2 Measuring and Graphing Speed

LABORATORY

2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students use a model cart system to measure the time it takes for a cart to travel a certain distance, and they use their results to calculate speed—a rate, or proportional relationship. They analyze and interpret motion graphs, and they identify that the slope of the motion graph represents the speed of an object at a given point in time. They learn the importance of a reference frame when quantitatively describing a moving object's speed and direction of motion.

NGSS CORRELATIONS

Performance Expectations

Working towards 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.

Disciplinary Core Ideas

MS-PS3.A Definitions of Energy: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

Science and Engineering Practices

Analyzing and Interpreting Data: Construct and interpret graphical displays of data to identify linear and nonlinear relationships.

Using Mathematics and Computational Thinking: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

Crosscutting Concepts

Scale, Proportion, and Quantity: Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.

Patterns: Graphs, charts, and images can be used to identify patterns in data.

Common Core State Standards—Mathematics

7.RP.A.2: Recognize and represent proportional relationships between quantities.

Common Core State Standards—ELA/Literacy

RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

WHAT STUDENTS DO

Students use a cart, ramp, and track to measure the time it takes for a cart to roll 100 cm. They calculate speed from their distance and time measurements and express it as a rate of motion. Students then match segments of a distance-vs.-time graph to portions of a narrative describing two students' journeys to school. The graphs allow students to determine both the speed and the relative position of an object with respect to a fixed point.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID) (optional)
1 Visual Aid 2.1a, "Graph of Teasha's Trip to School"
1 Visual Aid 2.1b "Graph of Josh's Trip to School"
* 16 paper clips or envelopes

- *For each group of four students*

2 track pieces
1 cart
1 ramp
* 1 meter stick
* 1 marker
masking tape
* calculator
* 1 book or heavy object (optional)

If using the timer method for measuring speed

1 timer

If using the magnetometer method for measuring speed

1 smartphone holder with cart attachment
2 disk magnets

2 large rubber bands
* 1 smartphone

- *For each pair of students*

1 set of 8 strips cut from Student Sheet 2.1, "Trip Strips"
1 Student Sheet 2.2, "Teasha's and Josh's Trips to School"
* 1 pair of scissors
* tape or glue

- *For each student*

1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID) (optional)

**not included in kit*

For Part A, decide if students will use timers or magnetometers for measuring speed. To use magnetometers, each group will need a smartphone that has the free *Science Journal by Google* app loaded onto it.

For Part B, make enough copies of Student Sheet 2.1, "Trip Strips," so that each pair of students will have one set of A–H strips. Separate the four sets on each Student Sheet by cutting it into quarters. Procedure Step 10 instructs students to further cut apart those sets into eight strips, but you may want to do this in advance. For convenience, each set of strips can be held together with a paper clip or placed in an envelope.

TEACHING SUMMARY

GET STARTED

1. Students are introduced to the concept of speed.
   a. Ask students what factors can contribute to a vehicle accident.
   b. Have students read the introduction and Guiding Question to the activity, and ask them how they think speed is measured.

DO THE ACTIVITY

2. If you have not previously done so, introduce the SEPUP model for collaborative work.
   a. Introduce SEPUP's 4–2–1 model for collaborative work.
   b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.
   c. Introduce strategies for effective group interaction.
   d. Explain how you will distribute materials.

3. Students conduct the investigation in Part A.
    a. Have students set up their track and data table.
    b. Ask students, “Why do you think you are asked to do three trials?”
    c. Show students how to measure the time it takes the cart to travel 100 cm.
    d. If using the timer method for measuring speed, use this step. If using the magnetometer method, skip this step and go to Step 3e.
    e. If using the magnetometer for measuring speed, use this step. If using the timer, skip this step.
    f. Circulate throughout the room as students conduct the investigation.
4. Students calculate speed in Procedure Step 7.
    a. Point out the equation for speed.
    b. If you have not already done so, introduce the crosscutting concept of scale, proportion and quantity.
    c. Ask students, “How does the crosscutting concept of scale, proportion, and quantity help us investigate speed?”
    d. Have groups share out the average speeds they calculated and compile them on the board.
    e. Direct students to Analysis item 1.
5. Students explore motion graphs as a way to depict speed in Part B of the Procedure.
    a. Ask students, “When you measured the speed of a cart rolling down a track, do you think the cart was going the same speed the whole time?”
    b. Let students know that they will analyze graphs of distance-vs.-time that show motion over a whole trip, as opposed to determining one average speed over a trip.
    c. As a class, read the scenario and review the diagram of Josh’s and Teasha’s trips in the Student Book.
    d. Introduce what a distance-from-home-vs.-time graph, a type of motion graph, looks like by sketching one on the board.
    e. Distribute Student Sheet 2.2, “Teasha’s and Josh’s Trips to School,” and direct students’ attention to the graphs.
    f. Have students complete Procedure Steps 11–14.
    g. When students have finished the investigation, discuss their choices for matching the strips to the graph segments.

BUILD UNDERSTANDING

6. Students answer Analysis items 2–5.

   a. (AID QUICK CHECK) Direct students to Analysis item 2.

   b. If students are struggling with interpreting the meaning of slope on these types of motion graphs, have a class discussion.

   c. Explain that Analysis items 3–5 provide additional practice for students in analyzing and interpreting the motion graphs.

TEACHING STEPS

GET STARTED

1. Students are introduced to the concept of speed.

   a. Ask students what factors can contribute to a vehicle accident.

      Students may suggest that not paying attention, not stopping in time, and slippery road conditions can contribute to vehicle accidents. Make sure that speeding or driving fast is mentioned. Explore students' ideas of speed using the units of measure described in the introduction and everyday examples. For example, in the United States, vehicle speed is typically measured in miles per hour (MPH) while kilometers per hour (km/h) is used for car speed in most other countries. Point out that scientists often measure everyday speeds in meters per second (m/s), but in this activity, students will measure speed in centimeters per second (cm/s).

   b. Have students read the introduction and Guiding Question to the activity, and ask them how they think speed is measured.

      If they respond with names of devices, such as a speedometer or radar gun, ask them how people measured speed before those devices were invented. All speed-tracking devices, whether modern or not, measure the time it takes to travel a distance. Guide students to understand that the basic method of measuring speed must involve measuring both time and distance.

DO THE ACTIVITY

2. If you have not previously done so, introduce the SEPUP model for collaborative work.

   a. Introduce SEPUP's 4–2–1 model for collaborative work.

      Explain that many of the activities in this book use the SEPUP 4–2–1 cooperative learning model. Students work in groups of four or in pairs to share, discuss, compare, and revise their ideas and to conduct investigations and activities. In all cases, each individual student is responsible for contributing ideas, listening to others, recording and analyzing their results, and monitoring their own learning.

b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.

In science, collaboration is essential for the development of new ideas and a better understanding of scientific concepts. However, scientists must publish only their own work and must give others credit when they build on others' ideas.

c. Introduce strategies for effective group interaction.

Explain or model what productive group interactions (both agreement and constructive disagreement) look like and sound like. For more information about group work, including two optional Student Sheets to help support students' interactions, see the Facilitating Group Interaction section of Teacher Resources II, "Diverse Learners."

d. Explain how you will distribute materials.

