Senior 2

Appendix 3:
In Motion

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A Visual Representation of Motion
Teacher Background

There are several ways to produce a visual representation of motion. To investigate position, velocity, and acceleration using a ticker-tape apparatus, attach a tape to an object that is in uniform or accelerated motion. For uniform motion, the dots will be evenly spaced; in accelerated motion, the spaces between the dots will increase. The same relationship can be seen with the measured data. The intervals for uniform motion are approximately the same and the intervals for accelerated motion become larger (or smaller if the acceleration is negative).
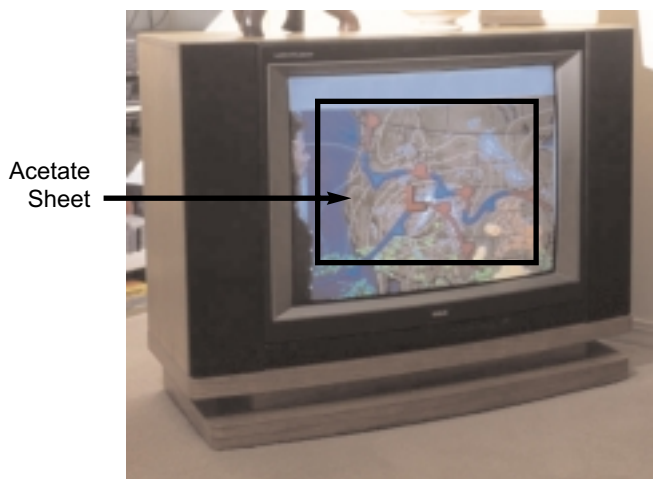
For Uniform Motion

1. Motorized toys will move across a table with a constant speed. By attaching a ticker tape to the back of the vehicle, a series of dots can be recorded on a tape. For uniform motion the dots will be evenly spaced.
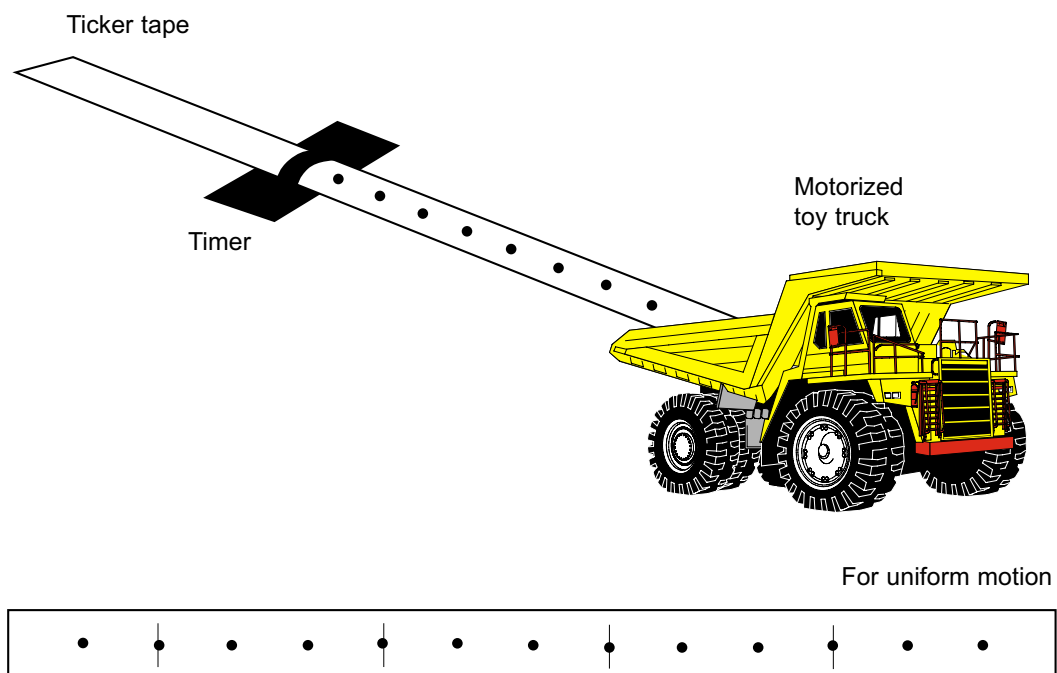

Figure 1

Students can measure the position from the origin and graph position versus time. It is usually convenient to group four to six dots together as one interval. Most timers will vibrate at 60 Hz which means that if you choose 6 intervals the interval of time is 0.1 seconds.

2. Video Analysis

Using a camcorder, videotape uniform and accelerated motion. For uniform motion you can use motorized toys or a ball rolling across a flat surface. A ball rolling down an inclined plane or an object in free fall will accelerate. Replay the videotape and place a mark on the acetate by advancing the tape frame by frame. The marks on the acetate can be interpreted exactly the same as the marks on the ticker tape. Using "canned" tapes of action scenes from movies and/or television, students can analyze "real world" types of motion.

