3. Energy and Momentum

In this segment, students analyze and investigate energy conservation and transfer, as well as momentum, impulse and collisions. Students are expected to design and conduct investigations.	
Student Science Performance	
Grade or course: High School Physics **Topic: Energy and Momentum**	**Title:** Energy and Momentum

Performance Expectation for GSE:

SP3. Obtain, evaluate, and communicate information about the importance of conservation laws for mechanical energy and linear momentum in predicting the behavior of physical systems.

a. Ask questions to compare and contrast open and closed systems.

b. Use mathematics and computational thinking to analyze, evaluate, and apply the principle of conservation of energy and the Work-Kinetic Energy Theorem.
   - Calculate the kinetic energy of an object.
   - Calculate the amount of work performed by a force on an object.

c. Plan and carry out an investigation demonstrating conservation and rate of transfer of energy (power) to solve problems involving closed systems.

d. Construct an argument supported by evidence of the use of the principle of conservation of momentum to
   - explain how the brief application of a force creates an impulse.
   - describe and perform calculations involving one dimensional motion.
   - connect the concepts of Newton's 3rd law and impulse.
   - experimentally compare and contrast inelastic and elastic collisions.

Performance Expectations for Instruction:

1. Design an investigation of energy transfer and power.
2. Explain open and closed systems.
3. Apply the Work-Kinetic Energy Theorem to multiple scenarios.
4. Develop and defend an argument of the design of an egg structure that illustrates the conservation of momentum.

Additional notes on student supports

Materials:

- spring or elastic pop-up toys
- inclined air tracks or cart tracks with extra masses
- metersticks/rulers
- stopwatches
- egg design challenge materials

Students will continuously obtain, evaluate, and communicate information. This is not a linear process. Students will communicate through writing and discussions to allow for formative assessment. This benefits the teacher, student, and whole group to guide instruction to clarify misconceptions or extend content.

Engaging Learners	**Phenomenon** Energy is conserved with a spring or elastic pop-up toy.
	Obtaining In-class demo: using a spring toy or elastic pop-up toy, show students how the toy changes during its action.

	With similar equipment, students complete investigations to determine initial velocity of toy, maximum height, potential and kinetic energies, and total energy. *Teacher Notes: students have most likely been exposed to principles involving energy conservation in previous courses of 8^{th} grade science and/or physical science.* In-class demo: after students measure and calculate variables above with pop-up toys, show two scenarios: • A near-frictionless inclined surface, such as an air track, with a glider or similar object to move down • An inclined surface with object that will show friction. Pose questions to students before letting object move down the inclines: • If objects are at the same height, which one should reach the bottom first? Why? • Before moving, how are the potential energies of the objects similar/different? • Will energy by conserved in both scenarios? With the inclines at the same height above floor/lab table, let objects move down inclines. The surface with little friction should allow the object to move to the bottom first. Students are challenged to analyze similar scenarios with inclined planes to determine how friction influences energy conservation. Students conduct a Claim—Evidence—Reasoning format as they investigate in the next phase.
	Evaluating Initially, students make claims about the two inclined planes or scenarios before investigating.
	Communicating Students share claims with other groups
Exploring	*Obtaining* Students complete investigations of the inclined plane scenarios; students gather evidence to support or modify their initial claims. Optional student lab sheet; can be used in combination with the Claim—Evidence—Reasoning sheet. An additional or alternative format would be to use an online simulation, such as PhET lab Energy Skate Park or Energy Forms and Changes, where energy forms and changes are seen/played with. (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu)

	Teacher Notes: the intent of this segment of the lesson is for students to gain experience with the Work-Kinetic Energy Theorem; instead of simply giving them the equation at the start of the lesson, students are understanding how friction, or the work due the friction force, impacts energy and motion. With inclines at similar heights and similar mass objects, students will have hands-on experience and data of the impact that friction has here. Measurement devices, such as photogates, could be used in this state but are not necessary.
	Communicating Student groups share information after completing investigation and establishing their reasoning.
	Evaluating While students share results with other groups through a white board or poster sharing session, be sure assess the reasoning. Possible questions to pose to students: • *Is the claim based on evidence? How?* • *If your investigation was repeated, how might results change?* • *How is energy being converted in each scenario?* • *What are the final and initial energies of the objects?* • *What impact would increasing the mass of the objects have on the energies? The friction?* • *What impact would increasing the length if the incline, not height, have on the experiment?* • *How would your group change the experiment in order to increase/decrease the final kinetic of the objects?* • *How would your group change the experiment in order to increase/decrease the influence that friction has?*
	Formative Assessment of Student Learning
Explaining Finalizing Model	*Obtaining* After exploring energy transformation and conservation, students complete an investigation of the rate of energy transfer in the Horsepower Lab. *Teacher Notes: students should design and plan the investigation; students will have to consider the definition of work and how it applies to their own power generation. The lab can be done with a flight of stairs and simple equipment.* During this phase, or as a part of the lab, students should also explain open and closed systems. Consider demonstrations, such cold soda cans that collect condensation, or insulated materials. Students can compare these to the body as they complete the horsepower lab and think of real-world applications of system types.