The materials management reflects the 4–2–1 structure of the classroom activities. The equipment kit typically contains materials in either sets of 16 (for each pair of students in a class of 32 students) or 8 (to be shared among groups of four), depending on how the activity is organized.

You might wish to distribute the materials in numbered containers. This will allow you to quickly check the contents of the containers and hold groups accountable for ensuring their materials are returned in good shape.

3. Students conduct the investigation in Part A.

a. Have students set up their track and data table.

Teacher's note: Before students complete the Procedure, make sure they have a way to prevent the cart from rolling off the track and falling to the floor. The cart will sustain damage and provide inconsistent results if repeatedly mishandled. Have students either place a book or other heavy object at the end of the track to prevent a runaway cart, or perform the experiment on the floor.

Students should be able to follow the diagram in their Student Books to set up the track and ramp on their tables. Make sure students position the track at least a few inches away from the edges of the table so that the cart is less likely to fall off the table. Students may need help placing the tape on their tables to mark the starting line and finish line. Explain that the two pieces of tape should be placed 100 cm apart.

b. Ask students, "Why do you think you are asked to do three trials?"

Students should have the sense that repeating a trial several times improves the quality of the data set, but have them try to articulate the reason why. Help students understand that one trial might have an odd result because of errors, and doing more trials will give more reliable results.

c. Show students how to measure the time it takes the cart to travel 100 cm.

Step 4 in the Student Book instructs students to follow your instructions for how to measure time in this activity. There are two methods for doing this. The first method involves the students using timers to visually start and stop depending on when the front of the cart passes the starting and finish lines, respectively. The second method involves using a smartphone with an app that can detect a magnet at the starting line and another magnet at the finish line. The second method requires the equipment listed under this option in Materials and Advance Preparation. The full description of each method is described below in Steps 3d (timer method) and 3e (magnetometer method).

d. If using the timer method for measuring speed, use this step. If using the magnetometer method, skip this step and go to Step 3e.

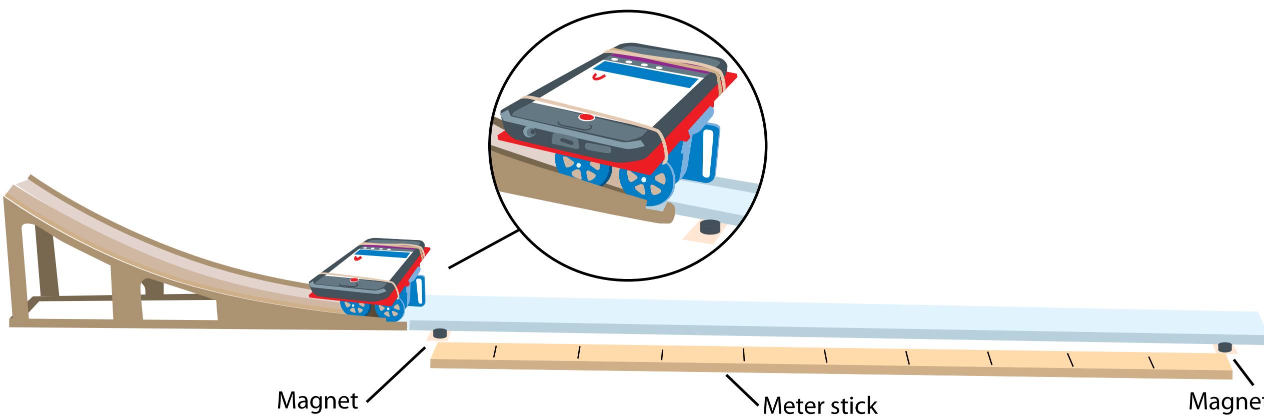
Have students familiarize themselves with the timer's buttons. Students will need only to start, stop, and reset to complete this activity. Have one student from each group volunteer to be the timer, and ask them to position themselves such that they can easily observe when the cart crosses the starting and finish lines. Tell them that they should start the timer the moment the front of the cart reaches the starting line and then stop the timer the moment the front of the cart reaches the finish line. It is important that students follow this convention for each of their three trials. Let students know that if they make a mistake in starting or stopping their timers, they should do a make-up trial.

e. If using the magnetometer for measuring speed, use this step. If using the timer, skip this step.

Refer to the diagram on the next page for the magnetometer setup. Pass out the additional materials, and ask students to slide the smartphone holder onto their carts. Caution students to handle the cart with the smartphone attached with care to avoid any damage to the phone. Have one student from each group volunteer to use their smartphone as the measuring device for this activity, and make sure that they have the *Science Journal by Google* application installed on their phone.

Have each group place one magnet on the starting line and one magnet on the finish line. Results are best if the two magnets have their north poles side up. Once students are ready to conduct their experiments, they should ensure the smartphone is securely attached to the smartphone holder using two rubber bands and that the app has the magnetometer showing. Once ready, students should press the red recording circle on their app and release their cart down the track.

When the cart has crossed the finish line, students can stop data collection. To measure the time it took for the cart to travel between the two magnets, students using the app can drag their finger from the first peak in their data to the second peak in their data, and note the times associated with each. The difference between the times recorded from each peak is the amount of time it took for the cart to travel the distance between the two magnets.



f. Circulate throughout the room as students conduct the investigation.

Students might notice that the cart slows down over the course of the track, and they may decide that this introduces errors in the experiment. If students raise this issue, point out that the cart should slow down consistently in each trial since the track is a controlled component of the experiment. Since the slowing is occurring across all trials, it is not a factor that will introduce noticeable errors in the data. If appropriate, briefly discuss the friction between the cart and the track, which is what slows the cart. Because friction is formally introduced later in the unit, it is sufficient at this point to merely identify it and its effects.

4. Students calculate speed in Procedure Step 7.

a. Point out the equation for speed:

speed = distance / time

Write the equation on the board, and introduce or review its use by asking such questions as, "What is the speed of a vehicle that travels 100 miles in 2 hours?" (50 MPH), and "What is the speed of a vehicle that travels 30 km in 1/2 hour?" (60 km/h). Reinforce the idea that the forward slash (/) is read as "per" and means "divided by."

b. If you have not already done so, introduce the crosscutting concept of scale, proportion and quantity.

Explain that crosscutting concepts bridge disciplines, and can be a lens or touchstone through which students make sense of phenomena and deepen their understanding of disciplinary core ideas.

Refer students to the chart in Student Book Appendix G, "Crosscutting Concepts," and point out the symbol and definition provided. Review the symbol for scale, proportion, and quantity, which shows a simple diagram of a number of squares of different sizes and proportions. Scientists use proportional relationships to compare measurements of objects and events. They often use mathematical expressions and equations to represent these relationships.

c. Ask students, "How does the crosscutting concept of scale, proportion, and quantity help us investigate speed?"

Students should recognize that speed is a proportional relationship quantifying an amount of distance covered in a particular amount of time.

d. Have groups share out the average speeds they calculated and compile them on the board.

Students should find that the cart takes between 1 s and 2 s to travel 100 cm, as shown by the sample data below. Results may differ depending on variations in the cart and track.

