Teacher Guide and Student Journal
Sample Activity and Planning Pages

Energy and the Electromagnetic Spectrum
MSPNG3

A Middle School Unit supporting Next Generation Science Standards and Michigan Science Standards

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Next Generation Science Standards
and the Michigan Science Standards

Developed and written by
Battle Creek Area Mathematics and Science Center
for

CEREAL CITY SCIENCE by BCAMSC

Energy and the Electromagnetic Spectrum

Pre-Activity Informational Pages

Activities

Appendix

NEXT GENERATION SCIENCE STANDARDS

Disciplinary Core Ideas/Performance Assessments	Activity
PS3.A: Definitions of Energy • Motion energy is properly call kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. (MS-PS3-1) • A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2) • Temperature is the measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (MS-PS3-3), (MS-PS3-4)	1, 2, 3, 4, 5, 6, 7, 8
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.	2,3
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	1,2,3,
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. *	8
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	1,2,3,4,
PS3.B: Conservation of Energy and Energy Transfer • When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5) • The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3-4) • Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)	1, 2, 3, 4, 5, 6, 7, 8
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. *	5,8
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	1,2,3,4,5
MS-PS3-5. Construct, use, and present argument to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.	1,2,3,4
PS3.C: Relationship between Energy and Forces • When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)	1,2,3,4
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	4,5

*The performance Expectations marked with an asterisk integrate traditional science content with engineering through a Practice and Disciplinary Core Idea.

NEXT GENERATION SCIENCE STANDARDS

Disciplinary Core Ideas/Performance Assessments	Activity
ETS1.A: Defining and Delimiting an Engineering Problem • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the design solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. *(Secondary to MS-PS3-3)*	1,2,3,4,5,8
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*	5,8
ETS1.B: Developing Possible Solutions • A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. *(Secondary to MS-PS3-3)*	1,2,3,5,8
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. *	8
PS4.A: Wave Properties • A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. (MS-PS4-1) • A sound wave needs a medium through which it is transmitted. (MS-PS4-2)	5, 6, 7
MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy of a wave.	5, 6, 7
MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	5, 6, 7
PS4.B: Electromagnetic Radiation • When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (MS-PS4-2) • The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. (MS-PS4-2) • A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. (MS-PS4-2) • However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (MS-PS4-2)	5, 6, 7
MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	5, 6, 7

NEXT GENERATION SCIENCE STANDARDS

Science and Engineering Practices/Performance Assessments	Activity
Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to describe phenomenon. (MS-PS4-2) • Develop a model to describe unobservable mechanisms. (MS-PS3-2)	1,2,3,4,5,6,7,8
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	1,2,3
MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	5,6,7
Planning and Carrying Out Investigations Planning and carrying out investigations in 6–8 builds on K–5 and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MS-PS3-4)	2,3,4,5,6,7,8
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	2,3,4,5
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Construct and interpret graphical displays of data to identify linear and nonlinear relationships. (MS-PS3-1)	1,2,3,4,5,8
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.	2,3
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories. • Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3)	1,2,3,4,5,6,7,8
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*	5,8

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NEXT GENERATION SCIENCE STANDARDS

Connections to Nature of Science	
Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed worlds. • Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon. (MS-PS3-5)	3,5
MS-PS3-5. Construct, use, and present argument to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.	1,2,3,4
Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS3-4), (MS-PS3-5), (MS-PS4-1)	1,2,3,4,5,6,7
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	1,2,3,4,5
MS-PS3-5. Construct, use, and present argument to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.	1,2,3,4
MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy of a wave.	5,6,7
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use mathematical representations to describe and/or support scientific conclusions and design solutions. (MS-PS4-1)	3,6,7
MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy of a wave.	5,6,7
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods. • Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings.	2,4,6,7

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NEXT GENERATION SCIENCE STANDARDS

Crosscutting Concepts/Performance Assessments	Activity
Scale, Proportion, and Quantity • Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. (MS-PS3-1), (MS-PS3-4)	1,2,3
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.	1,2,3
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	1,2,3
Systems and System Models • Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems. (MS-PS3-2)	1,2,3,4
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	1,2,3
Energy and Matter • Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion). (MS-PS3-5) • The transfer of energy can be tracked as energy flows through a designed or natural system. (MS-PS3-3)	1,2,3,4,5,8
MS-PS3-5. Construct, use, and present argument to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.	2
MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*	5,8
Structure and Function • Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. (MS-PS4-2) • Structures can be designed to serve particular functions. (MS-PS4-3)	5,6,7,8
MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	5,6,7,8
Patterns • Graphs and charts can be used to identify patterns in data. (MS-PS4-1)	2,3,5,6
MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy of a wave.	6

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NEXT GENERATION SCIENCE STANDARDS

Connections to Engineering Technology and Applications of Science	
Influence of Science, engineering, and Technology on Society and the Natural World • Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations. (MS-PS4-3)	6,7,8

UNIT AT A GLANCE

Activity	Time to Complete	Questions	Phenomena	Summary: Students Will…
1 Moving with Potential and Kinetic Energy	Preparation: 20 minutes Activity: 6 classes Lesson 1A: 55–60 min., 2 classes Lesson 1B: 55–60 min., 2 classes Lesson 1C: 55–60 min., 2 classes	How are roller coasters designed to provide fast, thrilling, and safe rides? What is the connection between potential and kinetic energy and the roller coaster ride?	**Roller coaster video with initial descent and loop** **Design challenge: Develop a model of a roller coaster within a set of criteria and constraints**	• Generate questions about how the car on the roller coaster moves. • Develop a driving question chart and activity summary chart. • Develop an engineering plan for their roller coaster model. • Test three different balls of different masses on their model roller coasters. • Measure mass • Measure distance • Investigate the effect of the mass of the ball on the speed on the roller coaster model.
2 Mass and Friction	Preparation: 15 minutes Activity: 7 classes Lesson 2A: 55–60 min., 2 classes Lesson 2B: 55–60 min., 2 classes Lesson 2C: 55–60 min., 2 classes Lesson 2D: 55–60 min.	How does the mass of a ball affect its speed and distance? How does the mass of a ball affect the amount of friction between the ramp and the ball?	**Roller coaster video with initial descent and loop** **Design challenge: Develop a model of a roller coaster within a set of criteria and constraints**	• Collect data to determine the effect of the mass of the ball on its motion down a ramp. • Collect data on the speed of each ball. • Collect data to determine the force applied by the different balls at the end of the ramp. • Collect data to determine how the mass of the ball affects the impact of its collision with sand.
3 Energy in the Skate Park	Preparation: 20 minutes Activity: 2 classes Lesson 3A: 55–60 min. Lesson 3B: 55–60 min.	How are the potential and kinetic energy transformations similar and different when comparing the motion of the roller coaster to the motion in a skate park?	**Roller coaster video with initial descent and loop** **Skateboarding on a half-pipe or ramp.**	• Use an interactive to make comparisons between potential and kinetic energy in a skate park and the roller coaster. • Use an interactive to determine the effect of the force of friction and thermal energy that leaves the system.