Acetate Sheet →

3. Motion Detector

Walk back and forth in front of motion detector
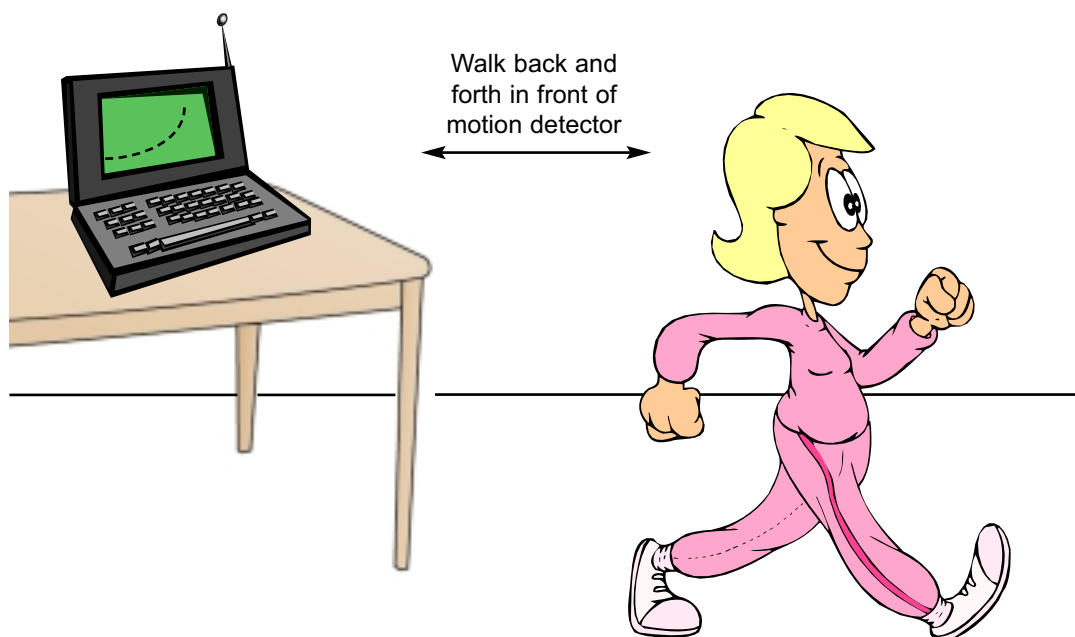
The corresponding graphs also indicate the type of motion. Students should be familiar with the following interpretations:

1. Horizontal line—no motion, the object is at rest

2. Oblique line rising up gently—constant velocity, "slow"

3. Oblique line rising up steeply—constant velocity, "fast"

4. Oblique line falling down—constant velocity in the opposite direction

Note: All interpretations are for graphs above the time axis.

Graphical Analysis

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1. Using a motion detector, try to make the following graphs by moving in front of the detector.

2. Describe your motion in terms of position, velocity, and acceleration.

3. Tell a story about some "real world" motion that each graph might depict.

4. Are any graphs not possible in the "real world"? If so, explain.

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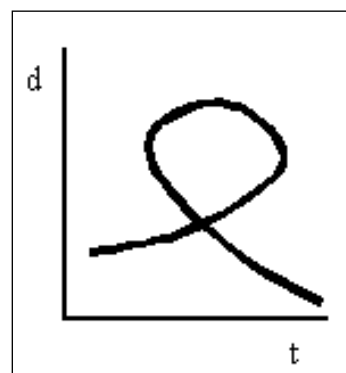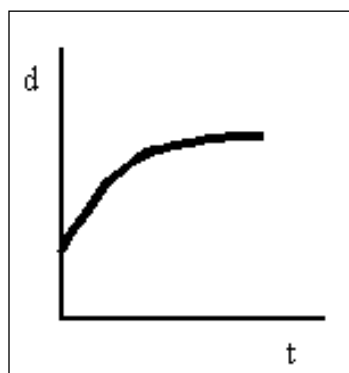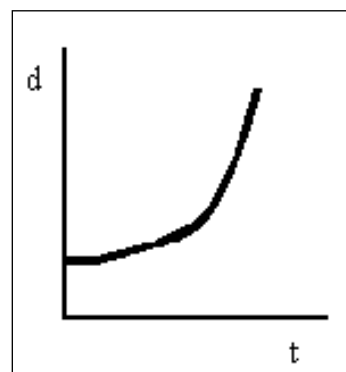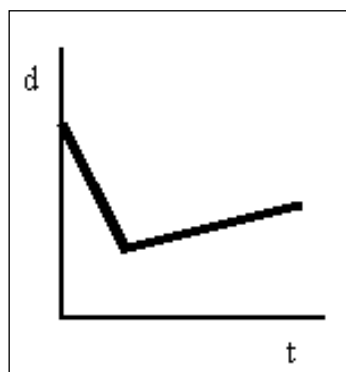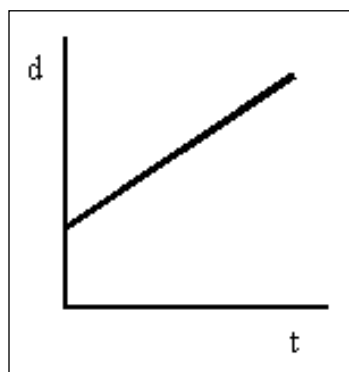
Force and Natural Motion (Historical Perspective)
Teacher Background

Newton's laws are developed qualitatively with the intention of using these principles of force and motion in later discussions about vehicular motion and collisions. An historical discussion can introduce the idea of inertia. Initially, Aristotle proposed that every terrestrial object had a natural motion toward the centre of the universe (Earth). To move otherwise, an object would be in violent motion under the influence of an external force. In Aristotle's physics, it was necessary to continually apply a force to keep an object moving. This idea can be challenged with a discussion of the flight of an arrow. Aristotle believed that the arrow kept moving because the air swirled around behind the arrow, continuing to push it forward. Many critics of Aristotle pointed out that, if this was the case, the air was both the mover and the resistance at the same time!

Two thousand years later, Galileo challenged Aristotle's views in his *Dialogues*. Students can read Galileo's words and draw their own conclusions about Galileo's view of inertia. Galileo thought that inertial motion was circular (i.e., an object free to move on the surface of the Earth would circumnavigate the Earth). Galileo proposed the following thought experiments using inclined planes. In A, if we release a mass down the plane, the mass speeds up. Then if we propel a mass up the plane it will slow down. Therefore, it follows that if the plane is neither up nor down (i.e., horizontal), the mass should neither slow down or speed up, but continue moving at a constant speed.

