Rolling with Roller Coasters

SLED
Science Learning through Engineering Design

Grade Level:	Total Time Required:
6	Two 50 minute class sessions

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Sources: National Science Digital Library and TeachEngineering at:
https://www.teachengineering.org/activities/view/wpi_amusement_park_ride

Lesson Objectives:

Students design, build and test model roller coasters using foam tubing. The goal is for students to understand the basics of engineering design associated with kinetic and potential energy to build an optimal roller coaster. The marble starts with potential energy that is converted to kinetic energy as it moves along the track. The diameter of the loops that the marble traverses without falling out depends on the kinetic energy obtained by the marble.

Students will be able to:

1. Describe how to apply potential or kinetic energy to power a model of a roller coaster.
2. Construct, test, and re-design a model of a roller coaster that uses PE and KE to function.
3. Identify PE and KE interactions within the model of the roller coaster.

Indiana Standards:

6.PS.3 Describe how potential and kinetic energy can be transferred from one form to another.

6-8.E.1 Identify the criteria and constraints of a design to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions

Next Generation Science Standards:

S-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ET1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Concepts and Vocabulary

Term	***Defined by a scientist or engineer***	***Defined by a student***
Kinetic energy	Energy associated with motion of an object.	Energy in motion
Potential energy	Energy an object has because of its relative location.	Energy at rest
Gravitational force	Force exerted between the Earth and an object that attracts the object toward the Earth.	A force that pulls an object down
Gravitational potential energy	Energy an object possesses because of its position in a gravitational field. Ex: a child on the top of a seesaw	
Elastic potential energy	Potential energy stored as a result of deformation of an elastic object. Ex: a stretched rubber band	Energy in a rubber band
Chemical potential energy	A form of potential energy related to the structural arrangement of atoms or molecules. Ex: a fully charged battery	
Conservation of Energy (optional)	The principle that the total energy of any isolated system is constant and independent of any changes occurring within the system.	
Friction	A force that resists the relative motion or tendency to such motion of two bodies or substances in contact; The rubbing of one object or surface against another.	Rubbing one object against another

Equipment, Materials, and Tools

Materials		
3-foot lengths of foam pipe insulation tubing, cut in half lengthwise (max of 5 per group)	String	2 different colored stickers: one marked “P” and the other “K”
16 mm marbles (5 per group)	Container to catch marbles	Push pins (if corkboard is accessible)
2 rolls of Duct tape	*Optional: Stickers with arrows to indicate vector direction*	

Tools		
Flexible tape measure	Ruler	Scissors

Science Content - Basics

The following science content is taken from the Hands-on Activity titled “Amusement Park Ride: ups and Downs in Design” from the TeachEngineering digital library collection at *www.TeachEngineering.org*. All rights reserved.

> Mechanical and civil engineers are involved in the design of roller coasters. Engineers must understand how the basic physics concepts of energy apply to a successful roller coaster. They must understand how to make it fast and fun, without compromising structural integrity, which is critical for ride safety.
>
> Roller coasters at amusement parks utilize potential energy and kinetic energy. Typically, a roller coaster car is pulled up by a motor, gaining its initial potential energy. Once at the peak point, no motors are connected to the car in any way. The car begins its winding and looping decent along a track that has been designed to safely transfer the potential energy into kinetic energy making it a thrilling ride. See the following on-line resource for more information: http://tlc.howstuffworks.com/family/roller-coaster3.htm.
>
> If the car is going through a loop-de-loop, and does not have enough kinetic energy, it will not stay on the track as it reaches the peak of the loop. Kinetic energy is measured as $KE = (0.5\ mV^2)$), where m is the mass of the object and V is the velocity. Potential energy is measured as $PE = mgh$, where m is the mass, g

is the gravitational force, and h is the distance above the reference point where the mass starts.

Ideally, all the potential energy is converted to kinetic energy. This never holds true, as some of the energy is lost to friction. Because of the loss of energy, the peak of the loops must be lower than the initial starting point of the car.

Space:
Due to the linear space required for the roller coaster models, consideration must be given to ample wall space required to execute the lesson. The models can be mounted on the walls and spaces, such as a classroom bulletin board or marker board, gym walls, and/or hallway walls may be most suitable. Due to the nature of the materials used, mounting to drywall is not recommended. Flexible space is also required such that student teams can mount, disassemble and remount when necessary.

Synopsis of Engineering Design Activity

Synopsis of the Design Activity:

Problem:	Indiana Beach wants to build a roller coaster to celebrate 85 years in business.
Goal:	Design a roller coaster that provides the thrills kids love, keeps cost to a minimum, and takes up little space.
Who is the client:	Indiana Beach theme park
End-User:	Roller coaster enthusiasts
What is the design:	Design a roller coaster that results in the greatest total loop diameter at lowest cost.
Criteria:	1. The marble must travel freely the entire length of the roller coaster track. 2. One or more loops may be in the design.
Constraints:	1. Only materials provided may be used. 2. Cannot use more than 5 pieces of tubing.