UNIT AT A GLANCE

Students Figure Out How to:	Practices/Crosscutting	PE at Lesson Level and Assessment
• Develop a sketched model of their initial ideas of how the roller coaster moves in the initial drop and loop. • Develop a scaled physical model of a roller coaster to meet criteria. • Design their roller coaster to accommodate three different balls with different mass. • Calculate speed using time and distance data. • Analyze and interpret their data. • Identify kinetic and potential energy within the roller coaster system.	**Asking Questions and Defining Problems** **Developing and Using Models** **Analyzing and Interpreting Data** **Constructing Explanations and Designing solutions** **Scale, Proportion, and Quantity** **Systems and System Models** **Energy and Matter**	**PE at Lesson Level** Explore the behavior of balls of different mass on a model roller coaster track. **Formative Assessment** Activity Pages initial models roller coaster plans What We Think chart Science Talk
• Recognize and solve challenges of getting the three balls to complete the roller coaster ride on their models. • Construct explanations from their data to solve problems of the three balls of different mass on the roller coaster model. • Plan and carry out an investigation to determine how the mass of the ball affects the speed it travels and the force it exerts in a collision.	**Constructing Explanations and Designing Solutions** **Analyzing and Interpreting Data** **Planning and Carrying Out Investigations** **Developing and Using Models** **Obtaining, Evaluating, and Communicating Information** **Cause and Effect** **Scale, Proportion, and Quantity** **Energy and Matter** **Systems and System Models** **Patterns**	**PE at Lesson Level** Plan and carry out investigations into the effect of mass and friction on the motion of three different balls on a roller coaster track. **Summative Assessment** Activity Page Science Talk Journal Entries roller coaster models roller coaster criteria
• Determine the transfer of potential and kinetic energy in the skate park system and the roller coaster system. • Explore the energy transfer due to friction. • Explore the thermal energy that is a result of friction within the skate park and roller coaster system. • Determine how friction affects the speed of the different balls as they travel along the track of the roller coaster. • Determine how energy is conserved in a system.	**Planning and Carrying Out Investigations** **Developing and Using Models** **Using Mathematics and Computational Thinking** **Engaging in Argument from Evidence** **Constructing Explanations and Designing Solutions** **Analyzing and Interpreting Data** **Cause and Effect** **Energy and Matter** **Systems and System Models** **Patterns**	**PE at Lesson Level** Use a simulation of motion in a skate park to make comparisons of potential and kinetic energy. Consider the effect of friction on the energy in the skate park and roller coaster systems. **Summative Assessment** Activity Pages Journal Entries Science Talk

UNIT AT A GLANCE

Activity	Time to Complete	Question	Phenomena	Students Will…
4 Particles on a "Roller Coaster"?	Preparation: 15 minutes Activity: 5 classes Lesson 4A: 55–60 min. Lesson 4B: 55–60 min., 2 classes Lesson 4C: 55–60 min. Lesson 4D: 55–60 min.	How does wrapping our hands around the hand boiler make the liquid bubble and move up the corkscrew tubing?	**Motion of the liquid in a hand boiler**	• Raise questions based on observations of the hand boiler • Mix hot and cold water to observe and collect data about the interaction between particles that are at different temperatures. • Make observations of an apparatus that provides evidence that heat moves from warmer objects to colder objects. • Make observations to gather evidence that when the temperature of air is increased, the particles move more rapidly and can apply a force.
5 The Sun Produces Light and Heat	Preparation: 20 minutes Activity: 5–6 classes Lesson 5A: 55–60 min. Lesson 5B: 55–60 min., 2 classes Lesson 5C: 55–60 min., 2–3 classes	How can we find out what causes the sunlight shining on the hand boiler to make the ethyl alcohol to move and bubble? How does the sun warm Earth?	**Motion of the liquid in a hand boiler when placed on black paper in the sunlight**	• Raise questions based on observations of the hand boiler on black paper and in the sunlight. • Carry out an investigation into the effect of sunlight on black and white boxes. • Plan and carry out an investigation about the effect of light on a variety of materials.
6 The Behavior of Light	Preparation: 15 minutes Activity: 6 classes Lesson 6A: 55–60 min., 2 classes Lesson 6B: 55–60 min. Lesson 6C: 55–60 min. Lesson 6D: 55–60 min. Lesson 6E: 55–60 min.	What happens to light when it travels through different media? What is the effect of light traveling through water and glass? How are rainbows made?	**Sunlight streaming through clouds** **Rainbows**	• Work collaboratively to demonstrate how light travels in a straight path. • Make observations of waves on water to apply to light and sound waves. • Use the Slinky toy as a model of waves. • Obtain information from text about light and how light travels. • Use simulations to determine the wavelength and frequency of waves and how energy travels in waves. • Make rainbows with prisms. • Conduct investigations into the effect traveling through different material has on light.