Figure A
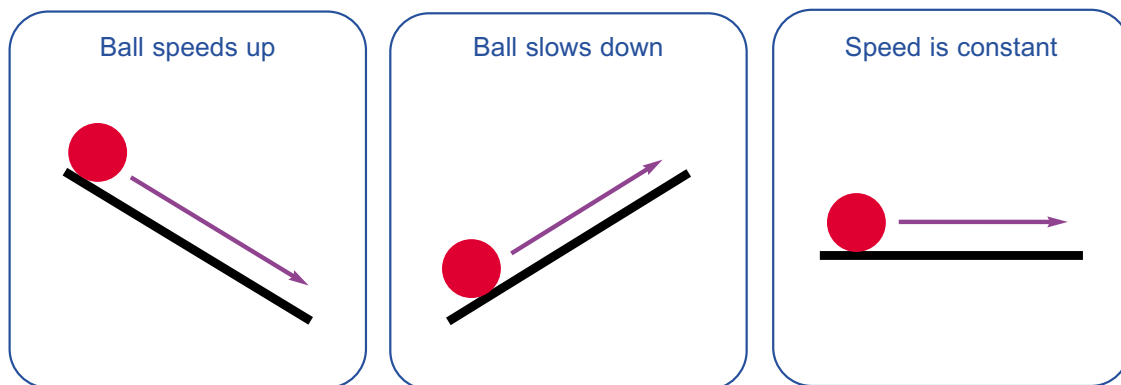
In B, a mass released down the plane will rise up the plane on the other side to the same height. If we decrease the angle of the right plane, then the mass must travel further in order to achieve the same height from which it is dropped. If we continue to decrease the angle, it follows that if the second plane has an angle of zero (i.e., horizontal), the mass will continue forever as it tries to achieve the same height from where it was dropped.

Figure B

Ball rises to the same height

Ball rises to the same height, but goes further
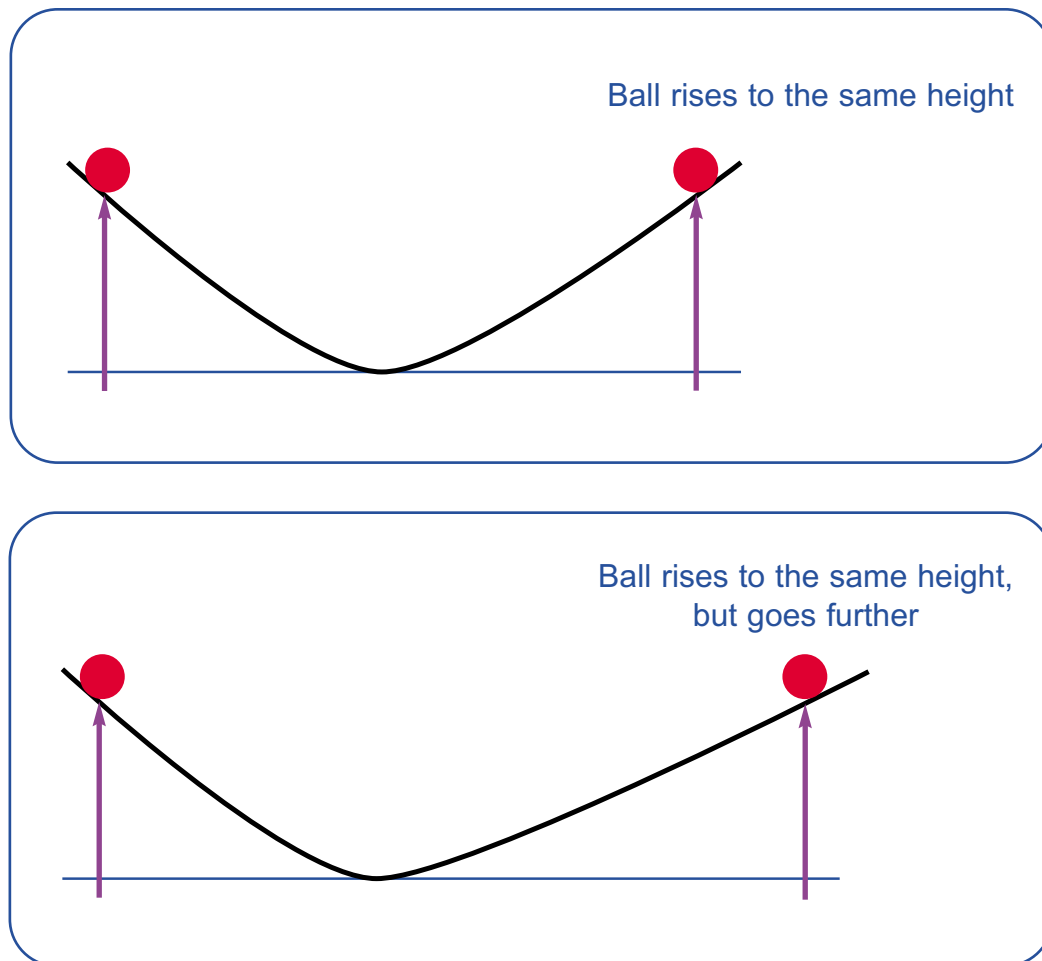
Descartes was the first to propose straight inertial motion and, later, Newton synthesized inertial motion in the *Principia*. We have since called inertial motion **Newton's First Law**.

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Galileo's Thought Experiment

We can imitate Galileo's thought experiment by using toy cars. Relate Galileo's story while demonstrating that the car will rise to almost the same height from which it was dropped. Discuss the limitations of the demonstration (friction) and relate to students that Galileo's great contribution to the way we practise science was his ability to idealize a situation.