CART SPEED

Trial	Distance (cm)	Time (s)	Speed (cm/s)
1	*100*	*1.34*	*74.6*
2	*100*	*1.36*	*73.5*
3	*100*	*1.14*	*87.7*
		Average	*78.6*

If any group's results are significantly different but are consistent (e.g. all faster or all slower), try to determine the cause. If only a few times are really different, point these out, and discuss whether or not to discard these outliers as "bad" data or to keep them in the data set. Such outliers are most likely to arise from human error when the timer is started and stopped. Sometimes students want to discard the outliers. In either case, point out that although these times are significantly different, it doesn't necessarily mean they are wrong.

e. Direct students to Analysis item 1.

This item will allow you to check if students can correctly calculate speed.

5. Students explore motion graphs as a way to depict speed in Part B of the Procedure.

a. Ask students, "When you measured the speed of a cart rolling down a track, do you think the cart was going the same speed the whole time?"

Lead students to the understanding that the cart started at rest, a speed of 0 m/s, and then sped up to its top speed, and eventually slowed down until it stopped and came to rest, once again having a speed of 0 m/s. Emphasize that when they measured the speed of the cart, they found its average speed over a distance of 100 cm (or 50 cm) on the flat part of the track. Distinguish this from instantaneous speed, or the speed at any given moment in time, as reflected on a speedometer.

b. Let students know that they will analyze graphs of distance vs. time that show motion over a whole trip, as opposed to determining one average speed over a trip.

The calculations students made in the first part of the activity used measurements from the end points (initial distance, final distance, and time interval), which gave no information about the speed in the middle of the trip. A cart could speed up and slow down and have the same average speed over the whole track as a cart that moved at a constant speed. Explain that a graph of distance vs. time is a powerful tool because it shows the motion at any moment of time during the whole trip.

c. As a class, read the scenario and review the diagram of Josh's and Teasha's trips in the Student Book.

Point out that the road from Josh's and Teasha's houses to the school is straight; thus, a trip directly to school wouldn't require any turning. This activity focuses on linear motion only, but because the graphs show changes as slopes or curves, students will likely think that the graphs show a change in direction (such as north, south, east, or west). To help dispel this misconception, remind students more than once during this activity that the graphs show what is happening during a trip on a straight road.

Teacher's Note: The motion graphs used in the Procedure are simplified to make them easier for students to analyze and interpret. There are points on each graph that would be problematic if these graphs were used to analyze acceleration; however, these graphs are not used for this purpose in this activity.

d. Introduce what a distance-from-home-vs.-time graph, a type of motion graph, looks like by sketching one on the board.

Point out that the vertical (y) axis represents distance from the starting point, and the horizontal (x) axis represents time. Review the definition of the slope of the line on the graph. To get them thinking about the interpretation of these graphs in the context of the activity, ask them to think about what each of the following means:

- A positive (upward) slope
- A zero slope (horizontal line)
- A negative (downward) slope

At this point in the activity, it is unlikely students will have a firm understanding, so accept all reasonable interpretations. This is a good time to check their background knowledge about graph reading to give you an idea of how much help they might need as they do the activity. Let them know they will be exploring how the slope on the graph relates to speed. Remind students of Interpreting Graphs in Appendix C in the Student Book to help them read and interpret the motion graphs. Eventually, students will be able to explain that

- a positive (upward) slope means the vehicle is moving away from home.
- a zero slope (horizontal line) means the vehicle has stopped.
- a negative (downward) slope means the vehicle is moving back toward home.

e. Distribute Student Sheet 2.2, "Teasha's and Josh's Trips to School," and direct students' attention to the graphs.

Pass out the trip strips (or blocks of trip strips to be cut apart) to student groups, making clear to them that the letters on each strip are for identification purposes only and have nothing to do with the order of events. Point out that only two of the strips, E and F, identify whose trip those strips belong to.

f. Have students complete Procedure Steps 11–14.

Circulate around the room, helping groups who are having difficulty matching the strips to the graph segments. You might tell them that Trip Strips C, D, and F are for Teasha's journey, and A, B, E, G, and H are for Josh's journey.

- For Teasha's trip, the chronological order of the trip strips is D, C, F.
- For Josh's trip, the order is G, E, A, H, B.

g. When students have finished the investigation, discuss their choices for matching the strips to the graph segments.

Solutions to the chronological order of the trip strips made from Student Sheet 2.1 based on the time-vs.-distance graphs from Student 2.2 can be displayed using Visual Aid 2.1a, "Graph of Teasha's Trip to School," and Visual Aid 2.1b, "Graph of Josh's Trip to School."

BUILD UNDERSTANDING

6. Students answer Analysis items 2–5.

a. (AID QUICK CHECK) Direct students to Analysis item 2.

This item provides an opportunity to check students' abilities to analyze and interpret motion graphs. Display or pass out the ANALYZING AND INTERPRETING DATA (AID) Scoring Guide, and tell students they will not be assessed using this Scoring Guide in this activity, but they will in a future activity. Point out how it has the same levels as the previous Scoring Guide but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment." A sample Level-4 response to Analysis item 2 can be found in Sample Responses to Analysis.

b. If students are struggling with interpreting the meaning of slope on these types of motion graphs, have a class discussion.

Focus on the idea that the slope for a distance-vs.-time graph is equivalent to the speed of the object. Emphasize that steeper slopes mean faster speeds and that a horizontal line (0 slope) means that the object has stopped and has a speed of zero (0). To do this, first introduce or review the equation for the slope of a line:

$$\text{slope} = \frac{\text{the change in y } (\Delta y)}{\text{the change in x } (\Delta x)}$$

Next, explain that since the y-axis is distance and the x-axis is time, the slope,

$$\frac{\Delta y}{\Delta x}$$

is actually the change in distance divided by the change in time, which is the formula for speed. The substitution can be shown as

$$\text{slope} = \frac{(\Delta y)}{(\Delta x)}$$

$$= \frac{\text{the change in the distance } (\Delta d)}{\text{the time interval } (\Delta t)}$$

c. Explain that Analysis items 3–5 provide additional practice for students in analyzing and interpreting the motion graphs.

If necessarily, help students understand that downward sloping segments of the line indicate that the vehicle has reversed direction and is returning to a position closer to the starting point. Students commonly misinterpret a negative slope as a slowing down, so be sure to emphasize that the steepness of the slope is the speed of travel and the direction of slope indicates if its moving forward or backward. These items provide an opportunity to reinforce the idea that all the graphs in this activity only reflect linear motion.

Teacher's Note: The motion graphs used in Analysis item 5 are simplified to make them easier for students to analyze and interpret. There are points on each graph that would be problematic if these graphs were used to analyze acceleration; however, these graphs are not used for this purpose in this activity.

SAMPLE RESPONSES TO ANALYSIS

1. What is a car's speed in m/s if it travels

a. 5 m in 0.1 s?

50 m/s

b. 5 m in 0.2 s?

25 m/s

c. 10 m in 0.2 s?

50 m/s

2. (AID QUICK CHECK) Identify a place on each motion graph where

SAMPLE LEVEL-4 RESPONSE

a. the line is flat. What does it mean when the slope of the line is zero?

A flat line means that the car isn't moving. If the car were moving, then the distance would be changing over time. A line with a zero slope means the y-axis isn't changing, and in this case, the y-axis is distance.

b. the slope of the line changes. What does a change in the slope of a motion graph indicate?

A change in the slope of the line means that the car is changing speed. When the line gets steeper, it means the car is covering a greater distance in a period of time. The car is going faster. When the line gets less steep, it means the car is covering a shorter distance in a period of time. The car is going slower.

