A2 Graphing Motion on the Rollercoaster

Key Question: *How does height on a rollercoaster affect speed?*

In this investigation, students discover that the speed of the marble is inversely related to its height on the track. The angle of the hill determines how quickly the marble reaches the bottom, but it does not determine what the speed of the marble is at particular points in its journey. Students also see that the speed of the marble does not depend on whether it is traveling uphill or downhill—it can have the same speed going uphill as it has going down. Students arrive at their understanding by learning to make and interpret a graph created from the data they collected.

Learning Goals

- ✔ Explore how height is related to speed.
- ✔ Make a graph of the motion of the marble on the Rollercoaster.
- ✔ Identify variables in an experiment.

GETTING STARTED

Time 50 minutes

Setup and Materials

1. Make copies of investigation sheets for students.
2. Watch the equipment video.
3. Review all safety procedures with students.

Materials for each group

- Physics stand*
- Rollercoaster with a steel marble
- CPO Timer and photogate (with a 9-volt battery or AC adapter and a cord for connecting the photogate)*
- Metric ruler (at least 30 centimeters) or meterstick*
- Simple calculator*

**provided by the teacher*

Online Resources

Available at curiosityplace.com

- Equipment Video: Rollercoaster
- Skill and Practice Sheets
- Whiteboard Resources
- Science Content Video: Speed vs. Time Graphs
- Student Reading: Graphing

NGSS Connection

This investigation builds conceptual understanding and skills for the following performance expectation.

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.*

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data	PS3.A: Definitions of Energy	Scale, Proportion, and Quantity

Vocabulary

control variable – a variable in an experiment that is kept constant

dependent variable – the variable in an experiment that is being tested to see how it responds to changes in the independent variable

direct relationship – a relationship in which one variable increases (or decreases) when the other variable increases (or decreases)

graph – a visual representation of data

independent variable – the variable that is being changed in an experiment to see how it affects the dependent variable

inverse relationship – a relationship in which one variable decreases when another variable increases

scatterplot – a type of graph that displays the individual coordinates for two variables

variable – a factor that affects how an experiment works

BACKGROUND

The goal of any experiment is to understand the relationship between variables. For example, what is the relationship between the speed of a marble and its height on the Rollercoaster? To answer the question, you set up an experiment and identify all of the variables. A **variable** is a factor that affects how an experiment works.

The variable you change in an experiment is called the **independent variable**. This is usually the variable that you can freely manipulate. For the experiment with the Rollercoaster, the height at which speed is measured is the independent variable. If you were experimenting with different brands of fertilizer on tomato plants, the independent variable would be the brand of fertilizer.

The **dependent variable** is the one that is being tested to see how it responds to the independent variable. In this experiment, speed is the dependent variable.

The variables you keep the same are called **control variables**. In the rollercoaster experiment, control variables include the release height of the marble, the release technique, the mass of the marble, and the diameter of the marble.

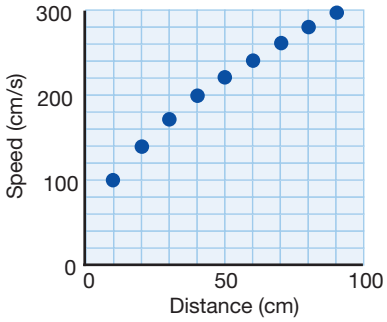
Speed and height are variables that are measured and recorded in this investigation. Once we have measured and collected data, it is often necessary to organize it visually and look for relationships. A **graph** is a visual way to organize data. In this investigation, students will create a **scatterplot** graph of their data. Scatterplots show how a change in one variable influences another variable.

When there is a relationship between the variables, the graph shows a clear pattern. The speed and distance variables (below left) show a **direct relationship**. In a direct relationship, when one variable increases, so does the other. When there is no relationship, the graph looks like a collection of dots. No pattern appears. The number of musical groups a student listed in one minute and the last two digits of his or her phone number are an example of two variables that are not related.

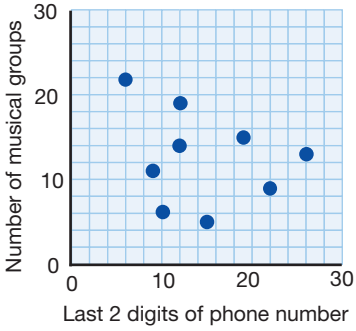
Some relationships are inverse. In an **inverse relationship**, when one variable increases, the other decreases. If you graph how much money you spend against how much you have left, you see an inverse relationship. The more you spend, the less you have. Graphs of inverse relationships always slope down and to the right.

