One Cart, Dozens of Mechanics Experiments

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HANDS-ON ACTIVITIES

From *Physics with Vernier*

- Cart on a Ramp
- Newton's Second Law
- Impulse-Momentum

From *Exploring Motion and Force with Go Direct® Sensor Cart*

- Getting Faster
- Newton's Second Law

Cart on a Ramp

(Sensor Cart)

This experiment uses an incline and a low-friction cart. If you give the cart a gentle push up the incline, the cart will roll upward, slow and stop, and then roll back down, speeding up. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What does the acceleration *vs.* time graph look like? Is the acceleration constant?

In this experiment, you will use a Sensor Cart to collect position, velocity, and acceleration data for a cart rolling up and down an incline. Analysis of the graphs of this motion will answer the questions above.

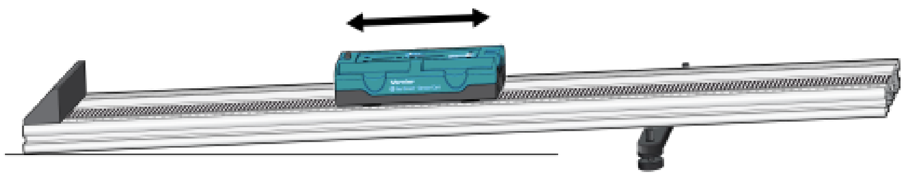

Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls freely up and down an incline.
- Analyze position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Sensor Cart
Vernier Dynamics Track
Adjustable End Stop

PRELIMINARY QUESTIONS

1. Consider the changes in motion that a cart will undergo as it rolls up and down an incline. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.
2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.
3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

Part I

1. Launch Graphical Analysis. Connect the Sensor Cart to your Chromebook, computer, or mobile device.

2. Place the cart on the track near the Adjustable End Stop. Point the **+x** arrow toward the top of the ramp. Click or tap Collect to start data collection. Wait about a second, then briefly push the cart up the incline, letting it roll freely up nearly to the top, and then back down. Catch the cart as it nears the end stop.

3. Examine the position *vs.* time graph. Repeat Step 2 if your position *vs.* time graph does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat data collection.

4. Answer the Analysis questions for Part I before proceeding to Part II.

Part II

5. Your cart can bounce against the end stop with its plunger. Practice starting the cart so it bounces at least twice during data collection.

6. Collect another set of data showing two or more bounces. **Note**: The previous data set is automatically saved.

7. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I

1. Export, print, or sketch the three motion graphs. To view the acceleration *vs.* time graph, change the y-axis of either graph to Acceleration. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Record your answers directly on the printed or sketched graphs.

   a. Identify the region when the cart was being pushed by your hand:
      - Examine the velocity *vs.* time graph and identify the region. Label it on the graph.
      - Examine the acceleration *vs.* time graph and identify the same region. Label the graph.

   b. Identify the region where the cart was rolling freely:
      - Label the region on each graph where the cart was rolling freely and moving up the incline.
      - Label the region on each graph where the cart was rolling freely and moving down the incline.

c. Determine the position, velocity, and acceleration at specific points:

- On the velocity *vs.* time graph, decide where the cart had its maximum velocity, just as the cart was released. Mark the spot and record the value on the graph.
- On the position *vs.* time graph, locate the highest point of the cart on the incline. Mark the spot and record the value on the graph.
- What was the velocity of the cart at the top of its motion?
- What was the acceleration of the cart at the top of its motion?

2. The motion of an object in constant acceleration is modeled by the equation $x = \frac{1}{2} at^2 + v_0t + x_0$, where x is the position, a is the acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola. If the cart moved with constant acceleration while it was rolling, your graph of position *vs.* time will be parabolic.

   a. Select the data in the parabolic region of the position graph.
   b. Click or tap Graph Tools, , for the position *vs.* time graph and choose Apply Curve Fit.
   c. Select Quadratic as the curve fit and click or tap Apply.
   d. Record the parameters of the fitted curve (the acceleration).

   Is the cart's acceleration constant during the free-rolling segment?

