Science Assessment System
Through Course Task

Slingshot Coaster

Grade Level:
9, 10, 11, 12

Phenomena:
Movement of Roller Coasters

Science & Engineering Practices:
Developing and Using Models
Constructing Explanations and Designing Solutions

Crosscutting Concepts:
Energy and Matter

Designed and revised by Kentucky Department of Education staff
in collaboration with teachers from Kentucky schools and districts.

Preparing to implement Through Course Tasks in the Classroom

What is a TCT?

- TCTs are 3-dimensional tasks specifically designed to get evidence of student competency in two dimensions, Science and Engineering Processes (SEPs) and Crosscutting Concepts (CCC), untethered from Performance Expectations (PEs)/standards. Tasks are sense-making experiences.
- Tasks are to be used formatively. The goal is for both students and teachers to understand areas of strength and improvement for the SEP(s) and CCC assessed within the task.

How do I facilitate a Through Course Task (TCT)?

- TCT facilitation is a collaborative process in which teacher teams calibrate understanding of the expectations of the task and refine strategies to be used during task facilitation.

Before the task:

1. Complete the TCT as a learner – compare understanding of task through the lens of success criteria (identified in the task) in order to understand expectations. Success criteria include:
    - What is this task designed to get evidence of?
    - What is the task asking the students to do?
    - What might a student response look like?
2. Identify the phenomenon within the task. Consult resources to assure teacher teams have a deep understanding of associated science concepts.
3. Collaborate to generate, review and refine feedback questions during facilitation.
4. Identify potential "trouble spots" and plan for possible misconceptions.

During the task:

5. Collect defensible evidence of each student's competencies in 3-dimensional sense-making for the task.
6. Ask appropriate feedback questions to support student access and engagement with the task in order to elicit accurate evidence of student capacities.

After the task:

7. Reflect on the task as a collaborative team.
8. Review student work samples to identify areas of strength and areas of need.
9. Determine/plan next steps to move 3-D sense making forward through the strengthening of the use of SEPs and CCCs.

Using the materials included in this packet:

- **Task Annotation:**
    - The task annotation is a teacher guide for using the task in the classroom. Additionally, the annotation gives insight into the thinking of developers and the task overall.

    - Each task has science and engineering practices, disciplinary core ideas, and crosscutting concepts designated with both color and text style:
        - **Science and Engineering Practices**
        - *Disciplinary Core Ideas*
        - Crosscutting Concepts
- **Student Task:** The materials to be used by students to complete the TCT.

Slingshot Coaster Task Annotation

After **analyzing models** that depict *changes in energy form along a roller coaster's path*, **construct an explanation supported with models** *for why a coaster rollback could occur*, using your understanding of energy conservation and energy transformation within a system.

Phenomenon within the task

Roller coasters "work" by transforming potential energy to kinetic energy to move the coaster around the track. Some of the energy in the coaster system is transformed into heat and sound due to interaction with the track and air. A common/typical roller coaster gets its initial energy from being pulled to an elevated height, giving the coaster gravitational potential energy. An Accelerator Coaster, sometimes called a slingshot roller coaster, is a roller coaster that launches its passengers at high speeds at the beginning of the ride. These coasters obtain their initial potential energy in a way comparable to a slingshot. When using a slingshot, the user builds elastic potential energy within the slingshot by drawing the object in its pocket backwards. When the object is released, the elastic potential energy is converted into other forms of energy, depending on the trajectory (the intended path) of the object, resistance to the object's motion and other factors. Similarly, accelerator coasters are drawn back prior to the start of the ride, then launched with enough energy to produce maximum speeds between 50 MPH and 150 MPH (22 m/s to 67 m/s). The amount of potential energy given to the coaster initially and the target speed for the coaster after launch are both part of the coaster's design. These target quantities depend on the maximum height of the coaster's track.

Some accelerator coasters, such as the Top Thrill Dragster at Ohio's Cedar Point amusement park, experience a phenomenon called a rollback. A rollback event occurs when a roller coaster does not launch with (or retain) enough energy to clear the maximum height of the roller coaster (in the case of Top Thrill Dragster, a height of 420 feet, or 128 meters). In a rollback event, the coaster will reach its maximum height prior to clearing the highest point on the track, then roll backwards down the hill towards its original starting point. As a necessary condition for a rollback event to occur, the coaster must reach zero kinetic energy prior to reaching the maximum height of the track. This may be caused by having too little "elastic" potential energy at the beginning of the ride (usually due to cold weather affecting the hydraulic mechanism efficiency), by having too much of its energy dissipated (e.g., from friction forces, such as air or track resistance) or by increased mass of the coaster due to passenger load.

