5. Exploring Velocity and Inertia

*Crash Test*

**Objectives**

In this activity students explore Newton's laws of motion. Students will use a motion sensor to measure the velocity of an object on a PASCAR. This PASCAR comes to a sudden stop and the object continues its motion.

Students will:

- Investigate the relationship between velocity and the distance an object is thrown after collision
- Explain how Newton's laws of motion are involved in this investigation
- Design and conduct a scientific investigation

**Procedural Overview**

Students gain experience conducting the following procedures:

- Setting up the work area and equipment to measure the velocity of a cart as it travels down an inclined track and collides with an obstacle
- Measuring the distance traveled by a "crash test dummy" after each collision
- Using math skills to relate the velocity of the cart to the distance traveled by the dummy

**Time Requirement**

- Introductory discussion and lab activity, Part 1 – Making predictions 40 minutes
- Lab activity, Parts 2 and 3 40 minutes
- Analysis 30 minutes

**Materials and Equipment**

*For each student or group:*

- Data collection system
- Motion sensor
- Dynamics track
- PASCAR or other cart or toy car
- Marble
- Small bean bag
- Meter stick
5. Exploring Velocity and Inertia

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between speed and velocity.
- Newton’s laws of motion.
- Use of measuring devices such as a meter stick to measure the length of objects or distances from one point to another.
- SI units of measure for length (m) and velocity (m/s).
- Math skills necessary to average a set of data and to graph data points on a set of coordinate axes (on graph paper).
- The basics of using the data collection system.

Related Labs in the Guide

Labs conceptually related to this one include:

- Motion Graphs
- Speed and Velocity

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system (identified by the number following the symbol: "●"). Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system ●(1.2)
- Connecting a sensor to the data collection system ●(2.1)
- Starting and stopping data recording ●(6.2)
- Displaying data in a graph ●(7.1.1)
- Adjusting the scale of a graph ●(7.1.2)
- Viewing statistics of data ●(9.4)

Background

“Speed” is the rate at which an object travels a certain distance. “Velocity” is the rate of change in the position of an object as it moves in a particular direction. “Position” requires a frame of reference from which motion or a location can be described. So, imagine you are listening to the
weather report and you hear a storm is moving at 40 kilometers per hour (40 km/hr). That would be the speed of the storm. If the weather reporter said the storm was moving at 40 km/hr east, that would be describing the storm’s velocity. Now if the weather reporter mentioned the storm was moving at 40 km/hr east from Medina. This gives the velocity of the storm as well as its current position, Medina, which is used as a frame of reference for the storm’s motion from there.

Sometimes, the direction component of velocity is not stated but is understood. For example, a paintball gun may state the maximum velocity of a fired paintball is 91 meters per second (91 m/s). The direction of the paintball is not stated, but is understood to be out from the barrel of the gun.

Newton’s first law of motion states that an object in motion will continue that motion with constant speed in a straight line unless a force acts on it. This resistance to a change in motion is referred to as “inertia.” A person riding in a car is traveling at the same rate as the car. If the car suddenly stopped due to an outside force acting on it, such as from a tree, the person would continue moving forward due to their inertia, until a force is applied to him or her. Hopefully, it is a seatbelt and not the dashboard that applies a force to the person! Inertia is why someone who is not wearing a seat belt gets ejected from the vehicle since there is no force acting to prevent the forward motion of the person.

Newton’s second law of motion states force equals mass times acceleration ($F = m \times a$). So the greater the acceleration, the more force acting on an object. In the case of the person riding in the car, the faster the acceleration of the person, the greater would be the resulting force of impact on someone who is not wearing a seatbelt.

**Pre-Lab Discussion and Activity**

Engage students in the following discussion or activity:

Investigate the movement of the PASCar. Try rolling the car around while keeping your hand on it. Try pushing the car gently and releasing it. Why does the PASCar move when you are pushing it with your hand?

You are applying a force to it.

Why does the PASCar keep moving even after you push it and let it go?

The car’s inertia keeps it in motion.

Why does the PASCar slow down and then stop?

Friction from the surface the car is traveling on and the air causes the car to slow down and stop.