3. Which student—Teasha or Josh—started out faster? Explain how you know this.

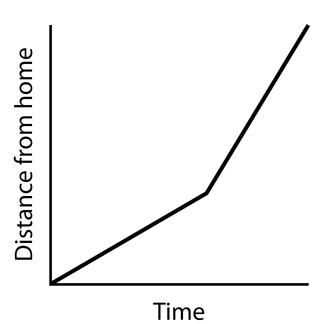
Teasha started faster than Josh did. I know this because I looked at the graphs, and Teasha's has a steeper slope than Josh's. Her slope for the first segment is 0.5 miles/minute, and Josh's is 0.4 miles/minute. Since Josh's slope is less steep than Teasha's, he wasn't moving as fast.

4. How far into the trip did Josh turn around? Describe what the graph looks like at this point in the trip.

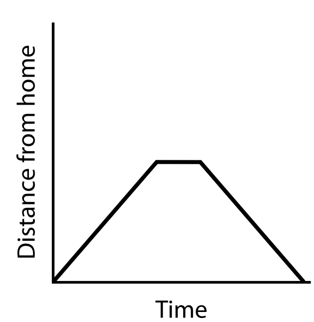
Josh turned around 6 minutes after he left home—5 minutes traveling 2 miles and 1 minute stopped. You know this because from Minute 6 to Minute 10, the slope of the graph is negative (downward), which indicates a reversal in the direction of motion. With a positive (upward) slope, the distance away from the starting point increases with time. With a negative slope, distance from the starting point decreases with time, which means that the car is getting closer to, or traveling back toward, the starting position.

5. Look at the motion graphs that indicate distance vs. time, shown below. Match the descriptions here to the correct graphs.

GRAPH 1

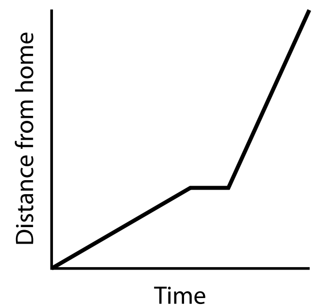


GRAPH 2



GRAPH 3

GRAPH 4



a. A car moving at a constant speed stops and then moves in the opposite direction at the same speed.

Graph 2

b. A car moving at a constant speed stops and then moves faster in the same direction.

Graph 4

c. A car moving at a constant speed changes to a higher constant speed.

Graph 1

d. A car moving at a constant speed changes to a lower constant speed.

Graph 3

EXTENSION 1

Have students post their results on the *SEPUP Third Edition Force and Motion* page of the SEPUP website at *www.sepuplhs.org/middle/third-edition*, and compare their data sets to those of students in other classes.

EXTENSION 2

Have students consider the following question: If the speed limit is 60 MPH, could the police give a speeding ticket to any of the drivers of the cars in Analysis item 1?

Hint: 1,000 m = 1 km = 0.62 miles

Because this problem requires some fairly complicated unit conversions, it may not be appropriate for all students. It is most suitable for students who enjoy solving challenging math problems.

The police could issue speeding tickets in items 1a and 1c because, in both cases, the car is going 112 MPH, but in 1b, it is going 56 MPH.

a. 50 m/s = (50 m/s) × (60 s/min) × (60 min/hr)

= 180,000 m/hr

180,000 m = 180 km

180,000 m/hr = 180 km/hr × (0.62 miles/km)

= 112 MPH

b. 25 m/s = (25 m/s) × (60 s/min) × (60 min/hr)

= 90,000 m/hr

90,000 m = 90 km

90,000 m/hr = 90 km/hr × (0.62 miles/km)

= 56 MPH

c. Same as a.

EXTENSION 3

Have students create one or more new characters also riding in cars for the scenario in Part B of this activity. For each character, students should make up another set of trip strips and a motion graph to go with them.

REVISIT THE GUIDING QUESTION

How can you measure and graph the speed of a moving object?

Speed is measured by measuring the time it takes an object to cover a certain distance. Thus, speed is a rate. Speed can be graphed with distance from a location on the y-axis and time on the x-axis. The slope of the line indicates the speed. The steeper the slope, the faster the object is moving. A flat slope means the object is not moving. A negative slope indicates the object is moving back toward the starting point.

ACTIVITY RESOURCES

KEY VOCABULARY

speed

BACKGROUND INFORMATION

SPEED

An object in motion takes time to change its position. Speed is the measurement of the rate of change in position and can be linear or rotational. The units for speed are a distance or an angle per unit of time, such as miles per hour or degrees per second.

Many moving objects do not travel at a constant speed. *Instantaneous* speed is the term given to the speed of an object at any "instant" during its journey. Average speed is the total distance the object traveled divided by the total time elapsed in traveling that distance. Objects can attain the same average speed through numerous different series of instantaneous speeds. For example, one car might travel a certain distance at a steady 40 MPH, while another makes the same trip at a speed of 30 MPH for 1 hour and 50 MPH for 1 hour. At the end of the trip, both cars will have made the trip at an average speed of 40 MPH although their instantaneous speeds were different.

VELOCITY

Speed (s) and velocity (v) are related concepts but are not the same thing. The velocity of an object includes both its speed and its direction. Whereas speed is a *scalar* quantity, velocity is a *vector* quantity, which means it must be described by an amount and a direction. This unit discusses the concept of speed only.

ACCELERATION

Acceleration will be addressed later in the unit. Acceleration is the time rate of change of velocity. Like velocity, it is a vector quantity that includes both an amount and a direction. In this unit, the discussion of acceleration is often limited to linear acceleration—a change in speed but not a change in direction—where the descriptions of "increasing" (+) and "decreasing" (–) are sufficient in describing the direction of acceleration. For simplicity, when nonlinear motion is mentioned, a "change in direction" is used to imply acceleration, but a specific direction is not provided.

Negative acceleration, like any acceleration, is a vector quantity that has both magnitude and direction. In linear motion, the term *negative acceleration* refers to acceleration that is a result of either a slowing down in a positive direction or a speeding up in a negative direction. For example, a car that applies brakes while moving forward (positive direction) in a straight line has negative acceleration because the acceleration is in the opposite direction as the velocity. However, a car that is speeding up while moving backward in a straight line (increasing negative values) is also said to have negative acceleration because although it is speeding up, it is doing so in the negative direction.

The term *deceleration* is used to refer to negative acceleration given in the first example above, that is, when the object is moving in a straight line in the positive (+) direction and has decreasing speed from an acceleration in the opposite direction (i.e., applying the brakes). Deceleration reflects the situation presented in the activity.

DISTANCE-VS.-TIME GRAPHS

The motion of an object is defined by its change of position over a period of time. Graphs of distance vs. time are useful in describing and interpreting motion that is linear. On such a graph,

- a straight line indicates a constant speed.
- a horizontal line indicates no motion, or zero (0) speed.
- a positively sloped line (upward) indicates motion away from the reference point, or positive velocity.
- a negatively sloped line on a displacement graph indicates motion toward the reference point, or negative velocity.
- a steeper slope indicates a faster speed.
- the value of the slope is the speed defined by the graphed units of time and distance.
- a curved line of changing slope indicates linear acceleration, or a change in speed.
- the rate of curvature represents the amount of acceleration.