UNIT AT A GLANCE

Students Figure Out How to:	Practices/Crosscutting	PE at Lesson Level and Assessment
• Develop models of the motion of the liquid in the hand boiler. • Critique and ask questions based on observations of the models of others. • Gather information from investigation and text to figure out how the hand boiler works and Earth gets heated. • Write a scientific explanation based on evidence. • Apply their understanding of thermal energy and how the sun warms Earth to the engineering design challenge.	**Asking Questions and Defining Problems** **Developing and Using Models** **Planning and Carrying Out Investigations** **Analyzing and Interpreting Data** **Constructing Explanations and Designing Solutions** **Obtaining, Evaluating, and Communicating Information** **Cause and Effect** **Energy and Matter** **Systems and System Models**	**PE at Lesson Level** Obtain information through investigation and analyzing and interpreting data on the effect of adding thermal energy to a system. **Formative Assessment** initial models and questions Science Talk Activity Pages **Summative Assessment** Journal Entry Activity Pages Science Talk final models
• Develop models of the motion of the liquid in the hand boiler on black paper and in the sunlight. • Critique and ask questions based on observations of the models of others. • Analyze and interpret data from their investigations. • Construct explanations based on data.	**Asking Questions and Defining Problems** **Developing and Using Models** **Planning and Carrying Out Investigations** **Analyzing and Interpreting Data** **Constructing Explanations and Designing Solutions** **Engaging in Argument from Evidence** **Cause and Effect** **Energy and Matter** **Structure and Function** **Patterns**	**PE at Lesson Level** Use their understanding of the effect of thermal energy on matter to figure out the motion of the liquid in the hand boiler and how the sun warms Earth. **Formative Assessment** initial models and questions Science Talk Journal Entry **Summative Assessment** investigations Science Talk Journal Entry models
• Develop a model to explain why light from the sun creates streaks of light through the clouds. • Develop a demonstration, using given material, to demonstrate that light travels in a straight path. • Use scientific reasoning to determine that heat needs matter to move from place to place but light can travel through space (nothing). • Relate models of mechanical waves and waves on water to light waves. • Develop models of how rainbows are made.	**Asking Questions and Defining Problems** **Developing and Using Models** **Planning and Carrying Out Investigations** **Obtaining, Evaluating, and Communicating Information** **Constructing Explanations and Designing Solutions** **Influence of Science, Engineering, and Technology on Society and the Natural World** **Cause and Effect** **Structure and Function** **Patterns**	**PE at Lesson Level** Develop and use a wave model to explain brightness, color, and bending of light as it travels through media. **Formative Assessment** initial models and questions Activity Page Science Talk Journal Entry **Summative Assessment** Activity Pages demonstrations Journal Entries class chart Science Talk

UNIT AT A GLANCE

Activity	Time to Complete	Question	Phenomena	Students Will…
7 **Beyond Visible Light**	Preparation: 30 minutes Activity: 5 classes Lesson 7A: 55–60 min., 2 classes Lesson 7B: 55–60 min., 2 classes Lesson 7C: 55–60 min.	How does ultraviolet light affect different materials? How do scientists know that there is light beyond visible light?	**Images of animals in the dark using infrared light** **Sunburned skin**	• Review their understanding of how light is necessary for sight. • Relate the light they see to the visible light on the electromagnetic spectrum. • Share ideas of how we can use special instruments to see in the dark. • Replicate the investigations of other scientists. • Use ultraviolet beads to determine where the effect of UV light is strongest.
8 **Warm It Up!**	Preparation: 20 minutes Activity: 3–4 classes Lesson 8: 55–60 min., 3–4 classes	What energy transfers take place in a solar oven? How can we solve a problem using energy from the sun?	**Engineering Design Challenge: Design a solar oven to meet criteria**	• Read the scenario to become familiar with the problem to solve. • Make a solar oven using the pizza box design. • Work in groups to design, build, and promote their product.

UNIT AT A GLANCE

Students Figure Out How to:	Practices/Crosscutting	PE at Lesson Level and Assessment
• Collaborate and share ideas and questions about how we can use special instruments to see in the dark. • Categorize questions by content. • Obtain information from what other scientists have learned through reading and other media. • Use data to support the understanding that there is light beyond the visible spectrum. • Construct a scientific explanation based on evidence. • Plan and carry out an investigation into the strength of ultraviolet light in different areas. • Read a label on a sunscreen bottle.	**Asking Questions and Defining Problems** **Obtaining, Evaluating, and Communicating Information** **Constructing Explanations and Designing Solutions** **Developing and Using Models** **Planning and Carrying Out Investigations** **Interdependence of Science, Engineering, and Technology** **Influence of Science, Engineering, and Technology on Society and the Natural World** **Cause and Effect** **Structure and Function**	**PE at Lesson Level** Obtain information through investigation and text to provide evidence of light beyond the visible spectrum. **Summative Assessment** Journal Entry Activity Pages Science Talk initial and final models investigations research projects
• Collect data on the original design and make improvements to meet criteria, • Present and explain how their ovens meet the criteria. • Develop and present an "infomercial" to sell their design.	**Developing and Using Models** **Constructing Explanations and Designing Solutions** **Analyzing and Interpreting Data** **Planning and Carrying Out an Investigation** **Energy and Matter** **Interdependence of Science, Engineering, and Technology** **Influence of Science, Engineering, and Technology on Society and the Natural World** **Structure and Function**	**PE at Lesson Level** Use information from investigations and lessons to solve an engineering problem. Construct, test, and modify a device that uses energy from the sun to heat food. **Summative Assessment** models—solar ovens presentations/infomercials

Moving With Potential and Kinetic Energy

Teacher Background Information

Today's roller coasters are faster and more exciting than ever. The physics that factors into designing modern roller coasters includes potential energy, kinetic energy, gravity, and friction. Most roller coasters are driven by the force of gravity and the conversion between potential and kinetic energy. The principle of how roller coasters work is the law of conservation of energy, that energy cannot be created or destroyed but is transferred from one object or form to another.

No longer is the science curriculum teaching "forms of energy." Energy is no longer described in terms of light energy, wind energy, and electrical energy, but instead energy is described as transferring from place to place. There are various mechanisms for transferring energy between systems, such as light, electricity, wind, and collisions between objects or particles.

In the construction of roller coasters, engineers must have a firm understanding of gravitational potential energy and kinetic energy. Gravitational potential energy is the energy that an object has because of its height above the ground. Gravitational potential energy is equal to the object's mass multiplied by its height multiplied by the gravitational constant (PE=mgh). The highest point of a roller coaster has the greatest gravitational potential energy, and the lowest point on the coaster has the least gravitational potential energy. On the roller coaster ride it is not an either/or for potential energy and kinetic energy. Each can be exchanged for the other: at certain points the cars of the roller coaster may have just potential energy (at the top of the first hill), just kinetic energy (at the lowest point), and at all points in between the cars have a combination of kinetic and potential energy.

In the unit *MSPNG1, Forces: Contact and Non-Contact*, students were introduced to potential and kinetic energy through the forces and motion related to colliding objects and the following Disciplinary Core Ideas and Performance Expectations:

PS2.A: Forces and Motion

- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1)
- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2)

ESTIMATED TIME

Lesson 1A: 55–60 minutes, 2 class periods
Lesson 1B: 55–60 minutes, 2 class periods
Lesson 1C: 55–60 minutes, 2 class periods

OBJECTIVE

Make observations and carry out investigations to find out how engineers design roller coasters using potential and kinetic energy.

KEY QUESTIONS

How are roller coasters designed to provide fast, thrilling, and safe rides?

What is the connection between potential and kinetic energy and the roller coaster ride?