3. The graph of velocity *vs.* time is linear if the acceleration is constant. Fit a line to the data.

   a. Select the data in the linear region of the velocity graph.
   b. Click or tap Graph Tools, , for the velocity *vs.* time graph and choose Apply Curve Fit.
   c. Select Linear as the curve fit and click or tap Apply.
   d. Record the slope of the fitted line (the acceleration).

   How closely does the slope correspond to the acceleration you found in the previous step?

4. Change the y-axis to Acceleration. The graph of acceleration *vs.* time should appear approximately constant during the freely-rolling segment.

   a. Select the data in the region of the graph that represents when the cart was rolling freely.
   b. Click or tap Graph Tools, , for the acceleration *vs.* time graph and choose View Statistics.

   How closely does the mean acceleration compare to the values of acceleration found in Steps 2 and 3?

Part II

1. Determine the cart's acceleration during the free-rolling segments using the velocity graph. Are they the same?

2. Determine the cart's acceleration during the free-rolling segments using the position graph. Are they the same?

EXTENSIONS

1. Use a free-body diagram to analyze the forces on a rolling cart. Predict the acceleration as a function of incline angle and compare your prediction to your experimental results. For a trigonometric method for determining θ, see the experiment, "Determining g on an Incline," in this book.

2. Even though the cart has very low friction, the friction is not zero. From your velocity graph, devise a way to measure the difference in acceleration between the roll up and the roll down. Can you use this information to determine the friction force in newtons?

Getting Faster

You may have noticed that an object rolling down a hill starts out slowly and then speeds up. In this activity, you will measure the maximum speed of a cart or toy car as it rolls down a ramp from different starting positions. You will use Graphical Analysis to measure the speed of a Sensor Cart.

OBJECTIVES

- Measure speed.
- Record data.
- Graph results.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Sensor Cart
1.5 m board
meter stick
books, bricks, or box to support ramp
large book

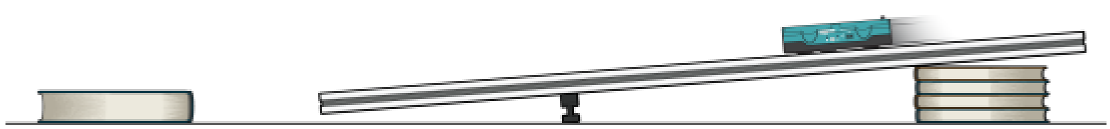

Figure 1

PROCEDURE

1. Connect to the Go Direct Sensor Cart and set up the data-collection settings.
   a. Launch Graphical Analysis.
   b. Connect the Sensor Cart to your Chromebook, computer, or mobile device.
   c. Click or tap Done.
   d. Click or tap Mode to open Data Collection Settings. Change End Collection to 3 s. Click or tap Done.

2. Set up the ramp.

    a. Set up the ramp as shown in Figure 1. The high end of the ramp should be no more than 30 cm from the floor.

    b. Place a large book on the floor about 50 cm from the bottom end of ramp. This book will stop your car after it comes off the ramp.

    c. If necessary, use tape or chalk to mark lines on the ramp at 40 cm from the bottom of the ramp, 60 cm from the bottom of the ramp, and 80 cm from the bottom of the ramp.

3. Position the cart at the top and center of the track as shown in Figure 1 with the **+x** arrow pointing towards the bottom of the track.

4. Collect data.

    a. Place your cart on the ramp so the front edge of the cart is at the 40 cm line.

    b. Click or tap Collect to start data collection, then release the cart.

    c. Examine the graphs. Are the graphs smooth, with no abrupt changes? If not, make adjustments and repeat data collection until you have smooth graphs.

5. Click or tap Graph Tools, , for the velocity *vs*. time graph, and choose View Statistics. Record the maximum speed in your data table.

6. Repeat Steps 4–5 two more times.

7. Repeat Steps 4–6 with the front of the car at the 60 cm position and again with the front of the car at the 80 cm position.

DATA

Table 1: Maximum Speed (m/s)			
Trial	40 cm	60 cm	80 cm
1			
2			
3			

Table 2	
Release position (cm)	Average maximum speed (m/s)

PROCESSING THE DATA

1. Calculate the average maximum speed for each release position. Show your work, and write the average values in Table 2.