	Evaluating Student experiments should show understanding of energy transformation, work, and rate of energy transfer.
	Communicating Students communicate results on lab sheets and through class discussion. Possible questions to pose to students: • *How is energy conserved during the experiment?* • *What types of energy are present?* • *How is energy transformed during the experiment?* • *What type of system is the human body (open, closed, isolated)? Why?* • *What factors influence power?* • *How could you increase your power output?* • *Why is power a useful unit for machines?* Optional Problems for energy conversion and transfer. These problems are used in conjunction with the Energy in a Roller Coaster simulation from PBS LearningMedia.
Elaborating Applying Model to Solve a Problems	**Phenomenon** An egg thrown into a loose vertical sheet will not break; this demonstration may surprise students and serves as an introduction to momentum and impulse. A sheet, or large fabric, can be hung from the ceiling away from a wall; have something soft on the floor to keep the egg from breaking as it falls. Even if the egg is thrown at high speed, it will not break; videos can be found online of possible setups.
	Obtaining Class discussion: Why does the egg not break in the demonstration? Quick write: have students individually write a response to the following questions: • What comes to mind when you hear the phrase "impact safety?" • What does car safety have to do with momentum? The egg drop challenge is a popular physics assignment, consider this as a design challenge. A possible challenge is for students to design a structure that will protect an egg from breaking after it is dropped from a certain height. The device should not use parachute design; the intent is for students to consider impulse and momentum transfer as the egg comes to rest after dropping. The student performance involves constructing an argument concerning momentum conservation.

<table>
<tr><td></td><td>Teacher Notes:
Parameters to consider:
Materials: limit the type or quantity that students use; for example, the design challenge could be “green” or recycled materials only.
Size: consider having maximum dimensions or mass.
Functionality: the device could have a requirement that the egg must be put in and taken out in less than 3 seconds (in comparison to seat belts).
Before students complete work on the design challenge, it is helpful to discuss examples of momentum conservation and provide opportunities for problem solving. Air tracks or cart tracks can be used for demonstrations and problem-solving examples.</td></tr>
<tr><td></td><td>Evaluating
The science practice of constructing an argument is evaluated during the egg drop design challenge. Students (or in groups) should be able to use evidence to construct an argument about how the design of their structure demonstrates momentum conservation, Newton’s 3rd law, and impulse.</td></tr>
<tr><td></td><td>Communicating
Students communicate predictions, evidence, and arguments in writing.</td></tr>
<tr><td>Evaluation</td><td>Assessment of Student Learning</td></tr>
<tr><td></td><td>Students are continually evaluated in this segment through class discussions, lab investigations, and student writing. Conduct a final argument session after the egg drop design challenge with an extension to car safety.</td></tr>
<tr><td>SEP, CCC, DCI</td><td>Science Essentials</td></tr>
<tr><td>Science and Engineering Practices</td><td>Asking questions and defining problems
Using mathematics and computational thinking
Planning and carrying out investigations
Engaging in argument from evidence</td></tr>
<tr><td>Crosscutting Concepts</td><td>Energy and Matter
Systems and System Models
Cause and Effect
Scale, Proportion, and Quantity</td></tr>
<tr><td>Disciplinary Core Ideas</td><td>From A Framework for K-12 Science Education:
PS2A: Forces and Motion
PS3A: Definitions of Energy
PS3B: Conservation of Energy & Energy Transfer
PS3C: Relationship between Energy and Forces</td></tr>
</table>

Additional Supports for struggling learners:

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

Reading:	Writing:	Math:
1. Provide reading support by reading aloud or doing partner reads 2. Have the teacher model what they are thinking when reading the text 3. Annotate the text with students so that they may refer to it as they work through the lab	1. The teacher can provide a sentence starter for the students. 2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic). 3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.	1. Provide calculators as needed. 2. Provide graph paper as needed.

Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should consider showing the demo more than once as needed for students to make observations.
2. The teacher should consider providing students a data sheet to record data.
3. The teacher should have clear and consistent guidelines for discussion. These guidelines should help students feel more comfortable and be more likely to participate.
4. The teacher should consider providing students with a CER template.
5. The teacher should consider providing students with sentence starters to give students a starting point on any writing assignments.
6. The teacher should consider providing students with multiple formats to share their work. These formats could include using technology, gallery walks or presenting.

Exploring:

1. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to drive student grouping.
2. The teacher should provide students with the lab sheet to record data.
3. The teacher should consider having students do both PhET simulations as practice and information gathering.
4. The teacher should consider having multiple formats for students to share their work. These formats could include using technology, gallery walks or presentations.
5. The teacher should consider providing students with a list of questions that they may use as they complete a gallery walk. This could help start conversations between students and make sharing easier.

