Project ASSESS (2016-18) – sponsored by
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UNIVERSITY OF LOUISVILLE
CENTER FOR RESEARCH IN MATHEMATICS & SCIENCE TEACHER DEVELOPMENT

PIMSER
Partnership Institute for Math & Science Education Reform

Classroom Embedded Assessment [CEA] Title: Gravitational PE and Roller Coaster

a. Targeted Performance Expectation(s)

7-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.

MS-ETS1-4
Develop and use 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.

b. Learning Goal(s)

1. Develop a model of a roller coaster using the given criteria and constraints.
2. Describe the transfer of potential (stored) energy to kinetic (motion) energy through the system (roller coaster model).
3. Explain how potential (stored) energy depends on the relative position of the marble on the roller coaster in terms of gravitational potential energy within the planet's gravitational field.

c. Instructional Context

a. This would come at the middle of a unit on Conservation of Energy and Energy Transfer, to assess students understanding of potential and kinetic energy and the transfer from one to another. This will be an opportunity to use the design process to create the model.

b. Students will have learned about some of the forms of energy, especially potential and kinetic energy
   i. Students will view Mystery Science, 4th grade video 3 – Why is the first hill on a roller coaster so tall?
   ii. Students will view and discuss PBS Roller Coaster interactive rollercoaster simulation; And they use the PHET roller coaster interactive https://phet.colorado.edu/en/simulation/energy-skate-park to explore different roller coaster designs and associated measures of PE, KE, speed)
   iii. Students will have explored the concept how a gravitational field (of a planet, moon, or star) can store energy depending on the arrangement of mass objects within that field. Using the PHET roller coaster interactive above, students can change the context to the Moon (less gravity), Jupiter (more gravity), or space (no gravity)
   iv. Students will connect the gravitational potential energy of a gravity field with the roller coaster context.

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c. Following lessons

- Focus on other examples of gravitational potential energy due to arrangement of objects interacting at a distance, both close to surface of Earth like roller coaster and farther in space. Examples: asteroid falling to impact Earth and resulting transformation of PE to KE to impact; comet falling toward Sun (and gaining speed as it does); skydiver jumping out of plane; water evaporated from ocean and lifted up into clouds; etc.

d. Student Task/Prompt– ***see end of document for copy of handouts to distribute to students***

- ***See Student Task Sheets at end***

a. Use the design process to design and construct a roller coaster using the criteria below.
    - Use only provided materials
    - Marble must travel the length of the roller coaster.
    - Must have one or more loops, two hills and one turn
    - Must have only one connection to the lab table and be no bigger than the lab table

b. After constructing the model draw a sketch of the model:
    - Identify and label the following points on the roller coaster
        - Most potential energy
        - Most kinetic energy
        - Point of transfer from potential to kinetic energy
        - Point of transfer from kinetic to potential
    - Use the model to explain the transfer of energy within the roller coaster.

c. Questions 7 and 8 on the student handout ask students to make explicit connections to gravitational potential energy, including considering if the context were the lower gravity on the Moon and how that would impact the performance of the roller coaster.

SEP= developing and using model DCI= Energy   CCC= Systems and System Models

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e. Success Criteria

Series of Criteria

1. Did the student's model meet the criteria and constraints set forth?
2. Did the student identify the points on the roller coaster that had the most potential energy, most kinetic energy, and points of transfer?
3. Did student correctly explain why he/she identified each point using the relative position of the marble on the model.

Exemplary Response

Student are able to create a model and sketch (on paper). Students should provide labels to inform their audience of their thinking. • Brainstorm-showing multiple ideas
Students are able identify transformation points, and greatest/lowest potential and kinetic energy points correctly. • Students are able to label energy transfer points (PE to KE) • Students are able to label greatest potential and kinetic energy points • Students are able to label lowest potential and kinetic energy points
Students are able to draw conclusions based on models that relative position of the object (marble on the roller coaster) determines the amount of P.E.

Question 7: This roller coaster is using gravitational potential energy because the marble starts off at a high hill, which means the marble has gravitational PE due to its position compared to the table top (using the table top as our reference). This gravitational PE (height above table) is then transformed into kinetic energy (speed) as the marble moves lower in the gravity field toward the table top.