2. Graph the results

   a. Disconnect the sensor cart from Graphical Analysis.
   b. Click or tap File, , and choose New Experiment. Click or tap Manual Entry.
   c. Enter the Release Position values in the first (X) column and enter the Average Maximum Speed in the second (Y) column.
   d. Change the column headings to Release Position (cm) and Average Maximum Speed (m/s).
   e. Describe the shape of the graph.

3. What happened to the maximum speed as you released the cart from higher points?

4. Explain two ways to make the cart's maximum speed greater, and explain why you think they would be successful.

EXTENSIONS

1. Repeat the experiment with a ramp with a different height.

2. Redo the experiment with different amounts of mass on the cart. Summarize your results in a few sentences.

Newton’s Second Law

(Sensor Cart)

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart’s velocity related to the force you apply? Or, is the force related to something else? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Sensor Cart will let you measure the force on a cart simultaneously with the cart’s acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton’s second law of motion.

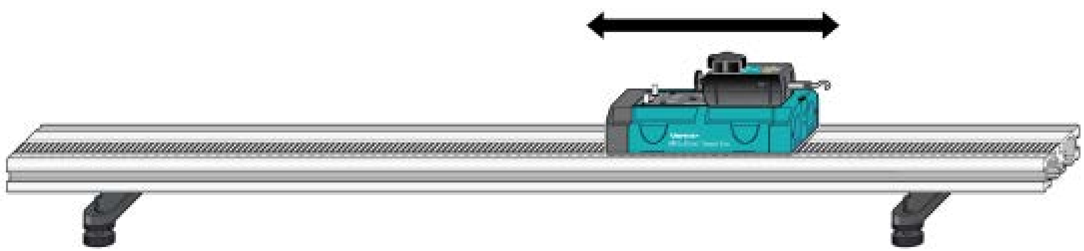

Figure 1

OBJECTIVES

- Collect force and acceleration data for a cart as it is moved back and forth.
- Compare force *vs.* time and acceleration *vs.* time graphs.
- Analyze a graph of force *vs.* acceleration.
- Determine the relationship between force, mass, and acceleration.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Sensor Cart with Force Sensor Hook
Vernier Dynamics Track
extra mass

PRELIMINARY QUESTIONS

Use a tennis ball and a flexible ruler to investigate these questions.

1. Apply a small amount of force to the ball by pushing the flat end of the ruler against the ball (see Figure 2). Maintain a constant bend in the ruler. You may need a lot of clear space, and you may need to move with the ruler. Does the ball move with a constant speed?

2. Apply a larger force and keep a constant larger bend in the ruler. Does the ball move with a constant speed?

3. What is the difference between the movement when a small force is applied versus a large force?

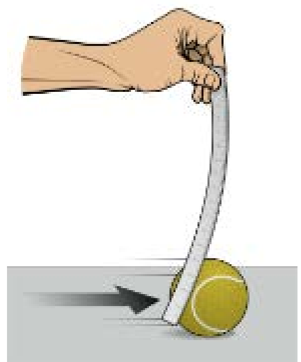

Figure 2

PROCEDURE

Trial I

1. Set up the equipment for data collection.

   a. If the force sensor hook is not connected to the Sensor Cart, screw the hook into the cart.

   b. Find the mass of the Sensor Cart and record the mass in the data table.

   c. Launch Graphical Analysis.

   d. Connect the Sensor Cart to your Chromebook, computer, or mobile device.

   e. Click or tap Sensor Channels. Deselect the check box for Position and select the check boxes for Force and X-axis acceleration. Click or tap Done.

   f. Click or tap Mode to open Data Collection Settings. Change End Collection to 10 s. Click or tap Done.

2. Place the Sensor Cart on the Dynamics Track on a level surface to prepare to zero the sensors. Verify the cart is not moving. To zero the force sensor, click or tap the Force meter and choose Zero. Then, before moving the cart, click or tap the X-axis acceleration meter and choose Zero to zero the acceleration sensor. The readings for both sensors should be close to zero.