Place a marble on the car as shown. Gently push the car. What happens to the marble when the PASCar is pushed?

The marble appears to move backwards.

Why do you think this happens?

The marble’s inertia keeps it from moving since there is no force acting on it while the PASCar accelerates out from under the marble.
Direct the students to “Thinking About the Question.” Discuss the answers to these questions as a whole group and come to a consensus.

Now direct the students to “Investigating the Question.”

**Preparation and Tips**

These are the materials and equipment to set up prior to the lab.

- Refresh the students on how the motion sensor works. This lab should be done after the students have had a chance to explore motion with the motion sensor.

- Attach the motion sensors to the dynamics track with the round gold screen perpendicular to the surface of the motion track prior to the start of the lab activity. The selector switch on the top of each motion sensor should be set to the “cart” icon instead of the “person” icon.

- To avoid spikes in the graph, have the student who is releasing the PASCAR move it as little as possible. This can best be done by resting their hand on the motion track and holding the PASCAR in place with a finger, then lift the finger off the PASCAR during the run, leaving the hand in the same position.

**Safety**

Add this important safety precaution to your normal laboratory procedures:

- Make sure the students set up their materials so that they have a safe, clear area to work.
Driving Question

How does velocity affect the distance a moving object, the "crash test dummy", is thrown after a collision?

Thinking About the Question

Why does an object keep moving after a collision such as a car crash?

Any object with mass has inertia, which is the property that resists a change in motion.

What is velocity?

Velocity is speed in a given direction.

How could you test to see how velocity affects the distance an object is thrown after a collision?

We could model car crashes at different velocities and measure the distances that an object flew after impact.

What materials would you need in order to do this?

We would need a dynamics cart and track, and an object like a bean bag to model the passenger. To cause the cart to crash, we would need a way of stopping it, such as a heavy book.

What are the characteristics of a good experiment?

In a good experiment, all of the variables are controlled except the one we want to test. Also, the results of a good experiment should be able to be replicated by another group.

Sequencing Challenge

Note: This is an optional ancillary activity.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

2. Incline a track to make a ramp for your PAScar and "crash test dummy" to accelerate down.

4. Record the velocity of the PAScar as it rolls along the motion track.

5. Measure the distance the "crash test dummy" flew after the collision.

3. Place a bean bag on the PAScar to model a person during the collision.

1. Make sure each member of your lab group is aware of safety rules and procedures for this lab.
5. Exploring Velocity and Inertia

Investigating the Question

Note: When students see this symbol “♦” with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1 – Making predictions

1. ♦ Write your prediction on how velocity affects the distance a crash test dummy is thrown after a collision? Explain your reasoning.

   We think that the higher the velocity of the PASCAR, the farther the crash test dummy will be thrown. It will be thrown farther because due to its inertia, it will continue to travel along at the higher velocity.

2. ♦ You will arrange the dynamics track so that it is inclined at three different angles, or heights. Your lab group members will decide whether to work from steepest incline to least steep, or least steep incline to steepest. Predict how the steepness, or slope of the incline, will be related to the velocity of the PASCAR.

   The steeper the ramp is inclined, the higher the velocity the PASCAR will be traveling when it hits the bottom and collides.

Part 2 – Equipment set up

3. ♦ Set up the motion track on the floor ensuring there is enough clear area for the crash test dummy to be thrown without hitting anything.

4. ♦ Incline the motion track using books or the adjustable feet on one end of the track.

5. ♦ Using the meter stick, determine the height of the track at the inclined end. This height will be used for Velocity 1. Record this as Height 1 in Table 1 at the bottom of this section.

6. ♦ Place a textbook at the end of the motion track so the cart will collide with its bound side.

7. ♦ Make sure the motion sensor is attached to the motion track and the gold disk is perpendicular to the track. Why should the disk be positioned perpendicular to the track?

   The screen should be perpendicular to the track so that the motion sensor can “see” down the track. If it does not, the position data will not be accurate.
8. ☐ Place the crash test dummy (bean bag) at the front of the PASCAR, sitting as if it were driving.

9. ☐ If the collision spot (the point where the cart will hit the book) is not already marked with tape, place a small strip of tape on the floor to mark it. Why is this tape needed?