PRE ASSESSMENT

- Give the Pre Assessment to assess the students' prior knowledge of the topics included in this unit.
- Additional time may be necessary beyond the estimated lesson time.
- This same assessment will be given at the end of the unit so the students' Pre and Post Assessment responses can be compared.
- Be consistent in administering the Pre and Post Assessment.
- The assessment and rubric are located in the Assessment section of the unit.

MATERIALS NEEDED

For each student:
Student pages

For each group of 4:
Tennis ball
Post-It Notes

Teacher provides:
Chart paper
Markers
Post-It Notes

PS3.A: DEFINITIONS OF ENERGY

- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. (MS-PS3-1)
- A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)

PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER

- When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5)

TEACHING TIP

The tubing used for the model roller coasters is 3/4 inch insulation tubing, cut in half. If your students are fully engaged in designing their roller coasters beyond the six foot length provided, tubing can easily be purchased at a hardware or building store. You can also purchase additional pre-cut tubing through Cereal City Science? (269) 213-3904

- All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. (MS-PS2-2)

MS-PS2-1. Apply Newton's third law to design a solution to a problem involving the motion of two colliding objects.

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.

Engage the Learner
During the initial phase of learning, students are introduced to a phenomenon of a fast-moving roller coaster and an engineering design challenge to build a model of a roller coaster. The phenomenon and challenge are used to raise questions, share current thinking, and develop an initial model to explain what they think is happening to make the roller coaster move. The class will develop questions that will guide further exploration into gravity, friction, potential energy, and kinetic energy.

Lesson 1A: Raising Questions about Roller Coasters

Advance Preparation
Prepare a space for a What We Think chart that includes the driving question and an activity summary table. Plan to have the chart visible throughout the activities that relate to the roller coaster phenomenon.

Example: What We Think chart

What We Think	What Questions Do We Have and How Can We Find Out?	What We Did	What We Figured Out	How Does This Help Us to Figure Out the Phenomenon?
Students' initial ideas about how engineers design fast, thrilling, and safe roller coasters	Students' initial questions about how the roller coaster works	Description of what students did (related to the science and engineering practices)	New information as a result of the lesson	

Make copies of the Pre and Post Assessment for your class. See Assessment section for the assessment and rubric.

Make copies of the Parent Letter and Activities to Do at Home to be sent home.

Preview websites that show roller coasters and the transfer from potential energy to kinetic energy. During this part of the learning it is important for students to express and relate their current ideas about roller coasters. When you show the video(s) of roller coasters in action, turn the volume off and DO NOT include any explanations that may accompany the video. Examples:

https://www.youtube.com/watch?v=pJqIlARk0BY

https://www.youtube.com/watch?v=eGlN25rFOxs

Caution: Some explanations in videos may give misinformation about energy.

Preview the following simulation:
https://www.myphysicslab.com/roller/roller-single-en.html

Preview the following website picture gallery:
https://www.ultimaterollercoaster.com/coasters/pictures/

Procedure
Engage the learner.
Show the class a video of a roller coaster. At the conclusion of the video, invite students to share their ideas about the roller coaster and questions they have about how it reaches such high speeds, makes loops, and remains safe for passengers.

Discuss the phenomenon of the roller coaster with the class to share their initial ideas of what engineers need to know about motion to construct a roller coaster like the one in the video. Allow time for students to share their ideas and experiences with roller coasters. Ask:

- Is there any science involved in designing and building a roller coaster?
- What makes you think that? Can you tell us more?
- What about engineering? What do they need to know about the science involved in roller coasters? Explain what you mean by ________________.

Display the What We Think chart. Ask students if anyone has ideas of how roller coasters work or the science and engineering behind the roller coasters. To steer the brainstorming in the correct direction and encourage students to draw on their previous experiences and learning, place the tennis ball on the edge of the desk. After a few seconds, nudge the ball so it drops to the floor and bounces and rolls to a stop. To get the students to rely on their basic understandings of forces and motion, ask:

- What do we know about what causes objects to move? What do you mean by that? (CC)
- What forces are acting on the cars on the roller coaster?
- Do they have engines?
- If they have engines, should they be called coasters?
- What makes them go?
- What forces were involved in the motion of the roller coaster in the video?

ASKING QUESTIONS AND DEFINING PROBLEMS
Asking questions and defining problems in 6–8 builds on K–5 and progresses to specifying relationships between variables and clarifying arguments and models.
- Ask questions
  - that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information.
  - to clarify and/or refine a model, an explanation, or an engineering problem.

DEVELOPING AND USING MODELS
Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.
- Develop a model to predict and/or describe phenomena.
- Develop a model to describe unobservable mechanisms.

TEACHING TIP
If students begin to use terms such as energy, speed, acceleration, kinetic energy, potential energy or velocity, make a note to visit the vocabulary as the terms become useful in describing the phenomenon. In the MS unit, Forces: Contact and Non-contact students were introduced to the concepts of kinetic and potential energy in the context of colliding objects and the transfer of energy among objects in the system.

SCALE, PROPORTION, AND QUANTITY

- **Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.**

Record students' initial ideas of the motion of the roller coaster on the What We Think chart. Discuss any ideas that relate to how the car is put into motion, the initial climb and descent, loops, and other observations of the motion and position of the car. Students may also add their ideas about the motion of the people in the cars and how they are affected by the speed and position of the car during the ride. Record all ideas at this time.

Divide the class into groups of four students. Distribute Post-It notes to each group. Ask students to individually write as many questions they have about roller coasters on a piece of scrap paper. When the students have exhausted their own list, ask them to join the group and share questions. Ask each group to choose three of their most important questions and write one question per Post-It Note. Give the students three to four minutes to write their three questions on three different Post-It Notes. Encourage students to focus questions on how the roller coaster works and what engineers need to know to design fast, safe, and exciting rides.

After all students have generated at least three questions, have them share their questions with their group of four and look for similar questions and categories. Facilitate the question sharing by circulating among the groups and listening to their discussion. To help students make connections among questions, ask:

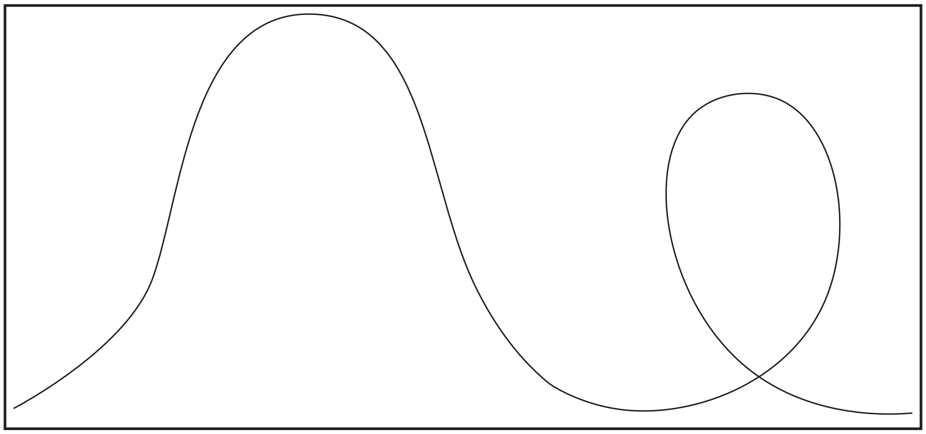
- ____________, how does your question about ____________ relate to any other questions from your group?
- How would you categorize your question? What is it mainly about?
- What do you think about what ____________ said? Do the rest of you agree? Why or why not?