To investigate the Law of Inertia:

1. Set up a track apparatus as shown and measure the angle of inclination of the ramp (2). Choose your best car for this activity.
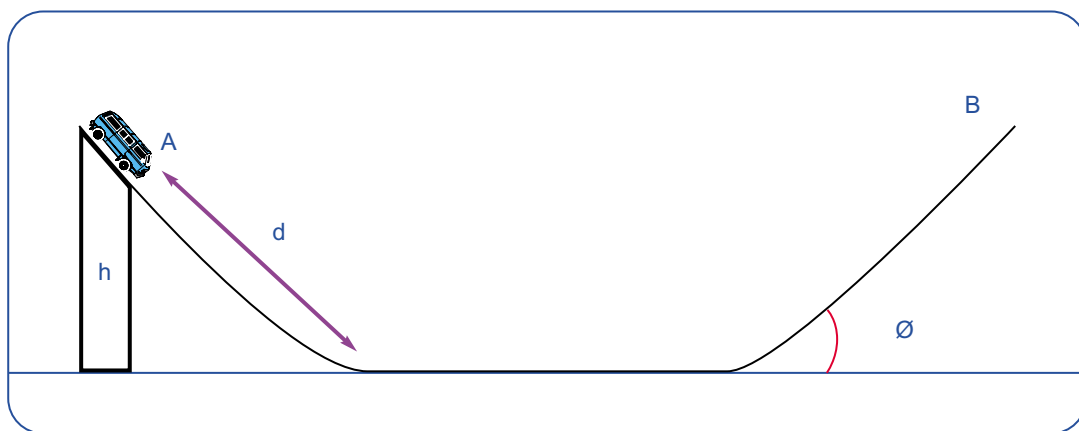
2. Measure the height from which you release the car at point A and then measure the height the car rises up the other side of the ramp at point B. How do these heights compare?

3. Measure the distance down the ramp and the distance up the ramp. How do these compare?

4. Decrease the angle of the up ramp and release the car from the same height. Again, measure and compare the heights and distances.

Questions

1. As the angle decreases, what happens to the distance the car travels along the up ramp? Why does this distance increase?

2. If the angle of inclination is zero, how far would we expect the car to go?

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Newton's First Law
Teacher Background

Newton's laws apply to all moving objects (and those that don't move too!). Motor vehicles are familiar moving objects that always obey the law—Newton's law, that is. According to Newton's First Law, a motor vehicle in motion will remain in motion, moving at the same speed and direction unless acted upon by an unbalanced force. When a moving vehicle suddenly stops in a collision, any unrestrained passengers in the car will continue to move with the same speed and in the same direction until they experience another force. This force is often called the *second collision*. Although we say the passengers have been "thrown" from the vehicle, they are really just continuing to move with the same inertia until they experience an unbalanced force in another collision. What are some of the factors that might influence how far an unrestrained passenger will be "thrown"?

Velocity of a Car on an Inclined Plane

For the following exercises, it is necessary to determine the velocity of a car on an inclined plane at regular intervals. Since the car accelerates down the plane, we must determine the distance up the plane from which the car is released in order to increase the velocity at a known rate. Several ways that this may be approached are included here, but it is not intended that all be introduced in the classroom.

1. **Historical Context**

   Galileo showed that an object that was accelerating (either in free fall or down a plane) would cover a displacement according to the odd numbers (1, 3, 5, 7, and so on) for equal time intervals. In other words, Galileo's ticker tape (if he had one) would look like this:

   Previously, we showed that velocity a time. Since the displacements in Galileo's example are across equal time intervals, the velocity must also increase proportionally for these intervals. That is, the velocity at C is twice the velocity at B, and the velocity at D is three times the velocity at B, and so on. Since the distance from the origin follows the pattern 1, 4, 9, 16 (add up the individual displacements), if we release a car from these positions on an inclined plane, we will know that the velocity increases proportionally. So we can choose convenient numbers (see example on the following page).

Ratio needed	Distance (from bottom of plane in cm)	Velocity (arbitrary units)
1	5	1
4	20	2
9	45	3
16	80	4
25	125	5

Students could be given the information in columns 2 and 3 with a brief explanation.

2. **Energy Considerations**

   If we release an object from above the surface of the Earth, its potential energy is converted in kinetic energy. That is:

   $$mgh = \frac{mv^2}{2}$$

   and $v = \sqrt{2gh}$

   So if we increase h by 4, v increases by 2; if we increase h by 9, v increases by 3. Note that we have the same ratio as before—1, 4, 9, 16, et cetera. Remember, in this case, h is measured as the distance above the surface. In any case, we get the same table as above.

3. **Calibration of the Inclined Plane** (recommended as a student activity)
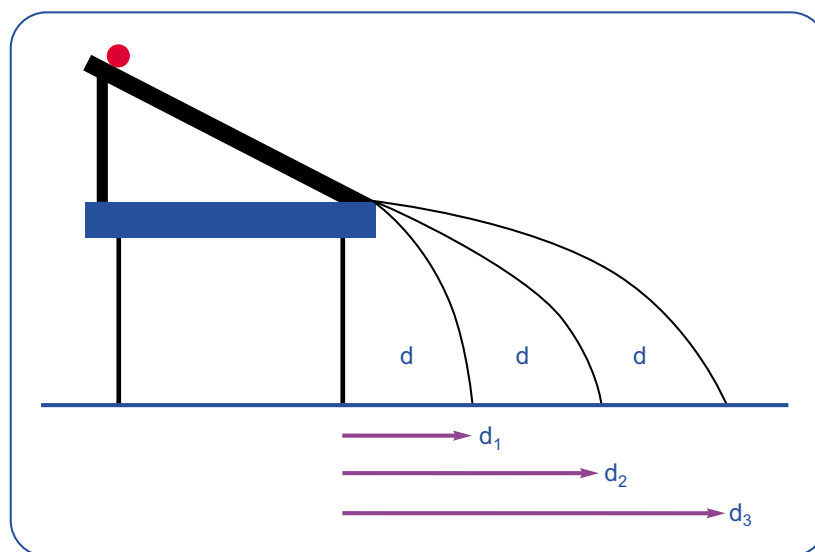
If we release a ball from point A, it accelerates down the plane to some velocity (v_1) and we find that it will fall to the surface some distance (d_1) from the edge of the table. Once the ball leaves the inclined plane, there are no forces acting in the horizontal direction (ignoring air resistance), and the ball moves away from the table with a constant velocity. **Note:** Gravity accelerates the ball only in the vertical direction.