REFERENCES

National Highway Transportation Safety Administration. (2015). *Traffic safety facts: Speeding*. Retrieved from *https://www.nhtsa.gov/risky-driving/speeding*

Name____ Date___________

STUDENT SHEET 2.1

TRIP STRIPS

A	Car takes 4 minutes to return home (30 MPH).
B	Car travels 4 miles in 8 minutes (30 MPH).
C	Car stops for 6 minutes while picking up a friend.
D	Car travels 3 miles toward school in 6 minutes.
E	Josh, realizing he may have forgotten his homework, pulls over, and looks through his backpack for 1 minute.
F	Teasha's car gets caught in traffic and travels 1 mile in 8 minutes (7.5 MPH).
G	Car travels 2 miles in 5 minutes.
H	Car stops for 2 minutes.

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B	Car travels 4 miles in 8 minutes (30 MPH).
C	Car stops for 6 minutes while picking up a friend.
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E	Josh, realizing he may have forgotten his homework, pulls over, and looks through his backpack for 1 minute.
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G	Car travels 2 miles in 5 minutes.
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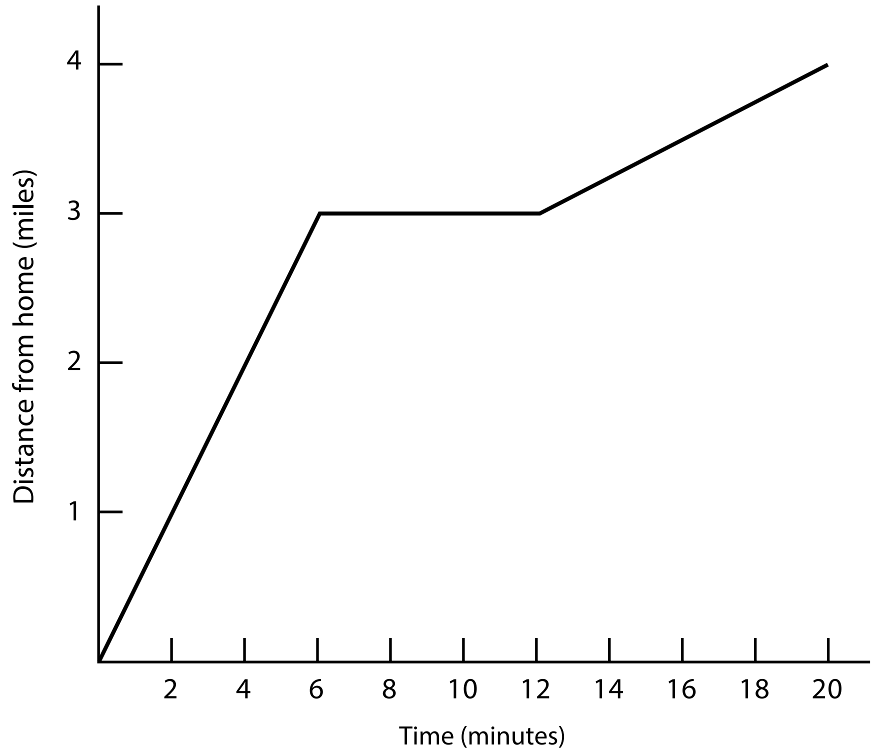
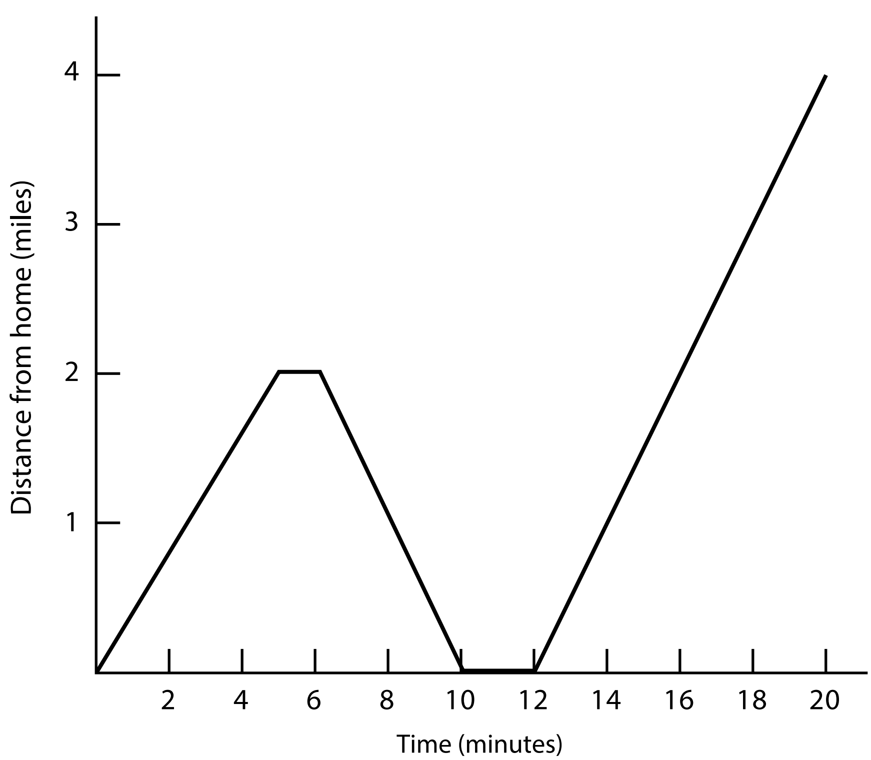
Name____ Date___________