3. You are now ready to collect force and acceleration data. Grasp the force sensor hook. Click or tap Collect to start data collection and roll the cart back and forth along the track covering a distance of about 10 cm. Vary the motion so that both small and large forces are applied. Your hand must touch only the hook and not the cart. Only apply force along the track so that no frictional forces are introduced.

4. Acceleration and force data are displayed on separate graphs. Sketch the graphs in your notes. How are the graphs similar? How are they different?

5. Examine the shape of the force *vs.* time and acceleration *vs.* time graphs. When the force is maximum, is the acceleration maximum or minimum?

6. One way to see how similar the acceleration and force data are is to make a new plot of force *vs.* acceleration, with no time axis.
   a. Click or tap View, ⊞, and choose 1 Graph to view a single graph.
   b. Click or tap Graph Tools, , and choose Edit Graph Options. Select Points as the Appearance. This removes the line connecting the data points on the graph. Dismiss the Graph Option box.
   c. Click or tap the axes labels and change the x-axis to X-axis acceleration and the y-axis to Force.
   d. Sketch the graph in your notes.
7. Fit a line to the graph of force *vs.* acceleration.
   a. Click or tap Graph Tools, , and choose Apply Curve Fit.
   b. Select Linear as the curve fit and click or tap Apply.
   c. Record the equation for the regression line and print or sketch your graph.

Trial II

8. Add 1–4 hexagonal bar masses to the cart. Record the total mass of the cart and additional mass in the data table.

9. Repeat Steps 3–7 for the cart with the additional mass. **Note**: The previous data set is automatically saved.

DATA TABLE

Trial I

Mass of cart (kg)	

Regression line for force *vs.* acceleration data

Trial II

Mass of cart with additional mass (kg)	

Regression line for force *vs.* acceleration data

ANALYSIS

1. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.

2. What are the units of the slope of the force *vs.* acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).

3. For each trial, compare the slope of the regression line to the mass being accelerated. What does the slope represent?

4. Write a general equation that relates all three variables: force, mass, and acceleration.

EXTENSION

Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration and force and determine the mass of the unknown. Compare your answer with the actual mass of the cart, as measured using a balance.

Newton's Second Law

Newton’s second law of motion describes the relationship among force, mass, and acceleration. In this activity, you will study the relationship between acceleration and mass, while keeping force constant. A cart carrying different masses will be pulled across a table by a hanging weight—the constant force. Acceleration will be measured using a Sensor Cart. You will plot a graph of acceleration versus total mass of the system, and then use the graph as you make conclusions about the relationship between mass and acceleration.

OBJECTIVES

- Use a Sensor Cart and Graphical Analysis to determine acceleration.
- Record data.
- Graph data.
- Make conclusions about the relationship between mass and acceleration.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Sensor Cart
masses for Sensor Cart
pencil or similar object
string
balance

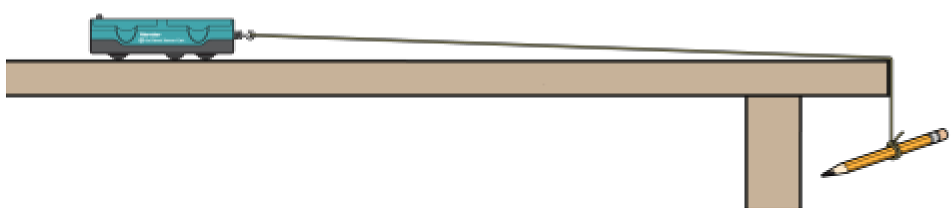

Figure 1

PROCEDURE

1. Record the individual masses of the cart, pencil, and all four cart masses in the data table.
2. Launch Graphical Analysis. Connect the Go Direct Sensor Cart to your Chromebook, computer, or mobile device. Click or tap Done.

3. Change the data-collection settings:

   a. Click or tap Mode to open Data Collection Settings. Change End Collection to 3 seconds. Click or tap Done.

   b. In this experiment, you will compare graphs of position, velocity, and acceleration. If only one graph is displayed, click or tap View, ▯, and choose 2 Graphs.