If we release the ball further up the plane it will accelerate down the plane to some velocity (v_2). If the ball lands in a way that d_2 is exactly twice d_1 then v_2 must be twice v_1. We can repeat the process in a way that the ball lands at $3d_1$, $4d_1$, and so on to calibrate the plane.

Example: 1. We release the ball from 5 cm up the plane and measure that it lands 3 cm from the edge of the table.

2. Make a mark 6 cm (2 x 3 cm) from the edge of the table.

3. Release the ball further up the plane such that it lands 6 cm from the edge of the table. Record the point from which the ball is released.

4. Repeat four or five times and your inclined plane is calibrated.

4. **Calculation of Velocity**

A. Release the car from some distance up the plane. Using a stopwatch, record the time it takes the car to reach the bottom of the plane.

   i. Calculate the velocity from $a = \dfrac{Dv}{Dt}$, that is:

   $Dv = aDt$ and therefore, $v_2 - v_1 = aDt$

   Since $v_1 = 0$, $v_2 = aDt$ where $a = g\sin q$

   So $v_2 = g\sin q Dt$

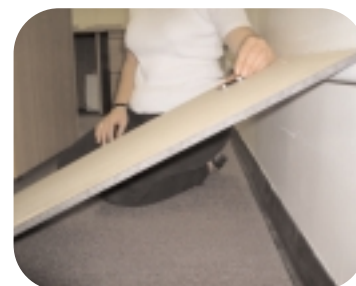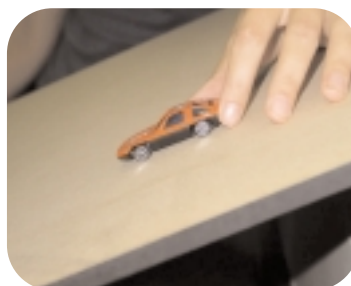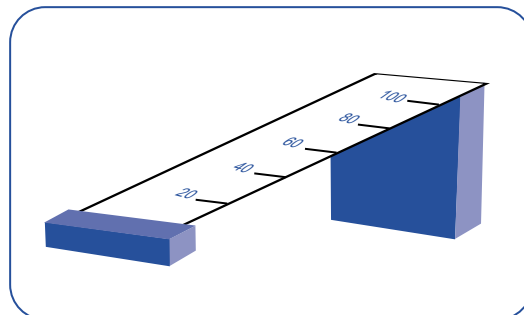   For example: if the angle of inclination is 15°, then $g = 10$ and $g \sin 15° = 2.6$ and $v_2 = 2.6$ x time.

B. If you allow the car to move a short distance across a flat surface, after it accelerates down the plane, the velocity will be constant. Use photogates to measure the time it takes the car to cover this distance and calculate velocity as distance over time.

Inertia and the Unrestrained Passenger

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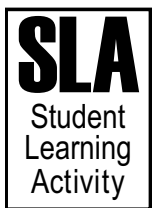
To investigate the relationship between speed and distance, demonstrate the activity of an unrestrained passenger traveling in a collision.

1. Set up an inclined plane and secure a barrier at the bottom of the plane. Mark the points on the plane from where you will release your car (see previous discussion: Velocity of a car on an incline).

2. Make a "passenger" using modeling clay and rest your passenger on the front of a flatbed cart (you can use a toy car).

3. Release your car down the plane so that the velocity increases at regular intervals, and record the distance the passenger is thrown after the collision with the barrier.

Speed	Trial #1	Trial #2	Trial #3	Average distance the passenger is "thrown" (cm)
1				
2				
3				
4				
5				
6				

Activity Follow-up Questions

1. Graph the speed of the cart versus the average distance the passenger is thrown.

2. What does your graph tell you about the relationship between the speed of a vehicle and the distance an unrestrained object is thrown?

Inertia and the Unrestrained Passenger

Distance Passenger is "Thrown" (cm)

Speed (Relative Units)