STUDENT SHEET 2.2

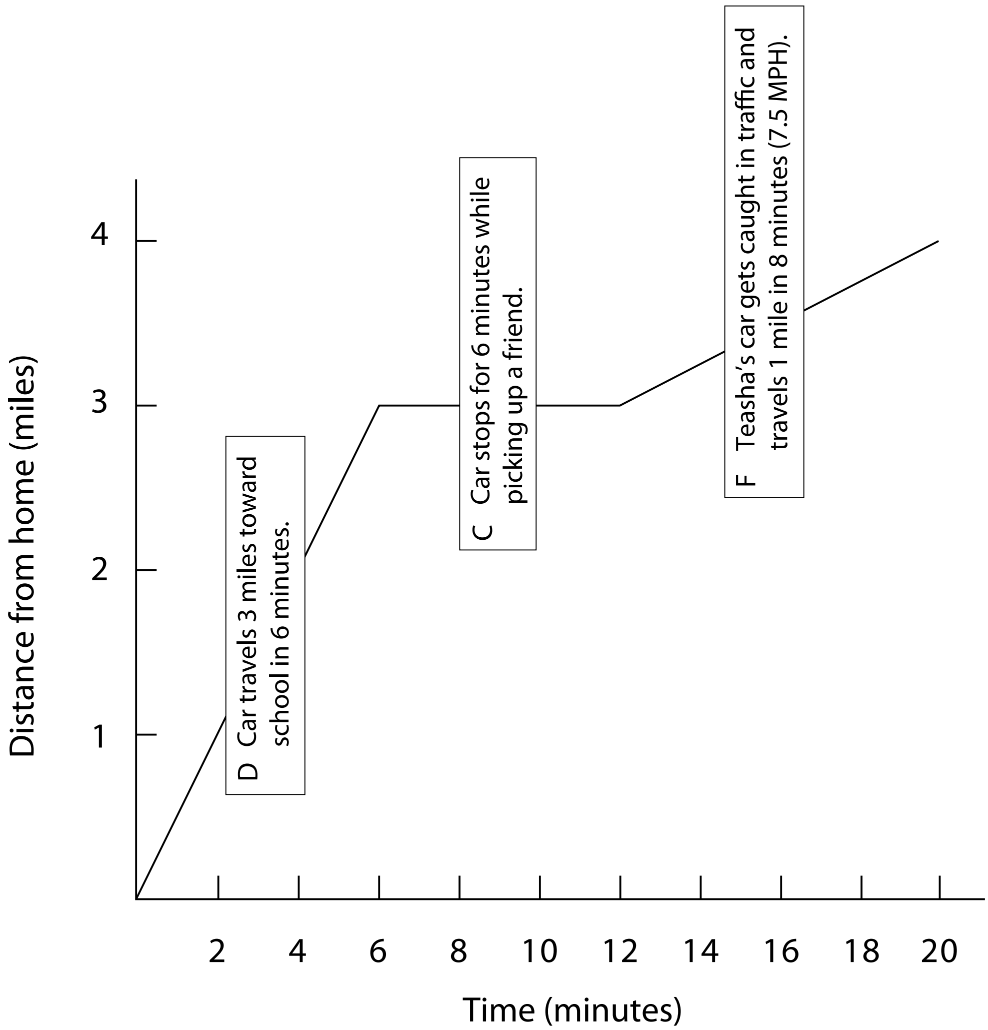
TEASHA'S AND JOSH'S TRIPS TO SCHOOL





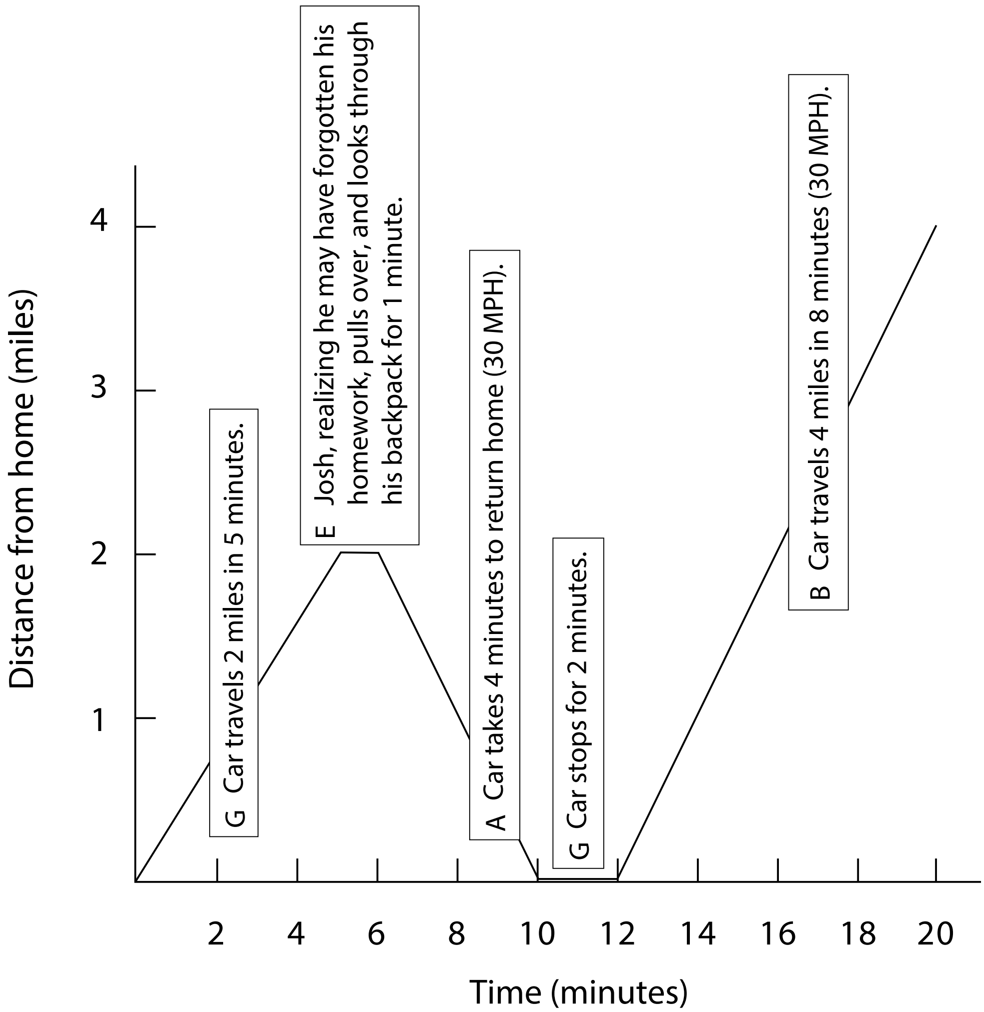
VISUAL AID 2.1a

GRAPH OF TEASHA'S TRIP TO SCHOOL



VISUAL AID 2.1b

GRAPH OF JOSH'S TRIP TO SCHOOL



3 *Speed and Kinetic Energy*

LABORATORY

1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students further investigate speed by carrying out an investigation that relates the speed of an object to its kinetic energy. Students analyze and interpret data to determine that when their carts are released from a greater height, they go faster (because more gravitational potential energy is transformed into kinetic energy). Students confirm the positive relationship between speed and kinetic energy by examining the transfer of energy from a cart to an object in its path. The quantitative relationship between speed and kinetic energy is examined in a later activity.

NGSS CORRELATIONS

Performance Expectations

Working towards 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.

Working towards MS-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.

Disciplinary Core Ideas

MS-PS3.A Definitions of Energy: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

MS-PS3.C Relationship Between Energy and Forces: When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

Science and Engineering Practices

Analyzing and Interpreting Data: Construct and interpret graphical displays of data to identify linear and nonlinear relationships.

Planning and Carrying Out Investigations: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.

Constructing Explanations and Designing Solutions: Construct an explanation that includes qualitative or quantitative relationships between variables that predict or describe phenomena.

Crosscutting Concepts

Scale, Proportion, and Quantity: Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.

Patterns: Graphs, charts, and images can be used to identify patterns in data.

Cause and Effect: Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Energy and Matter: Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion).

Common Core State Standards—Mathematics

6.SP.B.5: Summarize numerical data sets in relation to their context.

7.RP.A.2: Recognize and represent proportional relationships between quantities.

