The Rate of Motion

Strand Motion

Topic Investigating speed, velocity, and acceleration

Primary SOL PS.10 The student will investigate and understand the scientific principles of work, force, and motion. Key concepts include
- a) speed, velocity, and acceleration;
- b) Newton's laws of motion.

Related SOL PS.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
- b) length, mass, volume, density, temperature, weight, and force are accurately measured;
- c) conversions are made among metric units, applying appropriate prefixes;
- d) triple beam and electronic balances, thermometers, metric rulers, graduated cylinders, probeware, and spring scales are used to gather data;
- g) data tables showing the independent and dependent variables, derived quantities, and the number of trials are constructed and interpreted;
- h) data tables for descriptive statistics showing specific measures of central tendency, the range of the data set, and the number of repeated trials are constructed and interpreted;
- i) frequency distributions, scatterplots, line plots, and histograms are constructed and interpreted;
- j) valid conclusions are made after analyzing data.

PS.10 The student will investigate and understand the scientific principles of work, force, and motion. Key concepts include
- d) technological applications of work, force, and motion.

Background Information

The rate of motion is described by speed, velocity and acceleration. *Speed* is expressed in terms of average speed or instantaneous speed. *Average speed* of an object is determined by dividing the total distance traveled by the duration of time traveled. *Instantaneous speed* is the speed of an object at a given moment. For example, although your speedometer showed that you were traveling 50 mph (instantaneous speed) while driving to the grocery store, you also had to make many stops at stoplights. Therefore, your average speed for this total trip was only 25 mph. Radars are used by law enforcement officers to detect instantaneous speeds of automobile drivers.

Velocity is similar to speed as it describes how fast an object moves, but also includes the direction of the motion. Velocity may have a positive or a negative value, depending on the direction of the change in position. Speed alone would not be enough information for a pilot to navigate a plane or a meteorologist to describe the path of a hurricane; therefore, velocity is used.

Acceleration is the rate of change in velocity. Acceleration is calculated by dividing the change in velocity (final velocity - initial velocity) by the time traveled. If an object's motion speeds up, slows down, or changes direction, it is accelerating. When the object's motion slows down, the acceleration is described as being negative and can be referred to as deceleration. A car slowing down as it approaches a stoplight would have negative acceleration.

Motion was first explained over 300 years ago when Sir Isaac Newton presented the following three laws of motion:

- First law—An object at rest will stay at rest, and an object in motion will stay in motion at a constant velocity, unless acted upon by an unbalanced force.
- Second law—Force equals mass times acceleration.
- Third law—For every action there is an equal and opposite reaction.

Newton's first law is also called The Law of Inertia**.** *Inertia* is an object's resistance to change in its motion. Therefore, if no net force acts on an object, it will maintain a constant velocity. For example, a parked car is motionless with zero velocity and will remain still until an unbalanced force causes its velocity to change. Meanwhile, if you are driving a car at a constant velocity of 25 mph, you and the car will both maintain that velocity until an unbalanced force changes it. If your car hits a tree, then the car will stop, but your velocity will remain constant until an unbalanced force (seat belt or windshield) acts on you.

Newton's second law states that the net force of an object is equal to the product of its mass and acceleration ($F = ma$). A golf ball and a bowling ball rolling with the same rate of acceleration will produce different amounts of force when they hit the wall due to their different masses.

Newton's third law states that when two objects interact, they exert equal forces on each other in opposite directions. These two forces are called action and reaction forces. A bird flying in the sky uses its wings to push air downward and the air reacts by pushing the bird upward. The amount of force on the air equals the amount of force on the bird, and the direction of force on the air (downward) is opposite the direction of the force on the bird (upward).

Materials

- Meter sticks
- Timers or stopwatches
- Cones (to mark off course)
- 9-inch balloon is standard
- pen barrel or straw
- various materials to construct the racers

Vocabulary

acceleration, inertia, instantaneous speed, speed, velocity

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

In this activity, students will calculate the speed of performing different tasks involving various motions (e.g., walking, skipping, hopping).

Students will need to be familiar with the following formulas in this activity:

Speed = $\frac{\text{distance}}{\text{time}}$ $s = \frac{d}{t}$ Acceleration = $\frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$ $a = \frac{v_f - v_i}{t}$

Force = mass × acceleration $F = ma$

1. Guide students in constructing an appropriate table to use for collecting data during each of the trials. The table should show the independent and dependent variables, number of trials, and values derived. A sample table is shown at right.