4. Position the cart as shown in Figure 1. Be sure to have the **+x** arrow pointing in the direction of motion.

5. Attach one end of the string to the cart. Tie the pencil to the other end of the string. The string should be long enough to pull the cart for the entire length of the table. When you are ready to collect data, the pencil will hang over the edge of the table as shown in Figure 1.

6. Place all four masses on the cart.

7. Collect data.

   a. Place your cart at the starting position.

   b. Hold the cart in the starting position. Have a partner place the string over the edge of the table and hang the hanging weight from the string.

   c. Click or tap Collect to start data collection, and then release the cart. Catch the cart before it runs off the edge of the table.

   d. Examine the velocity *vs*. time graph. The graph should have a smoothly slanting line on it. **Note**: Repeat any trial that does not have a good velocity *vs*. time graph.

8. To display an acceleration *vs*. time graph, click or tap the y-axis label of the position *vs*. time graph, deselect Position, and select Acceleration. Leave the other graph as is.

9. Determine the mean acceleration of the cart.

   a. Use the Start and End markings on Figures 2 and 3 to help you identify the region of the graph where the cart was speeding up.

   b. On the acceleration *vs*. time graph, select the region where the cart was speeding up.

   c. Click or tap Graph Tools, ▯, for the Acceleration graph, and choose View Statistics.

   d. Record the average (mean) acceleration in the data table.

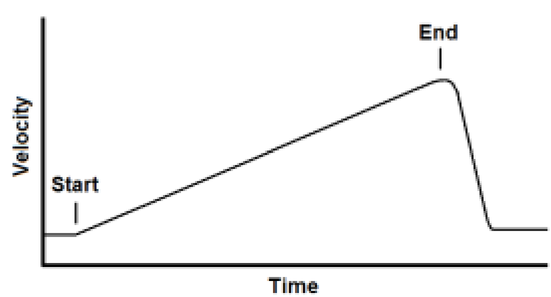

Figure 2

Figure 3

10. Repeat Steps 6–8 two more times. Start the cart from the same position each time.

11. Remove Mass #4 from the cart and repeat Steps 6–9.

12. Remove Mass #3 from the cart and repeat Steps 6–9.

13. Remove Mass #2 from the cart and repeat Steps 6–9.

14. Remove Mass #1 from the cart and repeat Steps 6–9.

ANALYSIS

1. Add masses and record total mass for each of the five combinations in the Data and Calculations table.

2. For each of the five combinations, calculate the average acceleration for its three trials. Record the results in the Data and Calculations table.

3. Graph the data.
   a. Disconnect the sensor cart from Graphical Analysis.
   b. Click or tap File, 🗋, and choose New Experiment. Click or tap Manual entry.
   c. Enter the Total Mass values in the first (x) column and enter the Average Acceleration values in the second (y) column.
   d. Change the column headings to Total Mass (kg) and Average Acceleration (m/s^2).

4. What is the relationship between mass and acceleration?

5. Does this agree with what you have read about Newton's second law of motion? Explain.

6. Which would need a larger force to accelerate at a particular rate: a sports car or a moving van full of furniture? Why?

DATA AND CALCULATIONS

Table 1: Mass (kg)					
Cart	Mass #1	Mass #2	Mass #3	Mass #4	Hanging mass

Table 2: Acceleration (m/s^2)			
	Trial 1	Trial 2	Trial 3
Cart and hanging mass plus masses 1, 2, 3, and 4			
Cart and hanging mass plus masses 1, 2, and 3			
Cart and hanging mass plus masses 1 and 2			
Cart and hanging mass plus mass 1			
Cart and hanging mass			

Table 3		
	Total mass (kg)	Avg. acceleration (m/s^2)
Cart and hanging mass plus masses 1, 2, 3, and 4		
Cart and hanging mass plus masses 1, 2, and 3		
Cart and hanging mass plus masses 1 and 2		
Cart and hanging mass plus mass 1		
Cart and hanging mass		

EXTENSION

What will happen to acceleration if you increase the mass of the hanging mass? Design an experiment to test your answer.

Impulse and Momentum

(Sensor Cart)

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:

$$\bar{F}\Delta t = mv_f - mv_i$$

Here, we will only consider motion and forces along a single line. The average force, $\bar{F}$, is the average *net* force on the object, but in the case where one force dominates and other forces are negligible, it is sufficient to use only the large force in calculations and analysis.