Common Core State Standards—ELA/Literacy

RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

WHAT STUDENTS DO

Students use the same cart system to explore the qualitative relationship between the speed of the cart and its kinetic energy. Students release the carts from different heights on the ramp and measure the speeds of the carts. Students know based on their understanding of energy transformation that a cart with a greater release height has more gravitational potential energy that can be transformed into kinetic energy of motion. They then use their understanding of energy transfer to investigate what happens when a block is in the path of a cart. Using different release heights, students compare how far a block placed on the track moves after a cart hits it. Students discover that a faster-moving cart moves the block farther—more kinetic energy has been transferred from the cart to the block.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

  1 Scoring Guide: ORGANIZING DATA FOR ANALYSIS (ODA) (optional)

  1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID)

- *For each group of four students*

  2 track pieces

  1 ramp

  1 cart

  1 block

  * 1 meter stick

  * 1 marker

  * calculator

  masking tape

If using the timer method for measuring speed

1 timer

If using the magnetometer method for measuring speed

1 smartphone holder with cart attachment

2 disk magnets

2 large rubber bands

* 1 smartphone

- *For each student*

  1 Scoring Guide: ORGANIZING DATA FOR ANALYSIS (ODA) (optional)

  1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID) (optional)

  1 Student Sheet 3.1, "Effect of Release Height on Cart Speed" (optional)

  1 Student Sheet 3.2, "Effect of Cart Speed on the Block" (optional)

**not included in kit*

Decide if students will use timers or magnetometers for measuring speed. To use magnetometers, each group will need a smartphone that has the free *Science Journal by Google* app loaded onto it.

This unit assumes that students have already completed a unit on energy and are familiar with kinetic energy and energy transfers and transformations. If they have not completed such a unit, you will need to determine how much time you will need to devote to familiarize your students with these concepts sufficiently to help them understand that in Part B, their moving carts can transfer energy to the block; measuring how far the carts move is an indicator of how much kinetic energy the moving carts have.

TEACHING SUMMARY

GET STARTED

1. Students review what they know about energy transformations and transfers.
   a. Write *kinetic energy* on the board, and ask students for a working definition.
   b. Have a student read the introduction aloud.

DO THE ACTIVITY

2. Students collect data on the effect of ramp height on speed.
   a. Explain to students that in Part A of the activity, they will conduct an investigation to examine the effect of release height on speed.
   b. Let students know whether they will use timers or magnetometers to measure speed.
   c. Circulate throughout the room as students carry out Procedure Steps 1–6.
   d. Consider distributing Student Sheet 3.1, "Effect of Release Height on Cart Speed."
   e. Have groups share out the average speeds they calculated for each release height, and compile them on the board.
   f. Direct students to Analysis item 1, and have them write a response in their science notebooks.
   g. Hold a brief class discussion about the patterns that students identified.
3. Students conduct Part B to explore the relationship of speed and kinetic energy.
   a. Direct students to Procedure Step 7, and have a brief discussion about students' initials ideas about the relationship between speed and kinetic energy.
   b. (ODA QUICK CHECK) Point out Procedure Step 9, which requires students to copy and complete a data table.
   c. Circulate throughout the room as students conduct the investigation.

BUILD UNDERSTANDING

4. (AID ASSESSMENT) Students identify the relationship between speed and kinetic energy.
   a. Let students know they will be assessed on Analysis item 2.
   b. Consider having a brief class discussion to summarize the main result.
   c. Direct students to Analysis item 3.
   d. Direct students to Analysis item 4.

TEACHING STEPS

GET STARTED

1. Students review what they know about energy transformations and transfers.

   a. Write *kinetic energy* on the board, and ask students for a working definition.

   Help students arrive at a definition that involves motion, such as motion energy, or energy of motion. Reinforce that every moving object, including the cars they ride in and the carts in their models, has kinetic energy.

   b. Have a student read the introduction aloud.

   Emphasize that in this activity, the cart gets kinetic energy from the transformation of gravitational potential energy. Remind students that they learned in the SEPUP Energy unit that gravitational potential energy is one type of potential energy. It is the energy stored due to an object's mass and height above the center of Earth. In the real world, our cars are able to move because of other kinds of transformations. Most typically, our cars rely on the transformation of chemical energy (from gasoline), although some modern technologies are using other kinds of transformations (e.g., electrical energy).

DO THE ACTIVITY

2. Students collect data on the effect of ramp height on speed.

   a. Explain to students that in Part A of the activity, they will conduct an investigation to examine the effect of release height on speed.

   Have a brief discussion about students' initial ideas about what they expect. Students are likely to say that cars released from higher will go faster.

   b. Let students know whether they will use timers or magnetometers to measure speed.

   The procedures for both of these methods were outlined in the previous activity, "Measuring and Graphing Speed," in this Teacher Edition.

   c. Circulate throughout the room as students carry out Procedure Steps 1–6.

   Probe each group for their predictions from Procedure Step 1 about the effect of release height on speed. Encourage them to use their understanding of energy transformations when making the prediction. A thorough prediction would be as follows: A cart released from Notch A has more gravitational potential energy than does one released from Notch B or C because the one from Notch A is higher above Earth's center. Because it has more gravitational potential energy, more is transformed into kinetic energy as the cart rolls down the ramp. This will result in the cart having a higher speed.

d. Consider distributing Student Sheet 3.1, "Effect of Release Height on Cart Speed."

This Student Sheet may be helpful if students need more assistance with organizing data, or conversely, if students are adept at organizing data but time is short.

e. Have groups share out the average speeds they calculated for each release height, and compile them on the board.

Below are sample data. Results may differ depending on variations in the cart and track.

EFFECT OF RELEASE HEIGHT ON CART SPEED

Release position	Distance (cm)	Time (s)	Speed (cm/s)	Average speed (cm/s)
A	*50*	*0.43*	*116*	
A	*50*	*0.40*	*125*	*123*
A	*50*	*0.39*	*128*	
B	*50*	*0.52*	*96*	
B	*50*	*0.57*	*88*	*88*
B	*50*	*0.62*	*81*	
C	*50*	*0.91*	*55*	
C	*50*	*0.84*	*59*	*56*
C	*50*	*0.94*	*53*	

f. Direct students to Analysis item 1, and have them write a response in their science notebooks.

This Analysis item allows each student to address their own prediction with their own data.

g. Hold a brief class discussion about the patterns that students identified.

If you have not already done so, introduce the crosscutting concept of patterns. Remind students that crosscutting concepts bridge disciplines, and can be a lens or touchstone through which students make sense of phenomena and deepen their understanding of disciplinary core ideas.

Refer students to the chart in Student Book Appendix G, "Crosscutting Concepts," and point out the symbol and definition provided. Scientists look for patterns because patterns allow them to discover relationships and develop questions about what causes these relationships.

Most students will have correctly predicted and identified the pattern that increasing the starting height increases the speed of the cart. When they are reviewing the data, remind students of the error due to timing the cart. It may be helpful when comparing speeds of the carts that traveled over different distances that the timing errors are more significant in the higher speeds because it is a larger portion of the time measured.

3. Students conduct Part B to explore the relationship of speed and kinetic energy.

   a. Direct students to Procedure Step 7, and have a brief discussion about students' initials ideas about the relationship between speed and kinetic energy.

      Encourage students to reread the introduction about the transformation of gravitational potential energy into kinetic energy of motion. Have students write a prediction for what would happen to a block in the path of the moving cart, and how what happens might depend on the cart's release height. Have a few students share out their predictions, encouraging them to use the scientific terms. A thorough prediction would be as follows: A cart released from Notch A has more kinetic energy because it is going faster. It will move the other object farther down the track because it can transfer more kinetic energy.

   b. (ODA QUICK CHECK) Point out Procedure Step 9, which requires students to copy and complete a data table.

      Note that while the structure of the data table is provided, students are required to identify the dependent and independent variables. If your students are not familiar with independent and dependent variables, it may be helpful to give them an everyday example question, such as, "How does the weather outside (independent variable) affect the kind of clothing you wear (dependent variable)?" Have a brief discussion about these questions to clarify the meaning of the two terms for students.