   This tape will help us measure from exactly the same point each time, even when we move the book. It prevents the initial position from being a variable in our experiment.

10. ☐ Start a new experiment on the data collection system. *(1.2)*

11. ☐ Connect the motion sensor to the data collection system. *(2.1)*

12. ☐ Display Velocity on the y-axis of a graph with Time on the x-axis. *(7.1.1)*

**Part 3 – Testing with the motion sensor and track**

13. ☐ After the PASCAR is in position, begin data recording *(6.2)* and release the PASCAR.

14. ☐ When the PASCAR’s motion stops, stop data recording *(6.2)*.

15. ☐ Measure the distance to the nearest 0.1 cm from the collision spot (marked with tape) to the middle of the crash test dummy. Record this distance in Table 2.

16. ☐ From your velocity graph, determine the maximum velocity of the PASCAR. *(9.4)* Record this velocity in Table 2.

17. ☐ Repeat the testing for a total of three trials for this height of the track. Record all results in Table 1.

18. ☐ After completing three trials for the first height of the motion track, change the height of the track.
5. Exploring Velocity and Inertia

19. Using the meter stick, determine the new height of the track at the inclined end. This height will be used for Velocity 2. Record this as Height 2 in Table 1.

20. Carry out three collisions at this height of the inclined motion track. Record all results (distance traveled and maximum velocity) in Table 2.

21. After completing three trials for Height 2 of the motion track, change the height of the track.

22. Using the meter stick, determine the new height of the track at the inclined end. This height will be used for Velocity 3. Record this as Height 3 in Table 1.

23. Carry out three collisions at this third height of the inclined motion track. Record all results in Table 2. Why do you think you were asked to complete three trials for each height rather than just one? Explain your reasoning.

We were supposed to do three trials so that we can average our results. An average of three results would minimize the effect of any errors we made during our experiment. If we had just one trial, and those measurements had errors, we would not necessarily know it because we would have no other data to compare it to.

Table 1: Height

<table>
<thead>
<tr>
<th></th>
<th>Height 1: 6.6 cm</th>
<th>Height 2: 8.5 cm</th>
<th>Height 3: 10.8 cm</th>
</tr>
</thead>
</table>

Table 2: Distance and velocity

<table>
<thead>
<tr>
<th></th>
<th>Distance Bean Bag Traveled (cm)</th>
<th>Distance Bean Bag Traveled (cm)</th>
<th>Distance Bean Bag Traveled (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>15.1</td>
<td>21.6</td>
<td>27.2</td>
</tr>
<tr>
<td>Trial 2</td>
<td>15.3</td>
<td>19.4</td>
<td>28.4</td>
</tr>
<tr>
<td>Trial 3</td>
<td>14.4</td>
<td>20.1</td>
<td>27.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Maximum Velocity of Cart: Height 1 (m/s)</th>
<th>Maximum Velocity of Cart: Height 2 (m/s)</th>
<th>Maximum Velocity of Cart: Height 3 (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>0.74</td>
<td>0.91</td>
<td>1.13</td>
</tr>
<tr>
<td>Trial 2</td>
<td>0.74</td>
<td>0.92</td>
<td>1.11</td>
</tr>
<tr>
<td>Trial 3</td>
<td>0.73</td>
<td>0.91</td>
<td>1.12</td>
</tr>
</tbody>
</table>
**Answering the Question**

**Analysis**

1. Look over Table 2 containing your experimental results. Do your results agree with your predictions from Part 1? Why or why not? Explain your thinking.

   According to our results, the data supports our prediction. We predicted the crash test dummy would go farther when it crashed at higher velocities than when it crashed at lower velocities. This was true for each trial we did.