Strong Relationship Between Variables

Distance (cm)	Speed (cm/s)
10	99
20	140
30	171
40	198
50	221
60	242
70	262
80	280
90	297



No Relationship Between Variables



# of groups	Last 2 digits
10	06
15	05
19	15
6	22
22	09
9	11
26	13
12	14
11	19

5E LESSON PLAN

Engage

Ask students to describe their favorite amusement park ride. Many students will describe some form of rollercoaster. Why do they enjoy rollercoasters? Do your students ever think about physics when riding their favorite rollercoaster? Ask students to consider what happens during a rollercoaster ride. What types of forces are involved? Ask students to identify applications of each of Newton's laws relative to the motion of a rollercoaster.

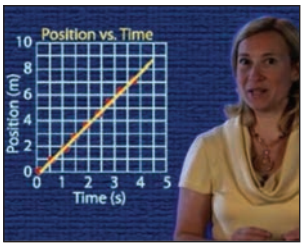
Then ask students, "How does the design of the rollercoaster affect the ride?" For example, is a coaster with lots of loops more exciting than one with fewer? Why? Then have students speculate about how a rollercoaster really works. Ask leading questions like, "What causes the cars on the coaster to move?" and "Is the speed of the cars the same at all points along the ride?"

Explore

Have students complete Investigation A2, *Graphing Motion on the Rollercoaster*. Students conduct an experiment to determine the relationship between speed and height on a rollercoaster. They make a graph of their data and identify the relationship, then describe how height affects speed.

Explain

Revisit the Key Question to give students an opportunity to reflect on their learning experience and verbalize understandings about the science concepts explored in the investigation. Curiosityplace.com resources, including student readings, videos, animations, and whiteboard resources, as well as readings from your current science textbook, are other tools to facilitate student communication about new ideas.



Science Content Video
Speed vs. Time Graphs

Elaborate

A fun extension of this investigation is to ask students to set the Rollercoaster up so that it connects to the physics stand on the 8th hole instead of the 5th hole. First, have them examine the setup and describe the height difference between the starting point and the hill. They should notice that the starting point is higher than the hill. In the original setup, the starting point and the hill were pretty much the same height. Then, have them write down a prediction about what they think will happen to the marble's motion as it moves along the track after being released.

Now have them release the marble and watch its journey closely. If everything is aligned properly, they should observe that the marble is actually airborne for a moment after it passes over the hill! If you have video capabilities, you can ask students to make a video of the experiment. Some video cameras have a slow-motion setting. Students can also conduct the entire experiment again using this setup and make a new graph to compare to their original.

Evaluate

- During the investigation, use the checkpoint ✓ questions as opportunities for ongoing assessment.
- After completing the investigation, have students answer the assessment questions on the *Evaluate* student sheet to check understanding of the concepts presented.

GRAPHING MOTION ON THE ROLLERCOASTER

Name _____ Date _____

A2 Graphing Motion on the Rollercoaster

How does height on a rollercoaster affect speed?

Materials:
- ✔ Physics stand
- ✔ Rollercoaster with a steel marble
- ✔ CPO timer and one photogate
- ✔ Meterstick
- ✔ Simple calculator

In this investigation, you will conduct an experiment to determine if there is a relationship between the variables of speed and height. A **variable** is a factor that affects how an experiment works. Height and speed are variables in the rollercoaster experiment. Can you think of others? An experiment usually has three kinds of variables: independent, dependent, and control. The **independent variable** is the one that is changed by the experimenter. The **dependent variable** is the one that is being tested to see how it responds to changes in the independent variable. **Control variables** are kept constant throughout the experiment.

❶ Making a prediction

You will use the data you collect in the experiment to make a graph of the motion of the marble on the Rollercoaster. A **graph** is a visual model that allows you to see if there is a relationship between variables. To make the graph, you will place the dependent variable on the *y*-axis and the independent variable on the *x*-axis. For the positions close to the start, you will have to measure from the base of the stand. Add the height of the base to the height you measure to get the total height.

a. Which variable (speed or height) will be placed on the *x*-axis of your graph? Which will be on the *y*-axis? Explain your reasoning.

Height goes on the *x*-axis because the values for height are under the control of me, the experimenter. Height is the independent variable. Speed goes on the *y*-axis because the speed calculations are the result of the height values. Speed is the dependent variable.

b. Discuss with your group what you think this graph will look like. Make a sketch of your predicted graph.

See 1b sample sketch.