Conduct a whole-class sharing of questions to post on the What We Think chart. Explain that in the following lessons, the class is going to attempt to answer as many of their questions as they can within the limits of classroom investigations and research. Ask a group to share one of their questions and how they categorized the question. Ask the class if any other questions were similar and would fit into the same category. Post all questions, by category, on the chart. Draw arrows between the questions and categories that are related or connected. Be sure all student questions are posted and honored.

When all the questions are posted and categorized, discuss the overarching or driving question that includes all their questions about the roller coaster. Example:

What do we need to know to build a safe and exciting roller coaster?

Replay the video and have students share their observations of motion and speed of the cars. Divide the class into groups of four. On the board or chart paper, draw a common segment of a roller coaster ride that includes a steep hill and a loop. Example:



Ask students to draw a model of what is happening during this segment of the roller coaster ride. Ask them to explain in their models the forces and other components that are necessary for the roller coaster car to move and stay on the track.

Have students draw and label the model in the Student Journal.

Draw a model of the drop and loop segment of the roller coaster that explains how the energy changes as the roller coaster safely moves on the track. Reminder: models are representations of your current thinking that explain a phenomenon. Be sure to use labels, arrows, and other symbols that represent the components that explain the roller coaster segment.

After the students have had the opportunity to draw their model on their own, divide the class into groups of four and encourage them to share their ideas within their group. Facilitate the group sharing by circulating among the students and listening to their ideas and observing their models. Allow time for students to make revisions based on the group discussion. As a class, revisit the What We Think chart and make additions and revisions, and add new questions as needed.

Facilitate the group model development by circulating among the students and listening and observing their ideas. To help groups in brainstorming their first model, ask:

- What observable or measurable changes are taking place within the roller coaster system? (CC)
- Can someone describe the system you are modeling? (CC)
- Where in the system are energy changes taking place? (CC)
- Where do you think the energy is coming from? (CC)
- Where do you think the energy goes? What makes you think that? (CC)
- Is the energy still within your system? (CC)
- How will you show the amount and changes of energy within your system in your model? (CC)

TEACHING TIP

Categories for student questions may include: speed, time, twists and loops, safety, force, starting, stopping, energy, coaster car, coaster track. Some questions may be appropriate in more than one category. Draw lines that connect related questions and categories. Students may suggest that speed is related to energy or that time is related to speed.

DEVELOPING AND USING MODELS

Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena.
- Develop a model to describe unobservable mechanisms.

SYSTEMS AND SYSTEM MODELS

- Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems. (MS-PS3-2)

ENERGY AND MATTER

- Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion). (MS-PS3-5)
- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS-PS3-3)

Explain that in the next few lessons, students will be engaged in carrying out investigations to answer their questions, become engineers, and design a model of a roller coaster that is fast, exciting, and safe. Remind students that these are their initial models and they will be able to revisit their initial thinking as they learn new information.

Assessment: Formative

Use the initial models and student ideas from the What We Think chart to assess their initial ideas about kinetic energy and potential energy.

Use the Activity Pages and initial models to assess the students' initial ability to develop a model to explain a phenomenon.

Lesson 1B: Sharing Ideas and Exploring Motion

Teacher Background Information
This lesson provides the opportunity for students to become engineers and collaborate on ideas to develop a plan to build a model roller coaster. They get their ideas on paper and then share, compare, and critique their plans.

Advance Preparation
Cut the foam tubing in half lengthwise so each group has a tube that is a trough for the balls to roll down.

Make copies of the *Roller Coaster Product Descriptor* for each student.

Set up a materials table to display the options students have for building their initial models of a roller coaster (foam tubes, marbles, wooden balls, steel balls, paper cups, PVC ramps, tape, scissors, and books for propping up ramps).

Plan for students to work in groups of four using the provided materials. Each group will have one length of foam tubing, one of each of the balls, one ramp, and two paper cups.

Write the following headings across the top of four pieces of chart paper:

1. Asking Clarifying Questions
2. Asking a Probing Question
3. Adding to an Idea
4. Respectfully Disagreeing with an Idea

Procedure
Explore the concept.
Explain that the class is going to design and develop models of roller coasters to figure out the science and engineering behind them and try to answer their questions. Introduce the design challenge in the Student Journal. Show the materials available for the roller coaster designs on the materials table. Distribute the *Roller Coaster Product Descriptor* to each student.

Your team of engineers is challenged with designing and developing a model of a roller coaster to present to a group of investors of a large amusement park company. Review the design criteria and, individually, develop a model that explains your ideas of a roller coaster design and then share and compare with your team.

Use the space below and draw your initial plan for your model of a roller coaster to meet the criteria.

Use the space below to draw the team plan for the model of a roller coaster.

Write an explanation of how your team roller coaster starts its motion and how the motion of the car will continue to the end of the track.

Before the students begin to draw their plan for the models, take this opportunity to discuss the Engineering Design Process (see Engineering Design Process in the appendix) and how models make their thinking visible and can be modified as they gain information.

MATERIALS NEEDED

For each student:
- student pages
- handout: *Roller Coaster Product Descriptor*

For each group of 4:
- foam tubing, 6 foot length
- marble
- steel ball
- wooden ball
- 2 paper cups (small)
- 1 ramp
- *Roller Coaster Photograph Card Set*

For the class:
- tape
- scissors

Teacher provides:
- tape
- scissors
- cutter (for cutting foam)
- books for propping up ramps
- timing devices
- chart paper

PS3.A: DEFINITIONS OF ENERGY

- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. (MS-PS3-1)
- A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)

PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER

- When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5)

TEACHING TIP
As they complete their initial plans for their models, circulate around the room and look for common ideas among the plans and listen for the vocabulary students are using to describe the possible motion on the roller coaster and design ideas. Make a note of key terms the students are using and concepts that they are trying to describe to address in the following lessons. Students may ask for clarification on some terms mention in the criteria. Refrain from defining the terms at this time. Ask students to rely on their own ideas and ideas of their teammates.