2. Average your results for each trial. Record the results of these calculations in Table 3 below:

   **Table 3: Average velocity and distance**

<table>
<thead>
<tr>
<th>Height</th>
<th>Average Maximum Velocity for All Trials (m/s)</th>
<th>Average Maximum Distance for All Trials (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height 1</td>
<td>0.74</td>
<td>14.9</td>
</tr>
<tr>
<td>Height 2</td>
<td>0.91</td>
<td>20.4</td>
</tr>
<tr>
<td>Height 3</td>
<td>1.12</td>
<td>27.7</td>
</tr>
</tbody>
</table>
5. Exploring Velocity and Inertia

3. On graph paper, plot the data you have averaged. Which is the independent variable, the velocity of the PASCar or the distance the dummy was thrown? On which axis of your graph should you display the independent variable?

The independent variable is the velocity of the cart, because that is the thing we varied intentionally. It should be plotted on the x-axis of our graph. The distance that the crash test dummy flew after the collision depends on the velocity, so the distance is the dependent variable. It should be plotted on the y-axis of our graph.

4. The bean bag and PASCar are models that represent a real-life situation. Explain what these models represent, including a description of what the collision represents.

The bean bag represents a person riding in a car. The PASCar represents the car the person is riding in. In this model, the person is not wearing a seatbelt, so the collision represents a real car crash in which the person is ejected from the car.

5. What property of matter is responsible for the crash test dummy (the bean bag) continuing to travel on for a distance after the PASCar has stopped?

Inertia is responsible for the dummy continuing to travel a certain distance.

6. Predict what would happen in a collision if there were two crash test dummies riding on the PASCar, one twice as heavy as the other. Use Newton's laws of motion to support your statements.

The heavy dummy would not fly as far as the lighter one because the collision gives the same force to each dummy. Since the heavier dummy has twice the mass, it should fly half the distance. The law of inertia explains why the dummies keep traveling after the cart has stopped. The 2nd law of motion states that force is equal to mass times acceleration. This means that the more mass an object has, the less it can accelerate with the same amount of force.

7. What role do seatbelts play in your safety in a car?

If you are a body in motion, you will stay in motion as long as no outside force acts upon you. The reason seatbelts are important for your safety is because they apply a force to the rider preventing them from staying in motion when the car stops suddenly.
8. If you were not wearing a seatbelt and your car did not have airbags, why would you suffer a more serious injury from a higher velocity crash?

If you are in a crash with no seatbelt on and your car stops suddenly, you will continue to move in the same direction you were traveling before the collision. The faster the car is traveling before the crash, the faster you will continue moving once the car stops. This would cause more serious injuries. Newton's second law is force equals mass times acceleration \((F = m \cdot a)\), so the greater the acceleration, the more force acting on an object.

9. What does this lab have to do with inertia?

Newton's first law states that an object in motion will continue that motion with constant speed in a straight line unless a force acts on it. In this lab, the book exerts a force on the PASCAR and the PASCAR stops. Since the crash test dummy is not attached to the PASCAR, there is no force on it except a small friction force. Due to this, the crash test dummy continues moving with the speed it had when the PASCAR reached the book.

**Key Term Challenge**

Fill in the blanks from the randomly ordered words below. You may use a word more than once if necessary.

<table>
<thead>
<tr>
<th>speed</th>
<th>velocity</th>
<th>acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>momentum</td>
<td>force</td>
<td>friction</td>
</tr>
<tr>
<td>inertia</td>
<td>frame of reference</td>
<td>motion</td>
</tr>
</tbody>
</table>

1. The **velocity** of a car tells how fast it is going in a certain direction.

2. A **force** is a push or a pull on an object.

3. An object's **momentum** is the product of its mass and its velocity.

4. **Motion** is described from a frame of reference.

5. An object's **inertia** causes it to resist changes in its motion.

6. Saying that a truck is traveling at 30 km/h is an example of **speed**.

7. The force that opposes the motion of a cart on a track or a car on a road is **friction**.

8. A **frame of reference** is a point assumed to be fixed and from which motion can be described.

9. An object's motion changes if it is acted on by some external **force**.
5. Exploring Velocity and Inertia

Further Investigations

Use various sizes of bean bags to see if their mass affects how far they are thrown.

Students could use the Internet or library to research how air bags work, and present their findings to the class in a paper or other form of presentation.

Research Isaac Newton’s three laws of motion. Ask students to give examples of Newton’s laws of motion in action in their daily lives.

Rubric

For scoring students’ accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.