Lesson Plan #1

Guiding Question - What will happen to a marble that travels down a circular path and why do you think the marble will move that way?

Time: 50 minutes

Procedure:

1. Distribute "Rolling Marbles" prompt [see Uncovering student Ideas in Science, Vol 3 by Page Keeley, p. 71 (http://www.uncoveringstudentideas.org/)]. Instruct students to read the prompt individually. Then, instruct the students to share their responses to the prompt with members of the class.

   Ask: *Which student does your group most agree with? Why?*

2. Write on the board, the names of the six students from the prompt and tally each student's responses to the question.

   Ask: *Why do you support this person's perspective?*
   What is your reason?
   Which student's perspective is the most accurate and why?

3. To test students' tentative ideas, use a self-created marble tower. A short video of a marble tower is available on at SLEDhub.org. Search for the file: Marble_Tower_SLED Rollercoaster _Kelley_2011.mov. Ask students to predict then observe.

   Ask: *What did you observe?*
   What path does the marble take and why?

4. Discuss with students the following: The best answer is Keira's answer. The marble leaving the track will take a straight line. This behavior is true of all objects: If no outside force works on an object, the object will travel in a straight line at a constant speed. (See Rolling Marble Appendix for more information).

5. Distribute the design challenge.

   Ask: *What is the goal?*
   Who is the user or client?
   What is the problem?
   What are the constraints?
   What materials will you use?

6. Instruct students to develop his/her individual plan in his/her design notebooks. Encourage students to label their sketches, include dimensions, and list the materials they will use.

7. Instruct students to work in small teams to share their plans. Next, instruct students to decide on one plan or design and to select a representative from the team to share his/her plan to the teacher for his/her approval.

8. Give each group one marble, a container to catch the marble, one foam tube piece (two halves), and a one piece of duct tape. Have each team design and test a preliminary prototype. The purpose of this task is to allow the students to work with the building materials, and to test the limits of the materials and of the momentum of the marble.

9. Students will return to their seats for class discussion:

   Ask: *What problems did you encounter when creating your preliminary prototype?*
   How did you position the track and marble at the start of the coaster, why?
   (Opportunity to present potential energy, gravitational energy)
   If you created a loop, where does the loop need to be compared to the start of the track in order to keep the marble rolling? Why? (Opportunity to present friction)
   What caused the marble to roll? (Opportunity to present kinetic energy)
   What did you observe as the marble changed directions? (kinetic to potential)
   Did the marble stop, if so why? (Opportunity to present friction)

   As the class discussion proceeds, write the key science terms on the board and have students record the terms and basic definition in their notebooks.

   Optional:
   Homework Assignment or Computer Lab Exercise: Encourage students to visit the following website: http://www.funderstanding.com/coaster. This website allows students to design a simple rollercoaster by virtually installing track sections with coaster features such as hills, loops, and curves. Variables such as speed, friction, and mass can be adjusted to create a functioning coaster. Have students identify what variables are adjusted to ensure a functioning coaster- the car completes the entire path of the track. Although this assignment requires extra time and/or scheduling a computer lab, the learning experience will be valuable for students to identify how variables must be adjusted to create a functioning roller coaster. The knowledge can later be used to properly make adjustment to their prototype models.

Lesson Plan #2

Guiding Question - Will your design work? Where is PE? Where is KE? How are KE or PE transformed?

Time: 50 minutes

Procedure:

1. Instruct students to revisit their team's design. Estimate the amount of materials needed, the cost of each material, and the total cost of the model. Instruct students to complete the *Roller Coaster Cost and Evaluation Worksheet* (See Appendix).

2. Permit additional materials to be purchased during the first phase of design and testing, about 30 minutes. Once materials have been obtained from the store, they may not be returned or exchanged.

3. Allow 10 minutes to finalize designs. Give each group one "P" sticker and one "K" sticker. Remind groups to use the stickers to mark the places on their roller coasters that have the greatest kinetic and potential energy.

4. Ask students to make decisions about the following:
   - The height of the first hill
   - The shape of the first hill
   - The exit path
   - The height of the second hill
   - The loop

5. If students have trouble making decisions about each of these items, help them get started by posing the following questions:

   Ask: The more energy a roller coaster has at the beginning of the ride, the more successful the ride. That means it needs to begin with a lot of potential energy. What factor do you think affects the amount of potential energy the roller coaster will have?

   Height affects the amount of potential energy the roller coaster will have. The higher the hill at the beginning of the ride, the more potential energy the roller coaster will have.

   Ask: What do you think is the safest way to "come down" from the first hill?

   By following a slightly curved path, the roller coaster will move gently down the hill.

Ask: How do you think the roller coaster should exit from the first hill?

Just as a roller coaster needs a gentle descent, it also needs a gentle exit. Because of the kinetic energy of the roller coaster, if it exited too quickly, it could run off the track.