Braking Distance

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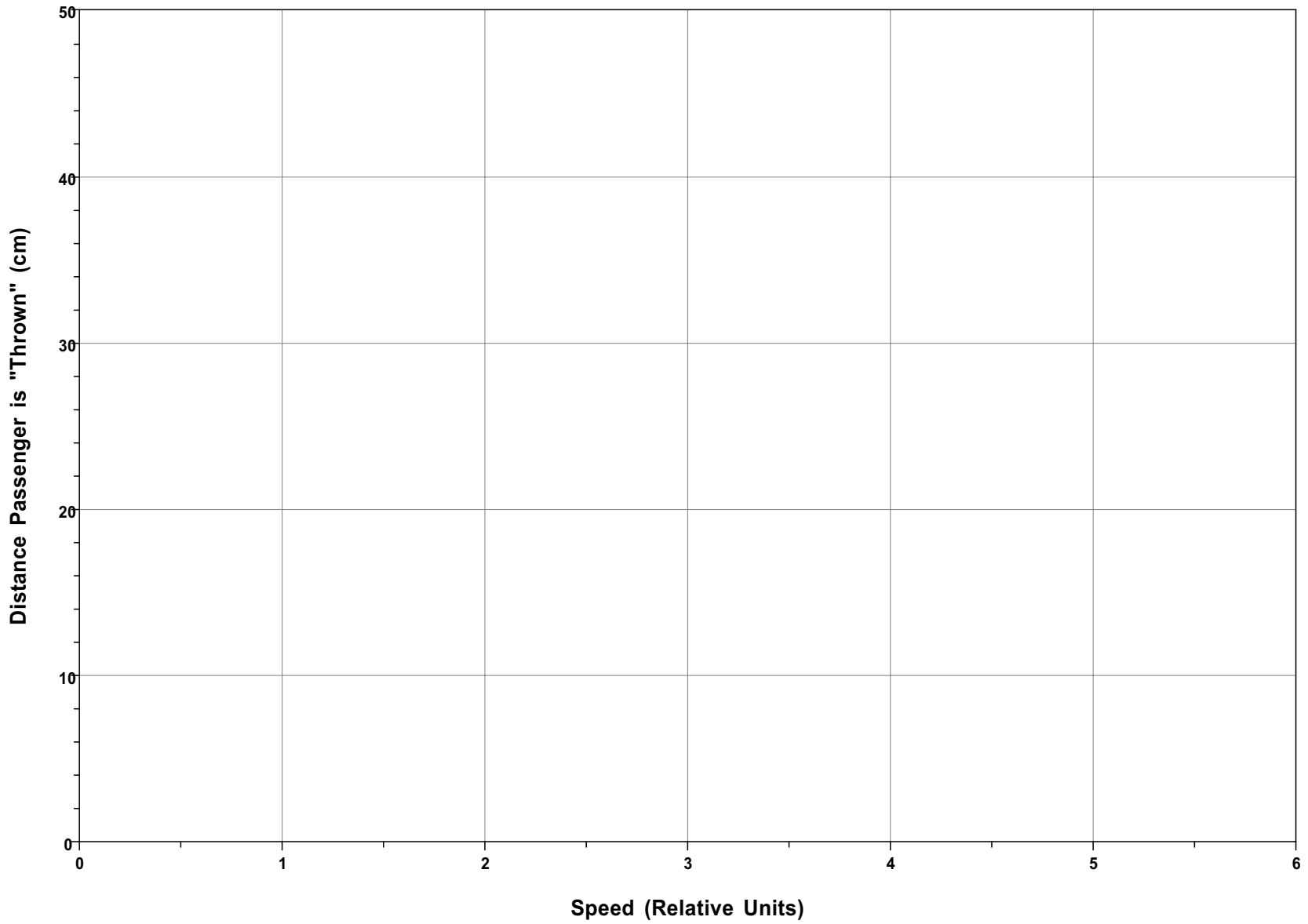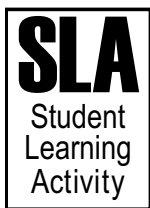
Purpose

To investigate the relationship between the velocity of a car and the distance it takes the car to brake.

When a car brakes, the brake pads press against part of the rotating wheel to apply a frictional force on the wheel. This frictional force causes the car to slow down and eventually stop. The distance the car travels while it is trying to stop is called the *braking* or *stopping distance.*

Procedure

1. Set up the track/ramp apparatus as shown. You can build a slider by cutting a 10-cm x 12-cm piece of paper along the dotted lines and folding it (see below).
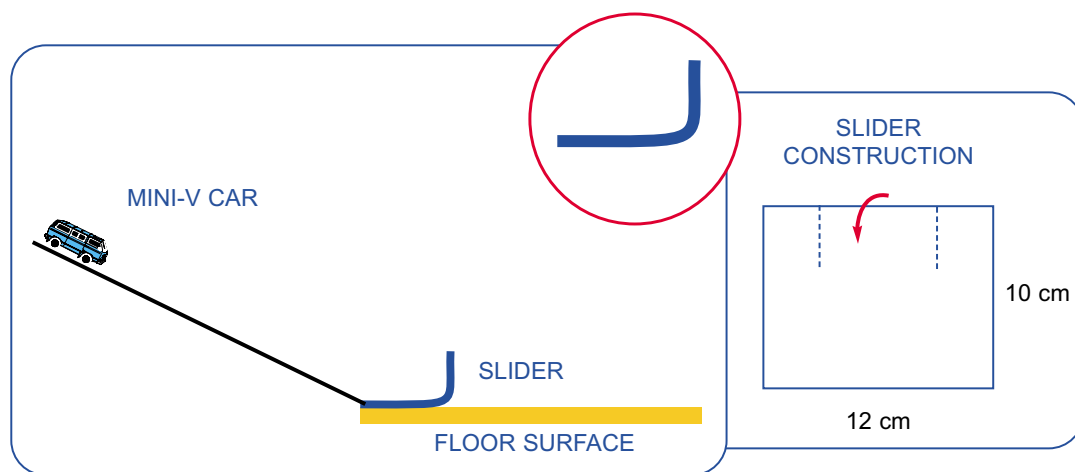
2. Release the car from some distance up the plane (see earlier discussion: Velocity of a car on an inclined plane).

3. Measure the distance the car travels in the braking sled. Repeat three times and calculate the average stopping distance.