How the phenomenon relates to DCI

The subject matter in this task is included in much of the energy content in the High School DCIs PS3.A, PS3B, and PS3C below:

PS3.A Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1),(HS-PS3-2)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light and thermal energy. (HS-PS3-2) (HS-PS3-3)

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1)

PS3.C: Relationship Between Energy and Forces

- When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)

What information/data will students use within this task?

Students will use the introduction and the graphical models provided to respond to the initial questions; these questions are provided to guide student thinking to make sense of how roller coasters "work." Students will need to be able to read bar graphs and connect to the motion of the coaster, energy transformations along the track and conservation of energy. Thus, it is important that students have conceptual understanding for the various forms of energy and energy conservation.

Familiarity with amusement parks and roller coasters may be helpful to more fully understand the task but this knowledge is not necessary. A good introduction to the slingshot roller coaster would suffice.

Ideas for setting up the task with students
Even though this phenomenon and its associated models are described and delineated within this task, students would benefit from an analogous demonstration, investigation or activity that highlights the relationship between kinetic energy, potential energy and energy dissipated from or within a system (e.g., PhET Energy Skate Park, ball-and-track investigations). In addition, showing students a video of an accelerator coaster undergoing a rollback event will help delineate this phenomenon (available on youtube).

Top Thrill Dragster Rollback https://www.youtube.com/watch?v=rKzl7F1HXYA
Top Thrill Dragster Double Rollback https://www.youtube.com/watch?v=iq-ITt8XDAY

The students could use experience from in-class activities/videos to support their responses, but will also need to utilize the models provided in constructing their explanations.

Intent of the Task for Assessment
This task was designed to determine if students can provide an explanation for why the rollback of a roller coaster would occur, and support that explanation with graphical models that represent the relative amounts of elastic potential, gravitational potential, kinetic and dissipated energy at various points along the track course. The explanation will provide evidence of a student's ability to think about the roller coaster as a system, using energy conservation as a fundamental rationale (whether implied or explicit) for accurately modeling energy transformation for the system that is consistent with a rollback situation.

Students develop understanding for how the relative amounts of each type of energy change at discrete points along the course by processing graphical models that depict these relative amounts of energy (part 1 of the task). In that way, students are learning how roller coasters "work," meaning how elastic potential energy is transformed in to required kinetic, dissipated and gravitational potential energy for the coaster to clear the maximum height. If students do not have success with part 1, then they will not be successful with part 2. Thus, it is recommended that understanding with part 1 be verified before a student proceeds with part 2. How this verification occurs is up to the teacher.

Students are then required to think about the components of the roller coaster as a system, specifically with respect to how the four forms of energy (elastic potential, gravitational potential, kinetic and dissipated) might be affected by variations of any of these components. For example, elastic potential energy would be affected by anything that causes variation in the mechanism that

provides the initial force (slingshot), gravitational potential energy required would be affected by variations in mass, and dissipated energy would be affected by anything that caused variations in friction losses, or any other dissipated sources.
If the original models show relative energy levels for a roller coaster that does not roll back, then these models would be different for a coaster that does roll back. In short, if the kinetic energy of the coaster falls to zero before the coaster reaches the highest point on the track, the coaster will roll back. However, students are asked to identify something in the system that could vary in a way to cause a rollback (or cause the kinetic energy of the coaster to be zero before reaching maximum height). This means they have to determine how the identified component would affect each of the forms of energy. They do not have to calculate actual energy levels, but they must be able to show them relative to the original coaster models.

Success Criteria

Evidence of Learning Desired based on Progression from Appendices

Developing and Using Models

- Use a model based on evidence to predict the relationships between systems or between components of a system.

Constructing Explanations and Designing Solutions

- Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of and within that system.