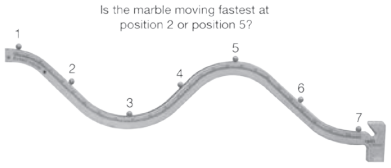
c. Write a statement, based on your graph, about how you think height and speed are related. Include whether you think there is a **direct relationship**, an **inverse relationship**, or no relationship at all. This will be your hypothesis for the experiment.

There is an inverse relationship between speed and height. The speed will decrease as the height of the Rollercoaster increases.

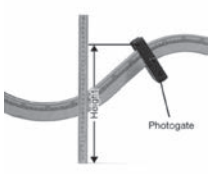
d. With your group, brainstorm other variables in the rollercoaster experiment that you will control.

Answers will vary, but may include mass and diameter of the marble, release height, and hole on the physics stand to which the Rollercoaster track is attached.

❷ Conducting the experiment



1. Set up the Rollercoaster the same way you did in the previous investigation.
2. Place the photogate at position 1 on the Rollercoaster (see diagram above).
3. Measure the height of the photogate at position 1 by measuring the height from the center of the hole for the light beam to the base of the physics stand. Then, add the height of the base to the height you measured. For other positions on the Rollercoaster, measure height from the table to the light beam hole.

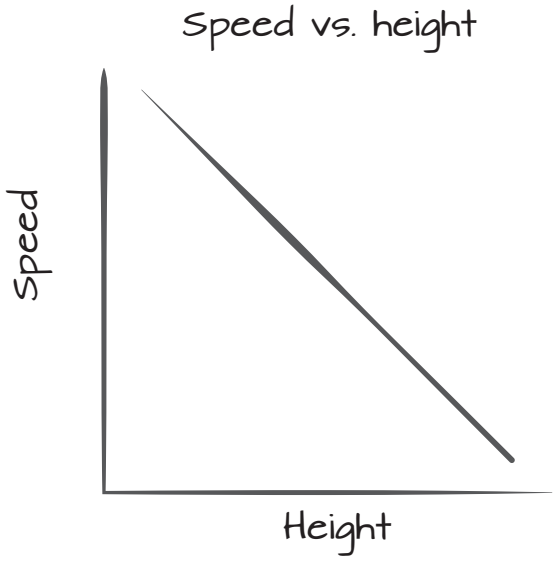


Guiding the INVESTIGATION

❶ Making a prediction

Part 1 is designed to introduce the concepts of variables and graphing variables. It is also designed to facilitate a hypothesis about how a graph of height vs. speed will look. Students should be familiar with identifying each axis of the graph, how to label a graph, and how to create a scale on a graph. Have students discuss what their graphs will look like in their groups, then have each group sketch their graph on a whiteboard or chalkboard for the class. This will help students begin to develop a model for the motion of the marble on the Rollercoaster that they can revisit and possibly revise after the experiment. It is important to stress that there are no right or wrong answers in Part 1; students are making hypotheses that they will test experimentally.

1b sample sketch



Explore INVESTIGATION A2

4. The distance traveled is the marble's diameter and is the same for each position. What is this distance? Record it in all rows of column three of the table below.

1.90 cm

5. Release the marble and record the time in column 4. Then calculate the speed of the marble. Record the speed in column 5.

6. Repeat steps 2 through 5 for each position on the track.

Sample data:

Position number	Height (cm)	Distance traveled by marble (cm)	Time from photogate A (s)	Speed of marble (cm/s)
1	33.4	1.90	0.0288	66.0
2	19.4	1.90	0.0125	152
3	15.7	1.90	0.0112	170
4	20.6	1.90	0.0136	140
5	31.7	1.90	0.0375	50.7
6	18.2	1.90	0.0130	146
7	10.4	1.90	0.0109	174

❸ Arguing from evidence

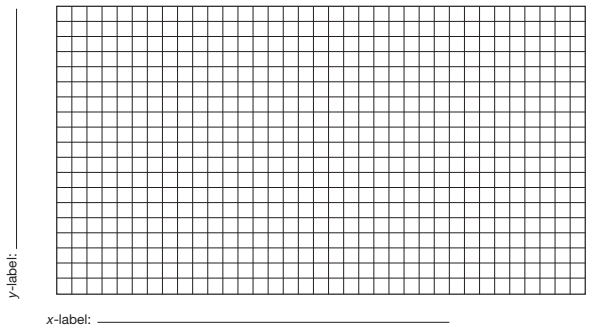
a. Look at the data in the table. Does the height of the marble on the Rollercoaster affect its speed? Provide evidence to support your answer.