DEVELOPING AND USING MODELS
Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena.
- Develop a model to describe unobservable mechanisms.

Discuss the benefits of getting initial ideas written and drawn and of testing and revising based on data from trials and the ideas of others. Explain that scientists and engineers go through a process before they present their final design and model and learn new information along the way. Discuss how the different types of models—drawing or sketches, and physical models or prototypes—are used to test ideas and make thinking visible to others. Ask students for ideas of how models help scientists and engineers. Discuss the initial drawing from the previous lesson and how that model remains unfinished until the students have gathered more information and evidence for their thinking.

Distribute the *Roller Coaster Photograph Card Set* to each group to help students brainstorm possibilities for designing their own roller coasters. Facilitate the individual and team brainstorming by circulating among the students and listening to their ideas. To help students rely on their own understanding and make connections among ideas, ask:

- How would you describe the problem you are trying to solve?
- What are some of the basic things you know about motion that will help you to design a roller coaster?
- Would it help to start to sketch it out?
- What do you know about getting things into motion? What is needed? Where will that come from in your roller coaster?
- What do you mean when you say _______________?
- Where will the coaster car be moving the fastest? What makes you think that?
- Where will the speed be the slowest? What makes you think that?
- What more do you need to find out to make sure your design gets the car to the end of the track?

After students have had the opportunity to put some of their own thoughts down on paper, have them share their ideas in their groups and develop a team model. When the groups are satisfied with their collective idea and have had time to share and brainstorm together, distribute chart paper and ask them to make their ideas public and share with the rest of the class.

When the groups are satisfied with their group design plans, have them display them in the room. Inform the class that these are just their initial plans and that engineers make revisions to their plans and models as they gain new information from trials and testing.

Explain that the class is going to do a gallery walk and listen to the ideas of others. Ask a student volunteer to explain how sharing ideas might help students help each other to develop a roller coaster model.

In order to conduct a friendly, nonthreatening critique, ask the class to establish some guidelines and rules for their critiquing methods. Ask students to create four anchor posters that will guide the class throughout the unit. Display the four posters with the questioning and critiquing categories. As a class, have students suggest how they might start a question or suggestion that asks a group to clarify, probe or dig deeper, disagree with, and add to an idea.

Anchor posters:

Respectfully Disagreeing With an Idea

- I agree with… but…
- I disagree with... because...
- I agree with part of your model but disagree with this part…
- I respectfully disagree because…
- I understand where you are coming from, but I have a different idea.
- I agree with you but also think…
- I see your reasoning, but I disagree with some of the ideas because...

Asking a Clarifying Question

- What do you mean by…?
- Can you be more specific about…?
- What makes you think that?
- What evidence do you have that supports that?
- How do you know?
- Can you tell us more about…?
- What do you mean by…?

Asking a Probing Question

- What do you mean by…?
- What makes you think that?
- If that were true, then wouldn't __________ be true?
- Where did you get this idea?
- How did you come up with…?

Adding to an Idea

- I agree with you, but also…
- I would like to add…
- I agree but also think…
- I agree with this part, but could you add…?
- Do you think adding ______ would make it more clear?
- I agree but have an idea that might add more clarity or information.
- Would it make it more clear if you added...?

Science Talk

Elaborate on the concept.

After the class has completed their questioning guidelines, do a gallery walk and invite each group to explain their models and thinking behind their roller coasters. Encourage students to ask questions of one another and make suggestions. If groups are hesitant to ask questions or make suggestions, begin the conversation by asking:

- Can you tell us more about this representation in your model?
- Do the rest of you agree? Why or why not?
- How is this model different from or similar to the previous model we viewed?
- What information from this model might you use to improve your own model?

CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Apply scientific ideas or principles to design, construct, and test a design of an explanation for real-world phenomena, examples, or events.
- Construct an explanation using models or representations.
- Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.
- Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3)

SYSTEMS AND SYSTEM MODELS

- Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems. (MS-PS3-2)

SCIENCE TALK
Science Talk is a conversation among the students that allows them to have the opportunity to orally express their ideas and listen to the ideas of others. Allow sufficient time for each student to express ideas and opinions. Create a classroom culture where all ideas are respected and considered.

Science Talk is not an add-on to science investigations. It addresses important science content and is a critical part of the lesson and learning. Science Talk can be whole group, small group and teams of two students. Through discussion with one another, students explore their ideas, make comparisons to the ideas of others, use evidence, and develop the skills to critique and prepare academic arguments. See Appendix, pp. 172–173 for Setting up your class for Science Talk.

- How are our models similar to and different from real roller coasters?

At the conclusion of the Science Talk, ask the class what more they need to know about motion, forces, energy, and gravity to help them in designing their roller coasters. Write their ideas on the What We Think chart. Listen for questions and ideas that relate to:

- How high or tall the first descent has to be to complete the track.
- What kind of ball should be used to roll down the track?
- How massive should the ball be to complete the ride?
- How big a loop or twist will the ball need?
- How can we make sure the ball stays on the track when it goes into the loop?
- How can we make sure the ball rolls to the end of the track?
- How can we model a full passenger car and an empty passenger car?

Explain that there are still questions to be answered and in the following lessons, the class will be exploring motion through the use of their roller coaster models and investigations that will give them information for their models.

Evaluate the students' understanding of the concept.
Assessment: Formative
Use the Activity Pages, student roller coaster plans, and Science Talk to assess the students' initial understanding of motion energy (kinetic energy) and stored (potential) energy and the relationship of kinetic energy to the mass of an object and to the speed of an object.

Use the Activity Pages to assess the students' understanding of how to construct and interpret data.

Use the Science Talk to assess the students' understanding of the role of friction on the motion of objects.

Lesson 1C: Building and Testing Model Roller Coasters

Teacher Background Information
During this lesson, students are given the opportunity to follow the Engineering Design Process to build the model and test their ideas. They are given little or no instruction at this time so they can gain information and generate new questions and ideas through the testing process. Students will be engaged in building a physical model of what they see in real life.

This lesson is not intended to complete their understanding. Student designs may not provide a track for all three balls, wooden, marble, and steel, to make it to the end successfully. The goal of the lesson is to raise more questions and identify the challenges and additional information needed to complete the roller coaster track that will support the three different balls and meet the roller coaster design criteria.