Success Criteria

- Student synthesizes the information in the models to describe changes in the various forms of energy between points A and E consistent with conservation of energy. (This criterion should be assessed prior to completing part 2 of the task.)
- Student explains how the identified component within the roller coaster system varies in a way to cause a rollback, consistent with conservation of energy and E_k =0 prior to reaching maximum height.
- Student supports the explanation with models to support a rollback situation that is consistent with conservation of energy within the system.

Possible Student Responses

Part 1:

a. Kinetic energy gets larger from position A to B and then decreases to position D. Kinetic energy increases from D to E.
b. Elastic potential energy starts out with 10 and then decreases to zero for the rest of the ride.
c. Gravitational potential energy stays the same from A to B and then increases from B to D. From D to E the gravitational potential energy decreases.
d. The total energy remains the same throughout the entire ride.
e. The dissipated energy increases from A to B and then increases between each of the positions.

Part 2:

- If the passenger load increases by too much, then the energy required to clear the maximum height could exceed the available kinetic energy.
- If the slingshot mechanism provides less initial energy for some reason, the rollback will occur because there is no kinetic energy at position D in the model.
- If friction on the track increases compared to the normal ride, there is more Ediss, and less kinetic energy (0 at point D), causing a rollback.

Other information teacher teams might find useful when preparing to use this task in the TCT process

When I gave the TCT for the first time, I gave the students the task with a short introduction. The question most frequently asked was, "What was meant by developing or revising the model in question 2?" We changed the question with wording that we believe is clearer. In the future, I would set up the task by showing a video of a slingshot roller coaster and a short discussion about the mechanics behind them. I would also allow students to discuss their experiences with these typeS of ride.

"Answers" to the task:

Part 1

- E_k increases from A to B, then decreases from B to D, then increases from D to E.
- E_e decreases from A to B.
- E_g increases from B to D, then decreases from D to E.
- E_{total} remains constant.
- E_{diss} increases from A to E.

Part 2: The cars of a roller coaster must reach zero kinetic energy prior to reaching the maximum height of the track in order for rollback to occur. Various components in the system could change the energy requirements in different ways, as described in the "Phenomenon" section of this document. As support, students should include one or more of the following:

- State that E_k reaches zero at Position D during the rollback event.
- State the difference in E_{diss} at Position D during a rollback event and during a normal ride.
- State that E_{diss} increases at a faster rate during a ride ending in rollback.
- State that E_k decreases at a faster rate during a ride ending in rollback.
- E_g reaches its maximum sooner during a ride ending in rollback.
- State that the roller coaster cars reach zero velocity before reaching the max height during rollback.

Extensions and/or other uses after the task is implemented

There is an optional extension to this task included that incorporates engineering design.

Another useful extension would be to have students estimate a relative height for a coaster that gets its initial potential energy as gravitational rather than elastic potential energy (slingshot). For example, what relative initial height (compared with the max height after launch) would be necessary for no rollback to occur?

Consider using student work from the task in various ways (student names removed):

- Select models that do not reflect a rollback situation and have the students work in pair to correct the models, while correctly accounting for the component that varied.
- Have student pairs compare the models for different components within the system that varies to cause a rollback, and identify similarities and differences in how the component that varies affected the energy transformations.