Explaining:

1. The teacher might consider providing an organizer for designing an investigation.
2. The teacher should consider using guiding questions to assist students in designing their investigation.
3. The teacher should consider doing multiple demonstrations to have students see open and closed systems.
4. The teacher should consider a formative assessment. Then the teacher can use that data to determine which students need reviewing, re-teaching or enriching.
5. The teacher should have clear and consistent guidelines for class discussions. These guidelines should help students feel more comfortable and be more likely to participate.

Elaborating:

1. The teacher should consider showing the demo more than once as needed for students to make observations.
2. The teacher should have clear and consistent guidelines for discussion. These guidelines should assist students in feeling more comfortable and be more likely to participate.
3. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include writing, drawing, diagraming or verbally explaining.
4. Students may need additional time to complete their assignment.
5. The teacher should consider providing students with an organizer to complete the design process.
6. The teacher should consider using guiding questions to assist students in the investigation design process.
7. The teacher should consider providing students with the list of things to consider when designing their structure to protect the egg.
8. The teacher should consider showing a video of momentum conservation.
9. The teacher should consider providing students with opportunities to practice solving problems.

Evaluating:

1. The teacher should consider giving students multiple formats to communicate their knowledge. This could be drawing, writing or designing a presentation.
2. Students may need additional time to complete their assignments.

Claim—Evidence—Reasoning

Guiding Question: How does friction influence energy transfer?
Claim:
Evidence:
Reasoning:

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Inclined Plane Lab Student Sheet

Objective: Investigate energy transformation and friction

Experiment Setup: draw diagrams of both inclines

Free-Body Diagrams: draw force diagrams of both scenarios; include a diagram before the object is in motion and during.

Procedure: What measurements will be made? What calculations are needed? Outline the experiment steps below.

Data/Results:

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Horsepower Lab Student Sheet

Objective: Investigate energy transformation and the rate of energy transfer in the human body.

Experimental Procedure: Outline the experiment steps below. Consider: what is required for work? What measurements and calculations will be needed?

Data/Results:

How much work was done? How much power?

Convert power to horsepower. How does this amount compare to other objects? Is there a machine that has similar output to you?

Post-Lab:

How does mass influence the rate of energy transfer?

Describe the energy transformations that take place during the experiment.

Extension: How does the energy used in the lab compare to energy measurements in food?

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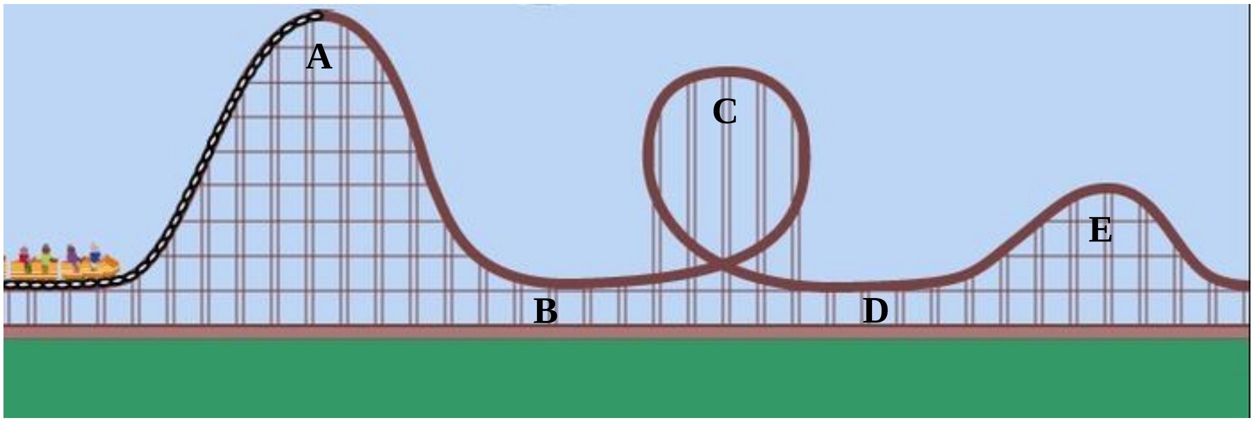
Roller Coaster Energy Conservation

A roller coaster with mass of 2400kg takes the following trip on a frictionless track. Use what you know about work, energy, and power to answer the following questions. Show all calculations.



Height A = 28 m   Height B = 3 m   Height C = 20 m   Height D = 3m   Height E = 12 m

1. On the first hill, how much work does the motor do?

2. If the coaster took 15 seconds to climb to the top of the first hill, what is the power output of the motor? Convert to horsepower.

3. The coaster comes briefly to rest at the top of the first hill. How fast is the coaster moving at the bottom of the hill? Convert to mph.

4. How much potential energy does the cart have at the top of the loop?

5. What happens to the cart velocity at the top of the loop?

6. How fast is the cart moving after leaving the loop at point D?

7. How fast is the cart moving at point E?

8. If friction was present (and it would be on a real coaster) how would this have changed your answers to questions 3 and 6?

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