Explore the Concept
This phase in the process of figuring out how roller coasters work provides the opportunity for students to engage in exploring materials and to conduct investigations into motion as it applies to roller coasters. As they gather new information through investigation, engineering trials, and informational text they develop models of roller coasters within a set of criteria.

Advance Preparation
Set up a materials table to display the options students have for building their initial models of a roller coaster (foam tubes, marbles, wooden balls, steel balls, paper cups, PVC ramps, tape, scissors, measuring tape, timing device, and books for propping up ramps).

Make copies of the *Roller Coaster Product Descriptor* handout for each student.

Procedure
Engage the learner/Explore the concept.
Divide the class into groups of four. Show the class the items on the materials table. Explain that the class will work in groups to design their roller coasters based on their models. Revisit the roller coaster design criteria and review as a class. Explain that the marble ball represents a normal car, the wooden marble represents a car with one passenger, and steel marble represents a full car and that the engineering team's goal is to have each type of ball (passenger load) successfully complete the track and safely land in the cup.

Explain that when engineers design objects and structures, whether home appliances, bridges, railways, skyscrapers, sports equipment, or amusement park rides, they work within what they call "constraints." Constraints are the project requirements and/or limitations. Engineers must take into consideration these constraints in order to come up with successful design solutions for the builders to follow.

MATERIALS NEEDED

For each student:
- student pages
- handout: *Roller Coaster Product Descriptor*

For each group of 4:
- foam tubing, 6 foot length
- marble
- steel ball
- wooden ball
- 2 paper cups (small)
- 1 ramp
- measuring tape
- timing device

For the class:
- tape
- scissors

Teacher provides:
- tape
- scissors
- cutter (for cutting foam)
- books for propping up ramps
- timing devices

PS3.A: DEFINITIONS OF ENERGY
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. (MS-PS3-1)
- A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)

PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5)

TEACHING TIP

If you have groups that would like more track, have them join another group and combine material. Caution: Make sure all students are actively engaged when working in the larger group.

DEVELOPING AND USING MODELS

Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena.
- Develop a model to describe unobservable mechanisms.

CAUSE AND EFFECT

- Cause-and-effect relationships may be used to predict phenomena in natural or designed systems.

Discuss the constraints that engineers might follow when designing a roller coaster. Listen for ideas that relate to:

- safety (safe for people taller than four feet high)
- available building material
- budget
- maintenance requirements
- weather conditions
- level of excitement (loops, drops, corkscrews, sharp turns)
- time frame for completion

Ask the class to identify some of the physics concepts that they might need to use to be successful in building the roller coaster. Students may think of the basic constraints that go along with the basic laws of physics and motion:

- gravity
- speed
- friction
- slope
- balanced and unbalanced forces

Set a timer for the groups to build their roller coasters. Refer to the Student Journal pages that provide space for students to record the data from their trials. Assist the class in organizing their data and deciding what they will measure and where they can make close observations.

Use the space below to record your data with the three different balls and changes your team makes based on your trials.

Ball						

Facilitate the group engineering process by circulating among the students and observing their trials, checking for data that they collect during their trials, and listening to their discussions. Check to see if students are using science concepts and terms from previous units such as balanced forces, unbalanced forces, kinetic energy, potential energy (stored energy), and gravity. To help groups to make connections among science ideas and the application to the roller coasters, ask:

- Why did you decide to start your roller coaster at this height? What is the force that starts your ball rolling? Can you say more about that?
- What is the effect of changing the height of the initial descent? (CC) What makes you think that? How do you know the ball will make it around the loop and/or up the next hill? (CC)

- Why do you think the ball stays on the track in the loop?
- What causes the ball to make the tight curve in your roller coaster? (CC)
- What does Newton's Law say about an object in motion?
- What is the effect of using balls with different masses? (CC)
- Were you able to make a track that will accommodate all three balls? What adjustments did you have to make?
- Where on your roller coaster is the ball moving the fastest? Slowest? Does that make sense? Why?
- Can someone explain that in terms of energy within the system? (CC)
- ______________, I heard you use the term *energy*, can you explain what you mean by that? Can you explain how energy moves from place to place?
- How does the ball continue to move up the hill? What do you mean by __________?

Students may need considerable time to make adjustments to their track after trials. Listen for students who, through their trials, recognize that:

- The top of the first hill must be the highest point on the roller coaster.
- Balls move fastest at the bottoms of hills and slowest at the tops of hills.
- Friction has an effect on the speed of the balls and needs to be minimized to maintain maximum speed.
- To avoid falling, balls must have a certain velocity at the tops of loops.
- The mass of the balls has an effect on the motion of the balls.

Science Talk
Explain the concept and define the terms.
When the time allotted expires, have all groups bring their coasters to a circle and prepare to share their roller coasters, data, successes, and challenges. Encourage groups to ask questions and make comments about the different designs and how some ideas worked and some did not. Remind students to use the charts developed in the previous lesson to facilitate constructive questioning and comments. Ask students to look for patterns in their successes and challenges. Discuss how information can be gained through their failures. Ask:

- What did we learn when we were unsuccessful in our first trials?
- __________, you used the term _______________. Can you explain what you mean by that?
- Do the rest of your agree? Why or why not?
- What challenges do we have to work out before we meet the criteria?

Record their common findings on the last three columns of the What We Think chart. Allow time for students to revisit and make revisions and additions to their initial plans in the Student Journal in Lesson 1A.

TEACHING TIP
As you facilitate the group roller coaster building activity, listen for key terms or the need for science terms that will help in explanations. Take notes of the students' use of terms to be used during the Science Talk. Check for references to energy, potential energy, and kinetic energy during their discussion.

ANALYZING AND INTERPRETING DATA
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Construct and interpret graphical displays of data to identify linear and nonlinear relationships. (MS-PS3-1)
- Analyze and interpret data to provide evidence for phenomena.
- Consider limitations of data analysis (e.g., measurement error) and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).
- Analyze and interpret data to determine similarities and differences in findings.

TEACHING TIP

Have students keep their roller coaster models assembled for the following lesson.

Assessment: Formative

Use the Activity Pages, student roller coaster models, and Science Talk to assess the students' initial understanding of motion energy (kinetic energy) and stored energy (potential energy) and the relationship of kinetic energy to the mass of an object and to the speed of an object.

Use the Activity Pages to assess the students' understanding of how to construct and interpret data.

Use the Science Talk to assess the students' understanding of the role of friction on the motion of objects.

ENGINEERING DESIGN PROCESS

The Engineering Design Process provides students with a series of steps to guide them as they solve problems and design and test products, models, and solutions. The process is cyclical, yet not necessarily in an order. Students are encouraged to evaluate as they progress through the process, revisit the mission often, and revise thinking and their plan multiple times as the process unfolds.