4. Repeat until you have five or six sets of data.

5. Graph braking distance versus speed.

Table A: Braking Distance

Distance "up the ramp" (cm)	Speed	Trial #1	Trial #2	Trial #3	Average braking distance (cm)
5	1				
20	2				
45	3				
80	4				
125	5				

Questions

1. Describe in your own words the relationship between velocity and braking distance.

_____

_____

_____

_____

_____

_____

_____

2. How does the stopping distance of different vehicles compare?

_____

_____

_____

_____

_____

_____

_____

3. How does a slippery surface affect the stopping distance?

_____

_____

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Braking Distance and Speed

Total Stopping Distance (cm)

Speed (Relative Units)

Reaction Time

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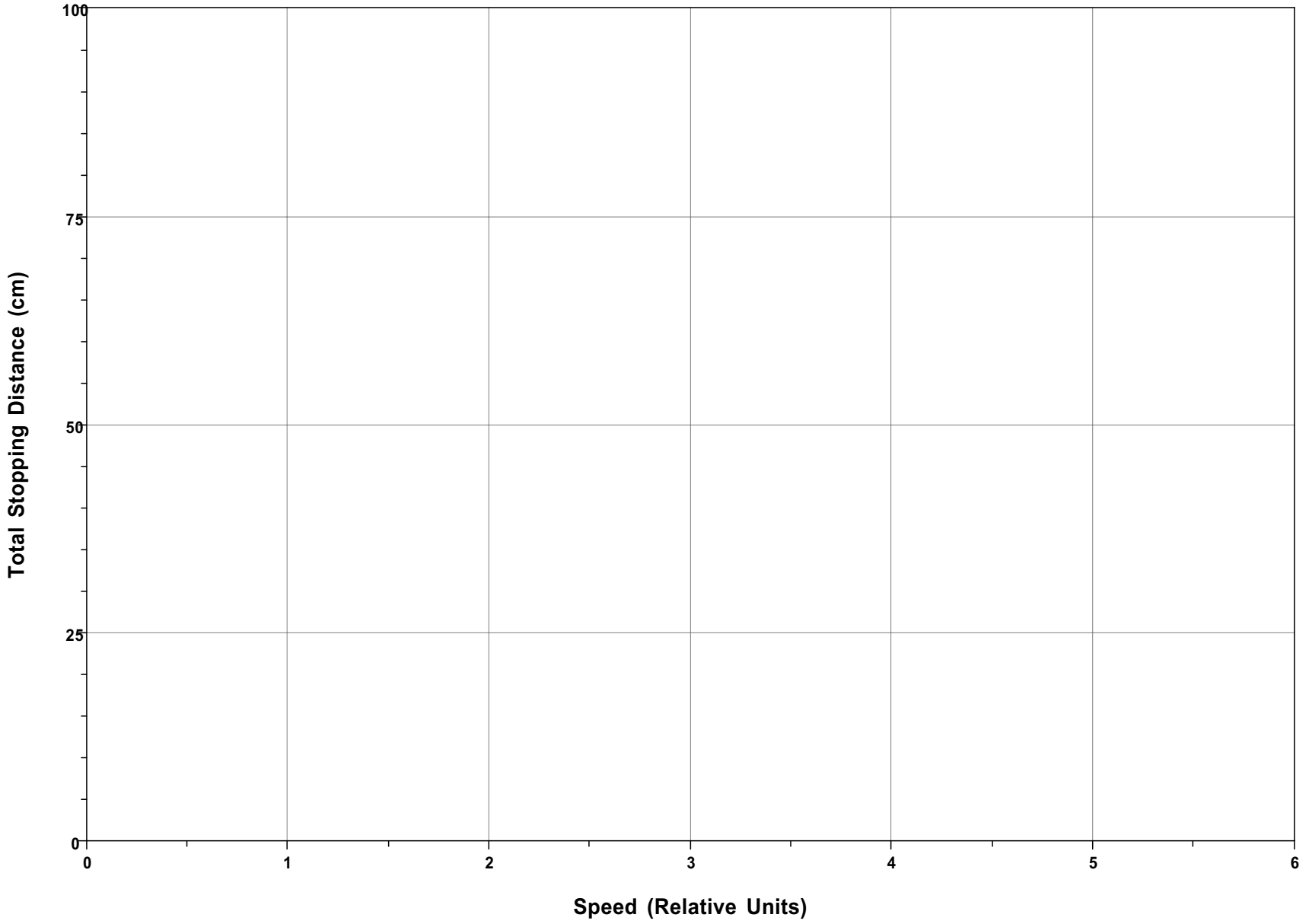
In the previous activity, we assumed that the brakes were applied instantaneously. In reality, every driver has a reaction time between observing that he or she needs to apply the brakes and applying the brakes. Find your reaction time as follows:

1. Hold your thumb and forefinger about 5 cm apart. Have a partner hold a metre stick so that the 30-cm mark is level with your thumb (see diagram).

2. Without warning, your partner releases the metre stick and you catch it by closing your thumb and forefinger. Record the distance mark where you catch it.

3. Repeat three times and take the average.
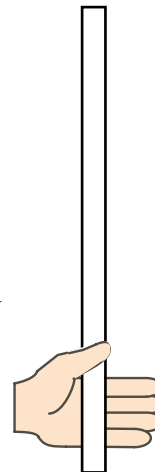
4. To find your reaction time use the following formula: time = $\sqrt{\dfrac{d}{5}}$

Note: There are several computer programs that you can use to measure reaction time. Try the following URLs for java applets that can be used to measure reaction time.

* <http://www.phys.hawaii.edu/~teb/java/ntnujava/Reaction/reactionTime.html>

* <http://www.bigriver.net/~rasmith/rt/rt.html>

* <http://members.tripod.com/fast_wheels/react.htm>

* <http://schoolsite.edex.net.uk/323/spreadsheet/html/reaction_time.html>

Total Stopping Distance

1. Calculate the distance the car travels during your reaction times as d = v x t and add this to the braking distance to get your total stopping distance.