Motion	Distance	Trial 1	Trial 2	Trial 3	Mean Time (s)	Speed (d/t)
Walk	5 m					
	10 m					
Skip	5 m					
	10 m					
Hop	5 m					
	10 m					

2. Gather students into groups of four. Give each group two timers and a meter stick.
3. Measure and mark off the "track." Place a cone at the 0 m, 5 m, and 10 m distance.
4. Each group member has a different role. Roles should include a recorder, a timer at the 5 m mark, a timer at the 10 m mark, and the person performing the task.
5. One at a time, a group member should complete one task (walk, skip, or hop) along the 10 meter track. The timers report their times to the recorder for that trial. Repeat the task 2 more times. Once 3 trials have been completed for each task, rotate roles. Continue rotations until all 4 members have completed each role and task.
6. Find the mean averages of the times collected. Use the average times to calculate the speed of each task for each group member at the 5 m mark and the 10 m mark.

In this activity, students will design and test a balloon car. Consider the following rules for this activity, but others may be added:

- The car must be powered by no more than 2 balloons.
- The students may build the car out of almost anything.
- The car must have at least three wheels. Wheels are defined as anything that is round and goes around.
- The wheels cannot be wheels from a toy car or other purchased car. They must be made out of something that was not originally meant to be used as wheels.
- The car may not leave the ground.
- The car must be capable of traveling at least 5 meters.

1. Have the students design and test their car. Distance and time data should be collected and speed calculated for each trial.
2. Have the students create a chart to collect their data and calculations.
3. Ask students to consider the design changes they should make to their car, using the existing materials that would allow their car to travel faster. Allow students time to modify their design and collect the distance and time data and calculate speed.

Assessment

- **Questions**
  - Looking at the data table, which task was performed at the greatest speed? How does that line appear on the graph? Which task was performed the slowest?
  - Did anyone's speed slow down between the 5 meter mark and the 10 meter mark on a task? If so, highlight that section on your graph and describe what happened.

  - Which task showed the greatest amount of acceleration? The least? How did you determine this? Use the formula for acceleration to calculate these values. Show your work.
  - If your mass was 80 kg, how much force would you produce at your greatest rate of acceleration? Least?
  - If you were balancing a book on your head as you tested each task, what would happen to the motion of the book when you stopped? Explain.
  - Which of Newton's laws best explains how the motions of walking, skipping, and hopping are possible? Explain.
  - Based on your speed of walking at the 10 meter mark, how long would take you to walk 1 kilometer?
  - Based on your rate of hopping at the 5 meter mark, how many centimeters would you hop in 10 minutes?
- **Journal/Writing Prompts**
  - Write a conclusion summarizing the results of your findings in this investigation. Compare and contrast the speed and rates of acceleration for the various motions. Identify one way to change or modify this investigation for future use.
  - Pilots and meteorologist are two examples of occupations that use the measurement of velocity in their daily work. Make a list of 10 other occupations that would use speed, velocity, or acceleration in their work. Describe.
- **Other**
  - Construct a distance-time graph displaying the data collected for your group in this investigation. Label all variables, units, and increments of measurement.

Extensions and Connections (for all students)

- Ask students to set up probeware with a motion detector. Use the probeware to collect motion data and construct distance-time graphs. Set the x-axis to measure time and the y-axis to measure distance. Students should begin collecting data and attempt to reproduce the following graphs with their motion. Once they have one of the graphs displayed on their probeware, they should show their teacher and have that box checked off.
- Discuss the following questions after the activity.
  - How was each graph formed?
  - Which graphs were the most difficult to reproduce? Why?
  - What does a flat line represent in a distance-time graph?
  - What type of motion creates a curved line?

Strategies for Differentiation

- Students should be split into five groups. Each group will be assigned one term to act out in the form of charades. Once a group has acted out their term, the class should discuss the definition of the vocabulary term and create a flash card for that term. Students should continue acting out the terms until all flash cards have been completed.
- Provide students with a labeled data table when necessary.
- Allow students to choose between creating their own graph, or following a guided model of graph construction.

- Have students use the data collected to discuss how the rates of acceleration for each motion changed, rather than calculating each. Have them identify the difference between positive and negative acceleration.
- Allow students to act out examples of Newton's first law of motion, such as the book-balancing example described in the assessment.