For this experiment, a Sensor Cart equipped with a hoop string will roll along a level track. Its momentum will change as it collides with the end stop at the end of the track. The hoop will compress and apply an increasing force until the cart stops. The cart then changes direction and the hoop expands back to its original shape. The force applied by the spring and cart velocity throughout the motion are measured by the Sensor Cart. You will then use data-collection software to determine the impulse in order to test the impulse-momentum theorem.

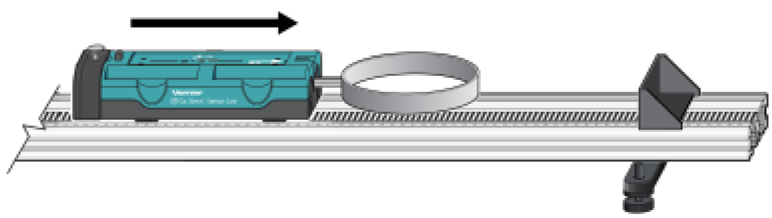

Figure 1

OBJECTIVES

- Measure a cart's momentum change and compare it to the impulse it receives.
- Compare average and peak forces in impulses.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Sensor Cart
Vernier Dynamics Track
Accessories from the Bumper and Launcher Kit: Hoop Bumper, clay, and clay holder

PRELIMINARY QUESTIONS

1. In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an airbag? How does it reduce injuries?

2. Two playground balls, the type used in the game of dodgeball, are inflated to different levels. One is fully inflated and the other is flat. Which one would you rather be hit with? Why?

PROCEDURE

1. Attach the hoop spring to the cart. Measure the mass of the cart and record the value in the data table.

2. Attach the End Stop to the end of the track as shown in Figure 1.

3. Place the track on a level surface. Confirm that the track is level by placing the cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track to level it.

4. Set up the sensor and data-collection software.

   a. Launch Graphical Analysis.
   b. Connect the Go Direct Sensor Cart to your Chromebook, computer, or mobile device.
   c. Click or tap Sensor Channels.
   d. Enable the Force channel in addition to the Position channel. Click or tap Done.

5. Zero the Force channel.

   a. Remove all force from the hoop spring.
   b. Click or tap the Force meter and choose Zero.

6. Set up the data-collection mode.

   a. Click or tap Mode to open data-collection settings.
   b. Change the Rate to 250 samples/s and End Collection to 5 s. Click or tap Done.

Part I Elastic collisions

7. Practice releasing the cart so it rolls toward the end stop, bounces gently, and returns to your hand. The cart must stay on the track.

8. Position the cart so that the cart is approximately 50 cm from the end stop. Click or tap Collect to start data collection, then roll the cart as you practiced in the previous step.

9. Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, repeat data collection.

10. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. To find these values, work with the graph of velocity *vs.* time.

    a. On the Velocity graph, select an interval corresponding to a time before the impulse, when the cart was moving at approximately constant speed toward the end stop.
    b. Click or tap Graph Tools, , and choose View Statistics. Read the average velocity before the collision (v_i) and record the value in the data table.
    c. Dismiss the Statistics box.
    d. Repeat parts a–c of this step to determine the average velocity just after the impulse, when the cart was moving at approximately constant speed away from the end stop. Record this value in the data table.

11. Now you will calculate the value of the impulse. Use the first method if you have studied calculus and the second if you have not.

    Method 1 Calculus version

    Calculus tells us that the expression for the impulse is equivalent to the integral of the force *vs.* time graph, or

$$\overline{F}\Delta t = \int_{t_{initial}}^{t_{final}} F(t)dt$$

    Calculate the integral of the impulse on your force *vs.* time graph.

    a. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
    b. Click or tap graph tools, , and choose View Integral.
    c. Read the value of the integral of the force data, the impulse value, and record the value in the data table.

    Method 2 Non-calculus version

    Calculate the impulse from the average force on your force *vs.* time graph. The impulse is the product of the average (mean) force and the length of time that force was applied, or $\overline{F}\Delta t$.

    a. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
    b. Click or tap Graph Tools, , and choose View Statistics.
    c. Record the average (mean) force value in the data table.
    d. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as Δt in your data table.
    e. From the average force and time interval, determine the impulse, $\overline{F}\Delta t$, and record this value in your data table.