Ask: What do you think the height of the second hill should be?

To build momentum for the rest of the ride, the hill should be fairly high. Potential energy increases as the height of the hill increases.

Ask: What shape do you think the loop should be?

As long as enough potential energy has built up so that the roller coaster has enough energy to finish the ride, an elliptical loop is the safest option.

6. When time is up, have each team step back from their roller coasters. Test each roller coaster individually by having a team member release the marble to go travel the track path. Remember, the marble must travel completely from start to finish with assistance. Permit two tries per coaster, though more testing can be done if time allows.

7. Instruct each team to measure the diameter of each loop in the roller coaster and total the cost of purchased materials in *Roller Coaster Cost and Evaluation Worksheet.*

8. Instruct students compute and record the loop diameter to cost ratio.

9. After each team has completed testing, come to a consensus as a class about the results. Lead a discussion on observations about effective and non-effective solutions.

   Ask: Was there a stronger design/construction that seemed to work?
   How did potential and kinetic energy play a role?
   Along with justifying the best design, did your group consider structural integrity?
   Is the ride safe?

Assessment

The following are possible sources of formative and summative assessment:

Formative assessment:

- Instruct students to complete the foldable/graphic organizer on PE vs. KE. Draw an image of a bowling ball at PE on one side and at KE on the other side. Open the foldable and instruct students to define each term and explain how PE can be transformed and vice versa. Instruct students to describe the difference between the two forms of energy.

Summative assessment:

- Collect and review design notebooks. Tally the number of times students use PE and KE to explain how their models performed. Use a rubric to determine level of accuracy with using the terms.
- Review letters to the lead engineer and determine how well students have: 1) identified key features using scientific concepts; 2) clearly articulated a rationale for his/her design.

Lesson Extensions and Resources

Activity Extensions:

Have students research either the history or safety of roller coasters. When was the first loop-the-loop used?

Have students calculate the potential energy of the marble at several locations along their tracks.

Design Activity
Student Resource

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Image from http://www.indianabeach.com/pages/indianabeach_history

The Indiana Beach theme park wants to build a new roller coaster ride to celebrate their 85th year in business. Indiana Beach is located on the shore of Lake Shafer so space is limited. The owners of the park would like you to design a roller coaster that provides the thrills kids love, keeps cost to a minimum, and take up little space. They are looking for engineering designs that optimize the ratio (inches of loop diameter/material costs) and requires limited linear space. Every section of a roller coaster has different characteristics. Some coaster track sections have very light turns while others have sharp curves and turns. Each of these features has limits on the safety and function of the ride.

Task: To design and construct a roller coaster that results in the greatest total loop diameter at the lowest cost. One or more loops may be used in the design. The total number of inches of all loop diameters is used to evaluate the coaster. The marble, which represents the roller coaster car, must travel freely the entire length of the roller coaster. Only the materials listed below may be used.

Team Score = Total cost of materials purchased *divided by* total loop diameter inches.

Materials: Your team may use only these materials:

3 feet pieces of foam tubing (your team may purchase up to 5 pieces of foam tubing)
Duct tape (sold by the foot)

Cost of Materials:

Material	Cost/ item
Foam Tubing	$3.00 / 3ft. section
String	$1.00 / 1ft. section
Duct Tape	$1.00 / 1ft.
Thumb tacks optional	$1.00 / 5 tacks
Building Space – how much space does your coaster require?	$5.00 per linear foot

Source: National Science Digital Library and TeachEngineering at:
https://www.teachengineering.org/activities/view/wpi_amusement_park_ride

Roller Coaster Cost and Evaluation Worksheet

Name: ____

Material	Cost/ item	# of items	Total cost
Foam Tubing	$3.00 / 3ft. section		
String	$1.00 / ft. section		
Duct Tape	$1.00 / 1ft.		
Thumb tacks optional	$1.00 / 5 tacks		
Building Space – how much space does your coaster require?	$5.00 / linear foot		

Total Cost in dollars: __________________________

Total Loop Diameter in inches: ___________________

Final Team Score = Total Cost (dollars) divided by Total Loop Diameter (inches)

Your score (show your work):

Writing Assignment

Lead engineer, Mr. Chell Nyquist, would like to know what you have learned about roller coasters and which design might be best for Indiana Beach's 85^{th} Anniversary.

Please prepare a letter that includes the following information:

- Three to five key design features necessary for a thrilling roller coaster
- Reasons for these respective features
- A detailed sketch and image of your design
- A compelling reason why your design should be selected as the final design for Indiana Beach's Anniversary

Please address your letter to the following:

Mr. Chell Nyquist
Purdue University
Hall for Discovery and Learning Research
207 S. Martin Jischke Drive
West Lafayette, IN 47907-179

PE

KE

Definition:

Explain how:

Definition:

KE can become PE

PE can become KE