Question 8

a) If moved to the Moon with 1/6 the gravity, the maximum potential energy of this roller coaster would be about 1/6 as much. The same height, but in a smaller gravity field, means that the potential energy is smaller too in the same proportion.
b) The roller coaster's maximum speed would be lower, since it would start with only 1/6 the potential energy at the top of the highest hill. This PE converts to kinetic energy (and hence speed), but there would be less PE to start with.
c) To achieve the same maximum speed, the roller coaster would need to have the same starting potential energy. With 1/6 the gravity on the Moon, the roller coasters' first and highest hill would need to be 6 times higher in order to get the same total starting potential energy.

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f. Next Instructional Steps

Identify which of the success criteria listed above was included in the student's model and explanation. In groups determined by which aspect was missing (e.g. not able to identify PE, KE or transfer points), use examples of a bouncing ball, pictures or videos showing gravitational interactions (P.E to K.E).

For students who got all (or most) of the model explanation reasonably complete, (while others are revisiting) might be to ask them to determine how speed is related to amount of potential energy. They may collect data using the physical models of the roller coaster.

g. Student Work Samples

NOTE: The student work was collected from a prior CEA version which was focused on speed and not as much on the transfer of energy, and did not include an explicit focus on PE-KE transfer, nor on the concept of PE in a gravitational field. Thus, those samples of student work are not particularly salient for this revised CEA.

h. Reflection and Revision

More explicit emphasis placed on the design process and using the model to determine the points of P.E., K.E. and points of transfer based on the position of the marble. Also, questions 7 and 8 along with associated prior instruction about gravitational fields and potential energy were added to place the context of this potential energy within a gravitational field. Subsequent instruction would revisit this concept (see end of "instructional context" box) with other phenomena. Also, this focus would serve well when later comparing potential energy due to magnetic fields, or static electricity fields.

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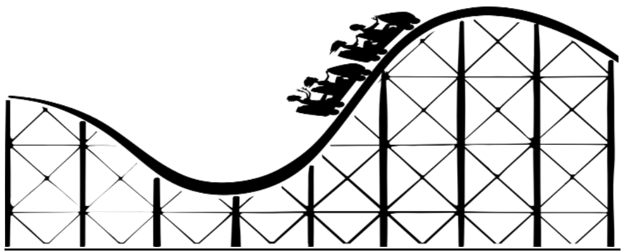
Energy in a Roller Coaster System



Imagine from Pixabay.com

Your Task: To design and construct a roller coaster based on the criteria below that results in the greatest total of loop diameter inches at the lowest cost with the most interesting design.

Materials:
6' lengths of foam tubing
3 toilet paper tubes
Masking tape

Design Criteria

1. The marble must travel the entire length of the roller coaster.
2. Roller coaster must include one or more loops, at least two hills and one turn.
3. Roller coasters may only have one connection to the lab table. Other than that, it must support itself.
4. Only the materials listed above may be used. Each group will also be provided with a meter stick that can be used for measurements but CANNOT be used as part of the roller coaster design.
5. The roller coaster width and length should be no bigger than the lab table.
6. Place tape across the end of the roller coaster to stop the marble.

1. **Brainstorm** ideas with your group and share them below.

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2. **Plan**: sketch your roller coaster model design in the box below.

3. **Build** the model then sketch the final design below.

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Use your model and the sketch you made to complete the following:

1. Identify and label the point on your roller coaster that has the most potential energy. Explain why you marked that particular point.

2. Identify and label the point on your roller coaster that has the most kinetic energy. Explain why you marked that particular point.

3. Identify and label a point on your roller coaster where half of the potential energy has turned into kinetic energy. Explain why you marked that particular point.

4. Identify and label a point on your roller coaster where kinetic energy is turning back in to potential energy. Explain why you marked that particular point.

5. Explain what you noticed about the position of the marble on the roller coaster and the relationship to energy transfer.

6. Describe one way you might change the model so that it may have more potential and kinetic energy. What does this have to do with the position of the model?

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7. Explain why the particular potential energy in this roller coaster design is GRAVITATIONAL POTENTIAL ENERGY instead of some other type of potential energy (like spring tension potential energy, or chemical potential energy, or magnetic potential energy).

8. Suppose you move your entire roller coaster to the Moon, which has about 1/6 the gravity compared to Earth.

   a. Explain how this move would change the magnitude of the roller coaster's maximum potential energy.

   b. Explain how this move would change the magnitude of the roller coaster's maximum speed.

   c. If you were to redesign the roller coaster so that the maximum speed on the Moon would be about the same as the maximum speed on Earth of your original design, what primary change would you need to make in the Moon design and why?

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