Engineers do not always follow the Engineering Design Process steps in order, one after another. It is very common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change the design. Engineers must always keep in mind the mission or problem they are trying to solve and the limitations (cost, time, material, etc.) that are part of the solution to the problem. Two key elements in working as an engineer are teamwork and design-test-and-redesign.

Mission

- Defines the problem and what the engineers are trying to design or build.
- Describes the limitations within which the engineers must solve the problem.

Brainstorm Ideas

- Imagine, discuss, and sketch possible solutions.
- Conduct research into what has already been done.
- Discover what materials are available, time frame, and other limitations.

Plan and Design

- Draw and write a plan.
- Design your solution through drawing and manipulating materials.
- Develop a plan or steps and a schedule.

Build

- Construct your engineering device or project.
- Follow your plan.
- Adjust and test along the way.

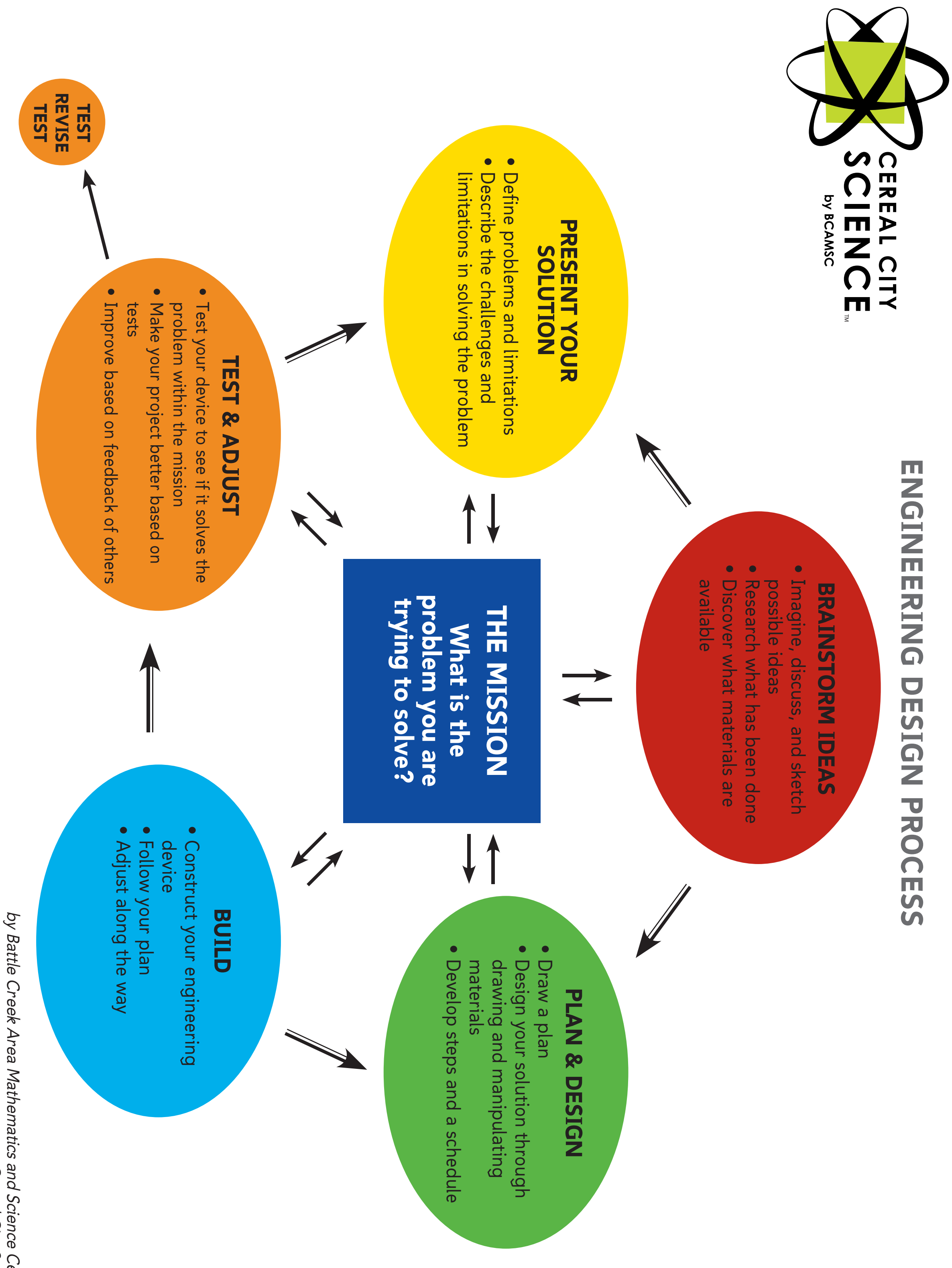
Test and Adjust

- Test your device to see if it solves the problem within the mission and limitations.
- Make your project better based on tests: Test → Revise → Test.
- Improve based on feedback of others.

Present Your Solution

- Demonstrate how your solution solves the problem.
- Define problems and limitations.
- Describe the challenges and limitations in solving the problem.
- Describe additional revisions that could improve the device or project.

ENGINEERING DESIGN PROCESS



by Battle Creek Area Mathematics and Science Center
Cereal City Science
Adopted from the Carnegie Mellon Robotics Academy

Student Journal
MS.PS.NGSS

Energy and the Electromagnetic Spectrum
MSPNG3

A Middle School Unit supporting Next Generation Science Standards and Michigan Science Standards

Name:_______________________________

Name: ______________________________

Date: ______________________________

Draw a model of the drop and loop segment of the roller coaster that explains how the energy changes as the roller coaster safely moves on the track. Reminder: models are representations of your current thinking that explain a phenomenon. Be sure to use labels, arrows, and other symbols that represent the components that explain the roller coaster segment.

Name: ______________________________

Date: ______________________________

Your team of engineers is challenged with designing and developing a model of a roller coaster to present to a group investors of a large amusement park company. Review the design criteria and, individually, develop a model that explains your ideas of a roller coaster design and then share and compare with your team.

Use the space below and draw your initial plan for your model of a roller coaster to meet the criteria.

Name: ______________________________

Date: ______________________________

Use the space below to draw the team plan for the model of a roller coaster.

Write an explanation of how your team roller coaster starts its motion and how the motion of the car will continue to the end of the track.

Name: ______________________

Date: ______________________

Use the space below to record your data with the three different balls and changes your team makes based on your trials.

<table>
<tr><td>Ball</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
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