      They also need to fill in the units of measure. You might use this data table as a Quick Check on how well students can organize data. Consider projecting the ORGANIZING DATA FOR ANALYSIS (ODA) Scoring Guide. Explain that they will not be assessed on this data table but that this skill is essential for the rest of the unit. Point out how the Scoring Guide has the same levels as previous Scoring Guides but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment."

For students who need more scaffolding, consider using Student Sheet 3.2, "Effect of Cart Speed on the Block." This sheet has the variables and units provided.

c. Circulate throughout the room as students conduct the investigation.

When student groups have finished all five trials for all three release heights (which correspond to speed), they should calculate the average for each height.

BUILD UNDERSTANDING

4. (AID ASSESSMENT) Students identify the relationship between speed and kinetic energy.

a. Let students know they will be assessed on Analysis item 2.

If you have not already done so, display or distribute the AID Scoring Guide, and review the levels as needed. For more information, see Teacher Resources III, "Assessment." A sample Level-4 response to Analysis item 2 can be found in Sample Responses to Analysis.

b. Consider having a brief class discussion to summarize the main result.

Teacher's note: Students are not identifying the relationship quantitatively in this activity; they will do so in a subsequent activity.

Students should be able to point out that the data show a clear relationship between speed and block movement because as the cart started higher on the ramp, the block moved farther. Assuming the block distance reflects the amount of kinetic energy that was transformed, and that a higher release height results in faster speed, students can conclude that there is a relationship between the increased speed of the cart and kinetic energy. Below are sample student data.

EFFECT OF CART SPEED ON THE BLOCK

Speed (release height)	Distance block moves (cm)					Average distance (cm)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
Fast (Notch A)	*12.5*	*15.5*	*15.0*	*14.0*	*15.5*	*14.5*
Medium (Notch B)	*9.0*	*9.0*	*8.0*	*9.0*	*9.0*	*9.0*
Slow (Notch C)	*5.5*	*5.5*	*5.5*	*5.5*	*6.0*	*5.5*

c. Direct students to Analysis item 3.

Analysis item 3 provides an additional opportunity for students to discuss the relationship between speed and kinetic energy.

d. Direct students to Analysis item 4.

Point out that this item has the bolded phrase "Car and Driver Safety." Throughout the unit, students will answer Analysis items that ask them to relate what they have learned about scientific concepts to the issue of car and driver safety. Students may find it helpful to return to their answers to these questions during the "Designing a Car and Driver Safety System" activity at the end of the unit. Analysis item 4 asks students to consider how the results of this investigation relate to car and driver safety.

SAMPLE RESPONSES TO ANALYSIS

1. According to your data from Part A, what is the effect of release height on speed?

   Student responses may vary. One sample response is shown here:

   The speed of the cart went from 123 cm/s to 82 m/s to 56 m/s as the height was decreased from Notch A to B to C. So the greater the release height, the greater the speed.

2. (AID ASSESSMENT) According to your data from Part B, what is the effect of speed on the movement of the block? Describe and explain the pattern you observed.

   SAMPLE LEVEL-4 RESPONSE

   The higher the notch that the cart was released from, the farther the block moved. The block moved farthest when released from Notch A. Because we know from Part A that a higher notch corresponds to a greater speed, this means that the faster the cart was moving, the farther the block moved.

3. Your friend says that an object moving at a faster speed has more kinetic energy. Do you agree with your friend? Use evidence from this activity to describe why or why not.

   I agree with my friend. The faster-moving cart has more kinetic energy because there was more gravitational potential energy transformed into kinetic energy of motion. We also saw that the faster-moving cart pushed the block farther along the track. This was because the faster-moving cart transferred more kinetic energy to the block when the cart hit it.

4. **Car and Driver Safety**: How do you think speed affects car and driver safety?

   The faster the car is moving, the more kinetic energy it has. This may mean that when a car gets into an accident, there is more energy transferred to the other cars or objects it hits. This might result in more damage or injuries.

REVISIT THE GUIDING QUESTION

What is the relationship between an object's speed and its kinetic energy?

The faster an object is moving, the more kinetic energy it has. We confirmed this by noting that a faster-moving cart pushes a block in its path farther than does a slower-moving cart.

ACTIVITY RESOURCES

KEY VOCABULARY

kinetic energy

speed

BACKGROUND INFORMATION

POTENTIAL AND KINETIC ENERGY

Potential energy is often referred to as stored energy, and it can come in many forms. Some of these are chemical (e.g., the energy in food and gasoline), gravitational (e.g., a tree about to fall), nuclear (i.e., the energy in the nucleus of an atom that is released by fusion or fission), and mechanical (e.g., the energy that is stored in a spring or rubber band).

Gravitational potential energy is a particular type of potential energy that is a result of an object's position above Earth's center. It depends on mass (m), the acceleration due to gravity (g), and height (h). Specifically,

gravitational potential energy = mgh

The higher and/or more massive an object is, the greater its gravitational potential energy. Imagine dropping a 1-kg mass from 1 cm above your toe. It will hurt but not too much. If you drop it from 1,000 cm above, it would impart 1,000 times more energy and could easily break a bone. Gravitational potential energy also depends on the mass of the object. When dropped from the same heights, a 10-kg mass will impart 10 times more energy than a 1-kg mass.

Kinetic energy (KE) is the energy an object possesses because of its motion. It is dependent on the mass (m) and velocity (v) of an object. Specifically,

KE = $\frac{1}{2}mv^2$

The faster an object is moving and/or the more massive it is, the greater its kinetic energy. Thus, if the mass doubles, the kinetic energy doubles. However, when the speed doubles, the kinetic energy quadruples.

ENERGY TRANSFER AND TRANSFORMATION

Understanding energy transfer and transformation is essential in the study of energy because these interactions present our only visible evidence of energy. Energy is an abstract concept and can only be observed during transfer or transformation. In this unit, the term *energy transformation* refers to the change of energy from one type, such as potential, to another, such as kinetic. Energy transfer describes the transfer of energy from one object to another, such as the transfer of the kinetic energy of a cart to a block.

ENERGY AND FORCE

The two terms *energy* and *force* are both related to motion and are often confused and misused. Energy is the ability of an object to do work (work, as used by physicists, relates to the force and distance an object is moved). Energy can be kinetic (the energy of motion) or potential (stored energy).

A force is a push or a pull that causes a change in motion. Unlike energy, forces cause objects to move but are not contained within the object. Forces exist only when two or more objects interact and are applied from one object to another.

This unit begins with a discussion of the kinetic energy of a moving object and later addresses the idea that forces are what cause an object to change speed (and/or direction).

Name____ Date__________

STUDENT SHEET 3.1

EFFECT OF RELEASE HEIGHT ON CART SPEED

Release position	Distance (cm)	Time (s)	Speed (cm/s)	Average speed (cm/s)
A				
A				
A				
B				
B				
B				
C				
C				
C				

Name____ Date__________

STUDENT SHEET 3.2

EFFECT OF CART SPEED ON THE BLOCK

Speed (release height)	Distance block moves (cm)					Average distance (cm)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
Fast (Notch A)						
Medium (Notch B)						
Slow (Notch C)						