Speed	Braking distance (cm)	Reaction time (s)	Distance traveled during reaction time (cm)	Total stopping distance (cm)
1				
2				
3				
4				
5				
6				

2. Graph Total Stopping Distance versus Speed, with speed on the *x*-axis. Make a sketch in this space, and reproduce your graph using the sheet provided by your instructor.

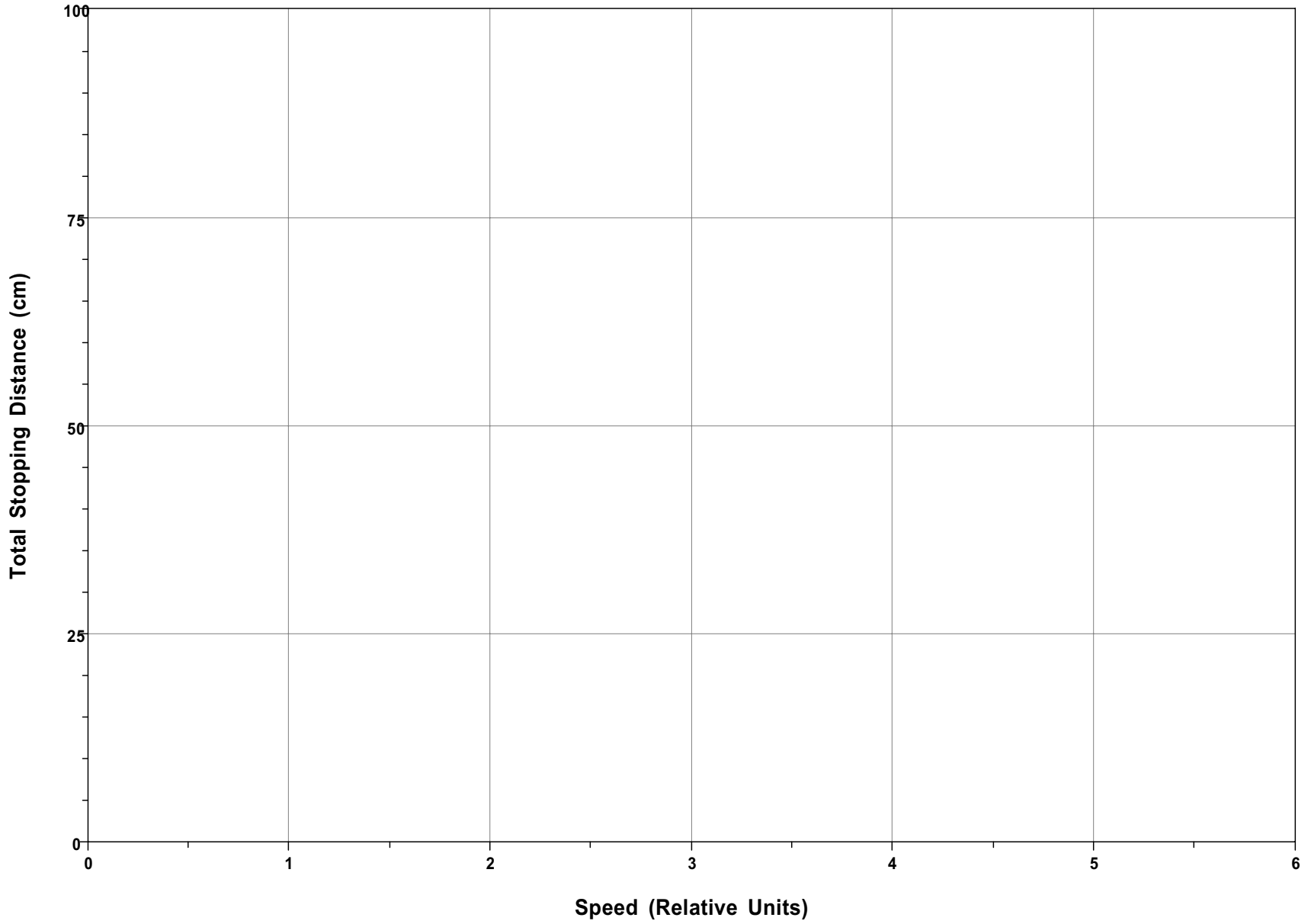3. What conclusions can you draw by comparing the two graphs?

_____
_____
_____
_____
_____
_____
_____

Reaction Time, Braking Distance, and Speed

Total Stopping Distance (cm)

Speed (Relative Units)

Calculating Braking Distance

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Student drivers are often given a table of braking distances for various speeds, without being given any indication of how these values are calculated. From the braking distance activity, we have determined that distance varies with the square of the velocity (v^2). Therefore, we can calculate braking distance from $d = kv^2$ where k is a constant of proportionality that represents the frictional conditions. The table shows the k values for different kinds of road conditions, using coefficients for kinetic friction (the coefficient of kinetic, or rolling friction, is generally slightly smaller than for static friction). The mathematical derivation is included for the interested teacher. Students can use known values to calculate braking distances for different speeds.

Proportionality constant (k) (velocity units are m/s)	Road conditions
0.06	rubber tires on dry concrete
0.1	rubber tires on wet concrete
0.25	rubber tires on ice

Derivation of the Mathematical (Symbolic) Relationship

Work done = change in kinetic energy

$$F\text{D}d = \frac{mv^2}{2} \quad \text{where F is the force of friction, (i.e., } F = \text{m}mg)$$

$$\text{m}mg\text{D}d = \frac{mv^2}{2}, \text{ therefore } \text{D}d = \frac{v^2}{2mg}$$

or simply, $\text{D}d = kv^2$ where $k = \dfrac{1}{2mg}$

Example:

The braking distance for a car that is traveling at 100 km/h…

Following the conversion of 100 km/h to 27.8 m/s,

$d = 0.06(27.8^2)$

$d = 46.3$ m