td>B. The ball transfers energy to Pedro’s racquet, causing the racquet to move backward.</td>
<td><strong>CT11.</strong> After the baseball player hits the ball and the ball moves into the baseball field, why does it eventually fall down, either to the ground or to the glove of another player?</td>
</tr>
<tr>
<td>C. Both A and B</td>
<td><strong>CT12.</strong> Imagine that the baseball hitter gently taps the ball rather than swinging with a lot of force. This causes the ball to roll forward on the ground. If another player doesn’t stop it, why will the ball eventually stop rolling?</td>
</tr>
</tbody>
</table>

**MC7.** Two objects are moving at the same speed. Object 1 is more massive than Object 2. Which of the following statements is true?  
A. Object 1 has more kinetic energy than Object 2.  
B. Object 2 has more kinetic energy than Object 1.  
C. The kinetic energy of both Object 1 and Object 2 are the same because they’re moving at the same speed.
Science Words to Know

cause and effect – a relationship between events or things, where one is the result of the other

data – the measurements and observations gathered from an experiment

energy – the ability to do work

experiment – a specific procedure that tests if a hypothesis is true, false, or inconclusive

force – a push or pull that acts on an object, changing its speed, direction, or shape

gravitational potential energy – the energy stored in an object as a result of its vertical position or height above the ground

gravity – the force of attraction between all matter; more massive objects have a stronger gravitational force

hypothesis – a clear and concise statement that can be proved true or false

kinetic energy – energy of motion

mass – a measure of the amount of matter that makes up an object or substance; measured in grams (g)

pattern – something that happens in a regular and repeated way

potential energy – energy that is stored

science – all knowledge gained from experiments
**scientist** – a person who follows a scientific process to discover new knowledge

**system** – a set of connected, interacting parts that form a more complex whole

**weight** – a gravitational force exerted on an object by a planet or moon; measured in newtons (N)

**work** – any change in position, speed, or state of matter due to force

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**Back Cover:**

The back cover shows a photograph of a roller coaster. How does energy transform between potential and kinetic energy in a roller coaster energy system?