12. Repeat Steps 8–11 two more times to collect a total of three trials; record the information in your data table.

Part II Inelastic collisions

13. Replace the hoop spring bumper with one of the clay holders from the Bumper and Launcher Kit. Attach cone-shaped pieces of clay to both the clay holder and to the end stop, as shown in Figure 2. Measure the mass of the cart and record the value in the data table.

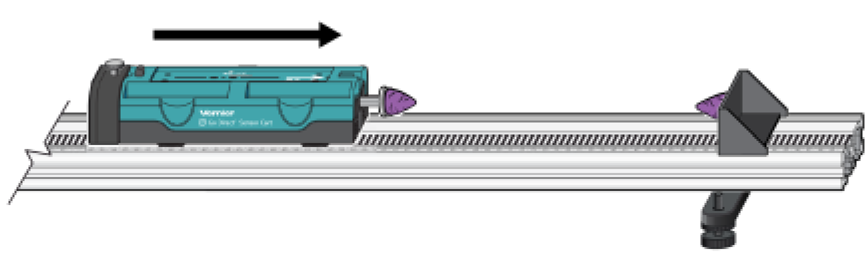

Figure 2

14. Place the cart on the track as shown in Figure 2. Click or tap the Force meter and choose Zero to zero the Force Sensor.

15. Practice launching the cart so that when the clay on the front of the cart collides with the clay on the end stop, the cart comes to a stop without bouncing.

16. Position the cart so that the cart is approximately 50 cm from the end stop. Click or tap Collect to start data collection, then roll the cart so that the clay pieces collide and stick together.

17. Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, reshape the clay pieces and repeat data collection.

18. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse.

    a. On the Velocity graph, select the interval corresponding to the time before the impact. Click or tap Graph Tools, , and choose View Statistics. Record the average velocity in the data table.

    b. Dismiss the Statistics box.

    c. Select the interval corresponding to the time after the impact. Then, click or tap Graph Tools, , and choose View Statistics. Record the average velocity in the data table.

    d. Dismiss the Statistics box.

19. Now you will calculate the value of the impulse. Similar to Step 11, use the first method if you have studied calculus and the second if you have not.

    Method 1 Calculus version

    Calculate the integral of the impulse on your force *vs.* time graph.

    a. Select the impulse, then click or tap graph Tools, , and choose View Integral.

    b. Record the impulse value in the data table.

    Method 2 Non-calculus version

    Calculate the impulse from the average force on your force *vs.* time graph.

    a. Select the impulse. Click or tap Graph Tools, , and choose View Statistics. Record the average force in the data table.

    b. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as Δt in your data table.

    c. From the average force and time interval, determine the impulse, $\bar{F}\Delta t$, and record this value in your data table.

20. Repeat Steps 16–19 two more times to collect a total of three trials; record the information in your data table. **Note**: You will need to reshape the clay pieces before each trial.

DATA TABLE

Mass of cart (elastic collision)	kg
Mass of cart (inelastic collision)	kg

Method 1 Calculus version						
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Impulse (N•s)	Change in momentum (kg•m /s) or (N•s)	% difference between Impulse and Change in momentum
Elastic 1						
2						
3						
Inelastic 1						
2						
3						

Method 2 Non-calculus version								
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Average force $\bar{F}$ (N)	Duration of impulse Δt (s)	Impulse $\bar{F}\Delta t$ (N•s)	Change in momentum (kg•m /s) or (N•s)	% difference between Impulse and Change in momentum
Elastic 1								
2								
3								
Inelastic 1								
2								
3								

ANALYSIS

1. Calculate the change in velocities and record the result in the data table. From the mass of the cart and the change in velocity, determine the change in momentum that results from the impulse. Make this calculation for each trial and enter the values in the data table.

2. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?

3. Look at the shape of the last force *vs.* time graph. Is the peak value of the force significantly different from the average force? Is there a way you could deliver the same impulse with a much smaller force?

4. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.