Yes, the lower the marble is on the track, the greater its speed. The higher the marble is on the track, the lower its speed.

Explore INVESTIGATION A2

b. Make a graph of speed versus height. Place speed on the *y*-axis of your graph and height on the *x*-axis. Plot the data points and label on the graph the position that each point represents. Do not connect the points with a line. This type of graph is called a **scatterplot**.

Title: _____

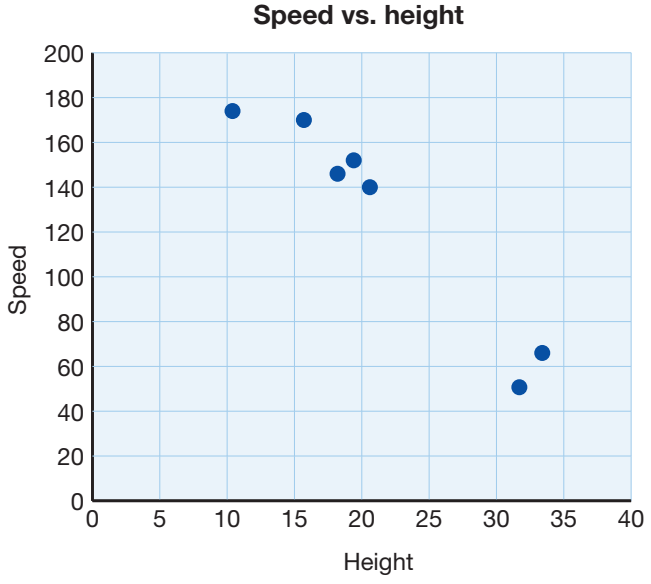


See 3b sample graph.

✓ **c.** What can you tell from your graph? Describe the relationship between the speed of the marble and the height.

The graph indicates that there is an inverse relationship between speed and height. The highest speeds that the marble reaches are at points 3 and 7, the lowest points on the track. As the marble goes downhill (points 1, 2, and 6), the marble's speed increases. At point 4, as the marble goes uphill, the marble's speed decreases. The slowest point on the track is at point 5, just before the marble goes down the second hill.

3b sample graph



Explore

INVESTIGATION **A2**

4 Drawing conclusions

a. Compare the predicted graph you made in Part 1 to the graph you made using your data. Were the graphs alike or different?

My predicted graph from Part 1 is similar to the graph I made in Part 3. Both graphs show the same relationship between speed and height: as height increases, speed decreases and vice versa.

✓ **b.** Which variable do you think has the largest influence on the speed of the marble: (1) height or (2) going downhill or uphill? Justify your response.

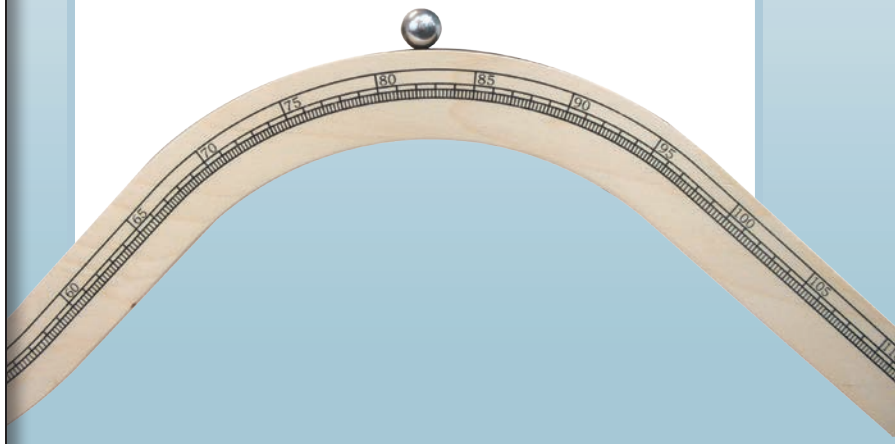
The speed of the marble and its height are inversely related—as the height of the marble decreases, its speed increases. Whether the marble is going uphill or downhill is not as important as the height of the marble on the track. For example, the lowest two points on the graph represent points 1 and 5. These points are far apart on the track but at similar heights. Also, points 2, 4, and 6 are clumped together on the graph. Each of these points is at a similar height, but at points 2 and 6, the marble is going downhill. At point 4, the marble is going uphill.

c. Why do you think making a graph is important for interpreting data? Give at least two reasons in your response.