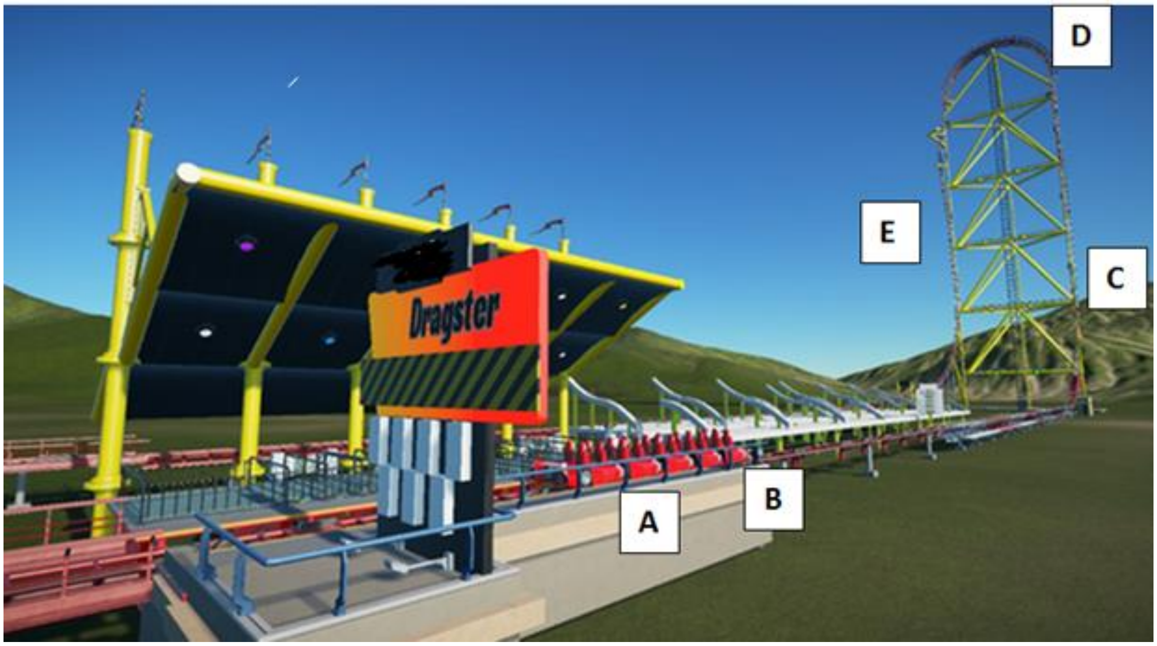
Through Course Task – Slingshot Coaster

Background

An accelerator coaster is a roller coaster that launches its passengers at high speeds at the beginning of the ride. These rides are comparable to a slingshot. When using a slingshot, the user builds elastic potential energy within the slingshot by drawing the object in its pocket backwards. When the object is released, the elastic potential energy is converted into other forms of energy, depending on the trajectory (the intended path) of the object, resistance to the object's motion and other factors. Similarly, accelerator coasters are drawn back prior to the start of the ride, then launched at maximum speeds between 50 MPH and 150 MPH (22 m/s to 67 m/s). The amount of potential energy given to the coaster and the target speed for the coaster after launch are both part of the coaster's design. These target quantities depend on the maximum height of the coaster's track.

Some accelerator coasters, such as the Top Thrill Dragster at Ohio's Cedar Point amusement park, can sometimes experience a phenomenon called a rollback. A rollback event occurs when a roller coaster does not clear the maximum height of the coaster track (in the case of Top Thrill Dragster, a height of 420 feet, or 128 meters). In a rollback event, the coaster will reach its maximum height prior to clearing the highest point on the track, then roll backwards down the hill towards its original starting point. (Retractable magnetic brakes slow the coaster down in these events so that no one is harmed in the process.)

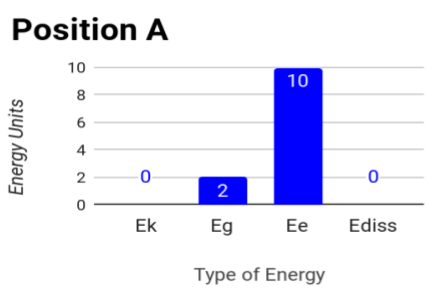
Roller Coaster Track Positions

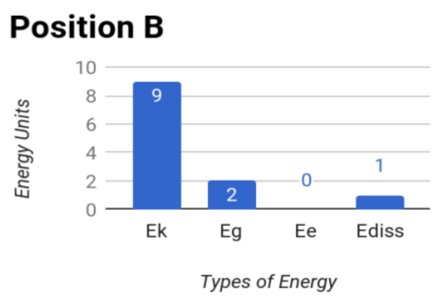


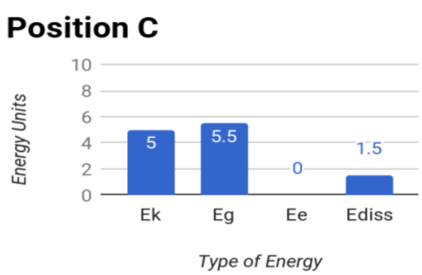
This diagram identifies 5 different positions along the track of an accelerator coaster. The following table describes the motion of the coaster at each position.