It is easier to interpret information on a graph because a graph is like a map or picture of the information. A graph also allows you to see how two variables are related to one another. It is harder to understand how two variables are related from a table, especially if there are many rows and columns on the table.

TEACHING TIP

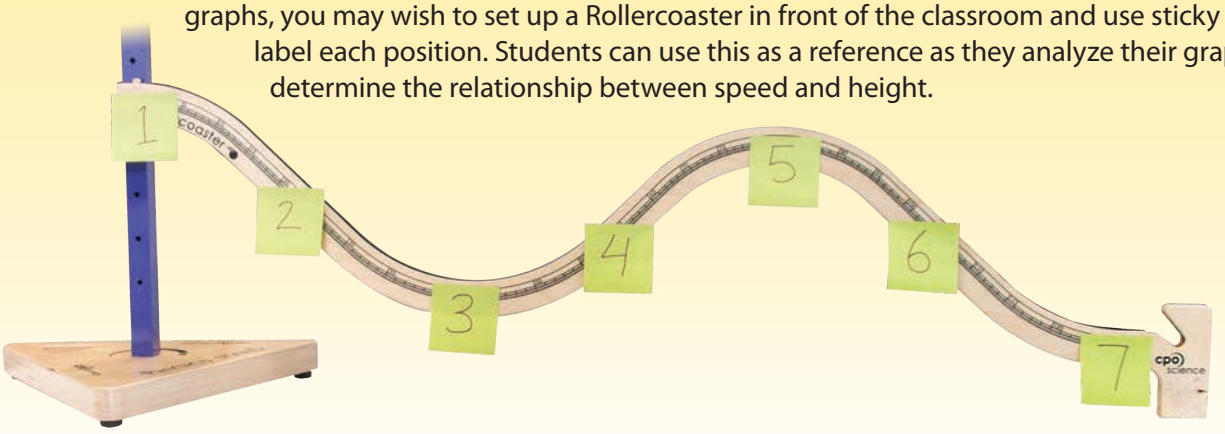
A fun challenge In the investigation, students release the marble from the highest starting point on the track. Challenge students to find the minimum release height that will allow the marble to make a complete journey on the track. There is a release height that will allow the marble to travel to the top of the hill, and then stop at the very top! This release height is difficult to find, but if you have the time, challenge your students to find it.



Guiding the INVESTIGATION

❸ Arguing from evidence

In this part of the investigation, students create a scatterplot graph of their data. You may wish to review the types of graphs prior to this part. Stress that students should not draw a line of best fit for this graph. The investigation asks them to label each point on the graph with the position number on the Rollercoaster. As they create their graphs, you may wish to set up a Rollercoaster in front of the classroom and use sticky notes to label each position. Students can use this as a reference as they analyze their graphs to determine the relationship between speed and height.

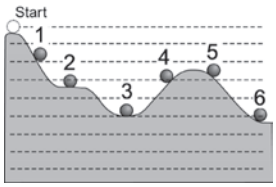


Evaluate

INVESTIGATION **A2**

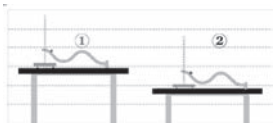
Name _____ Date _____

1. Suppose a rollercoaster was shaped like the drawing below. List the numbered positions in order from where the marble would have the fastest speed to where the marble would have the slowest speed.



Fastest 6, 3, 2, 4, 5, 1 slowest

2. Suppose you measured the speed of the marble at the lowest place on the Rollercoaster by repeating the activity on two tables of different heights as shown to the right. Would your results be any different?



The results should be the same for both rollercoasters. The important quantity is the height drop from the beginning of the track, not the absolute height.

Evaluate

INVESTIGATION **A2**

Name _____ Date _____

3. Suppose a rollercoaster makes a loop as shown in the diagram at right. Describe what will happen if you start the marble at each of the three places shown. Your answers should state whether the marble makes it around the loop and anything else you think might happen along its path. Use sketches to show the path the marble will take for each of the three starting places.

Sketch for Position 1

Sketch for Position 2

Sketch for Position 3

Position 3 cannot rise to the top and is the most likely to begin rolling backward before reaching the top of the loop. Position 2 might rise to the top but is likely to reach zero velocity and roll backward without making it around the loop. Position 1 is the most likely to make it around the loop.

WRAPPING UP

Have your students reflect on what they learned from the investigation by answering the following questions:

What is the relationship between the speed of the marble and its height on the rollercoaster? When is the speed the fastest? When is it the slowest?

Notes and Reflections