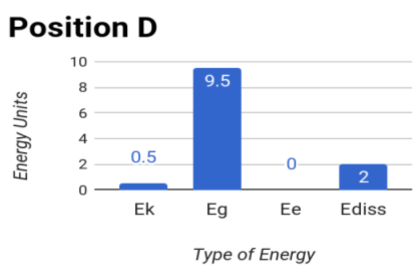
Position	Motion of Coaster
A	At rest, drawn back by launch mechanism, the instant before launch occurs
B	Moving forward the instant after launch occurs
C	Moving upward towards the top of the hill
D	Moving towards Position E, just before the maximum height of the track
E	Moving downward towards the finishing point of the roller coaster

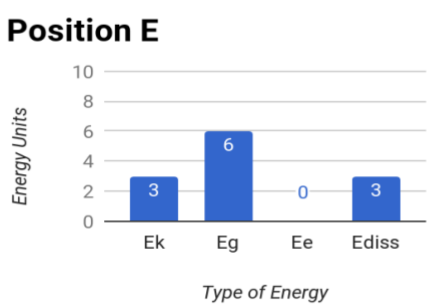
These graphs are models that illustrate the relative amounts energy at the designated positions along the track when **rollback does not occur**. The various energy forms include: kinetic energy (Ek), the energy of motion, gravitational potential energy (Eg), energy due to gravitational pull, elastic potential energy (Ee), stored energy due to stretching or compression and energy dissipated (Ediss), the energy transferred from the roller coaster to the track and the air due to friction or other "losses."











The Task

1. The system represented by the models includes the cars of the coaster, its passengers, the track and the air. Use these models to think about how energy changes forms as the coaster moves along the track for the **normal accelerator coaster ride** (no rollback). Answer the following questions to guide your thinking:

   a. How do the models account for the speed of the coaster?
   b. The height of the coaster changes throughout the ride. What effect does this have on the various forms of energy?
   c. What do you notice about the total energy throughout the ride?
   d. Describe the change(s) in energy dissipated between Point A and Point E.

2. Why do rollbacks *sometimes* occur? Rollbacks can be caused by a number of factors that will change the energy in the system. These factors can include strong headwinds during the run, increase in passenger load, increase in friction due to cold weather or inadequate lubrication on the track or something affecting the slingshot mechanism energy output (such as cold weather affecting hydraulic function).

Your task is to choose one of the factors above and revise the original models or develop a new model (3-5 graphs at locations along the track) to illustrate how the energy would change due to your identified factor. On the picture below, show the locations you will use in your model.

Explain how your models account for the rollback.

Slingshot Coaster Task Extension: Suppose there is an accelerator coaster that experiences rollback events more frequently than the average accelerator coaster.

a. Using your analysis of the models provided and your understanding of energy and energy changes within a system, suggest a modification to the design of the roller coaster that would reduce the number of rollbacks that occur. Using the relevant vocabulary, explain how your modification would reduce the number of rollbacks.

b. Identify one potential <u>unintended</u> consequence of this design modification.

The included extension to the task will assess to what degree students can suggest a viable modification to an accelerator/slingshot coaster's design that will reduce the number of these events. It will also determine if students are able to foresee any unanticipated consequences of their design modification.

Possible Student Responses

Extension A:

- A modification could be increasing the amount of elastic potential energy at the bottom.
- Add a lubricant to the track's surface.
- Put a wind blocker during high wind times.
- Decrease the mass of the riders.

Extension B:

- The car goes too fast at the top and goes off the track.
- The car sustains damage from going too fast on the turn.
- Riders are injured travelling too fast at the top.

Reasonable "answers"

Task extension, part A: One of the following:

- A reduction of the total mass of the roller coaster cars
- An increase in elastic potential energy input before launch
- A reduction of the maximum height of the track
- The application of a substance/coating to the track to reduce friction
- The enforcement of a maximum weight limit to passengers, or
- Other feasible ideas that would potentially prevent E_k from reaching zero at Position D

Task extension, part B: The roller coaster cars have too much kinetic energy or speed, then it may result in one of the following:

- Injury of passengers
- Mechanical problems with the track or cars
- Degradation of/damage to the track or cars
- A shorter/less enjoyable ride for passengers
- Increased stress on the car restraints
- Longer wait times for the ride (if the modification involves removing a car segment), or other reasonable consequences directly associated with the student's proposed design modification