Physics Experiments Using Guided Inquiry

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HANDS-ON ACTIVITIES

Current from a Changing Field

● Current Sensors
● Magnetic Field Sensors

Impulse and Momentum

● Force Sensors
● Motion Sensors

Current from a Changing Field

Perhaps you have heard that light consists of electromagnetic waves. What does that mean? What is the relationship between the “electro” and the “magnetic”? While this may not be something you can solve today or even this week, this investigation should start you on the path to discovering this amazing connection.

PRELIMINARY OBSERVATIONS

Observe the demonstration of a magnet moving relative to a coil of wire. What does the galvanometer do and what factors might affect the galvanometer reading?

PROCEDURE

1. Discuss and decide on what variables you will use to explore the current generated in a coil of wire by a moving magnet. Remember that there can be only one dependent variable.
2. Develop a purpose and a procedure for your investigation.
   - Your purpose should ask a question or propose a relationship between variables.
   - Include the measurement equipment you will use.
   - Decide how much data or observation to take in order to have enough information to satisfy your purpose and stand up to questioning by your peers.
   - Remember to change only one independent variable at a time.
3. Carry out the investigation and record your data and observations. Make sure all group members have access to the data.

ANALYSIS

Is the graph of the variables you measured a linear graph? Consider the range of data and the expected value of the dependent variable when the independent variable is zero. Also consider the uncertainty in your data. How well do you know the values you controlled and measured?

Develop a model for your data and discuss with your group how your variables fit into that model. When you discuss the results with your class, be sure to share your model and ideas. You may want to do some research on magnetic induction.

EXTENSIONS

1. A current in a wire generates a magnetic field. A changing magnetic field induces current in a wire. Use these principles to transfer energy wirelessly between two circuits, demonstrating that it works by lighting a small bulb or LED, or transmitting a sound signal.

2. Investigate flashlights and emergency radios that are charged by turning a crank or shaking. Explain how this works and build your own flashlight that works this way.

3. Investigate the role of transformers in electric power transmission, and build and demonstrate a small transformer. **CAUTION**: Do not work with household (mains) current. Use only a regulated laboratory power supply.

Impulse and Momentum

We have studied objects moving at constant velocity and objects that are moving with a constantly changing velocity (constantly accelerating). Now we want to look at how an object's state of motion is changed. What has to happen for something to start or stop moving? What has to happen for something to change its speed, direction of travel, or both? How do we quantify the change and the cause of the change?

PRELIMINARY OBSERVATIONS

1. A hoop spring is used to apply a force to a stationary cart on a track. Observe the spring, the motion of the cart, and the force *vs*. time graphs.

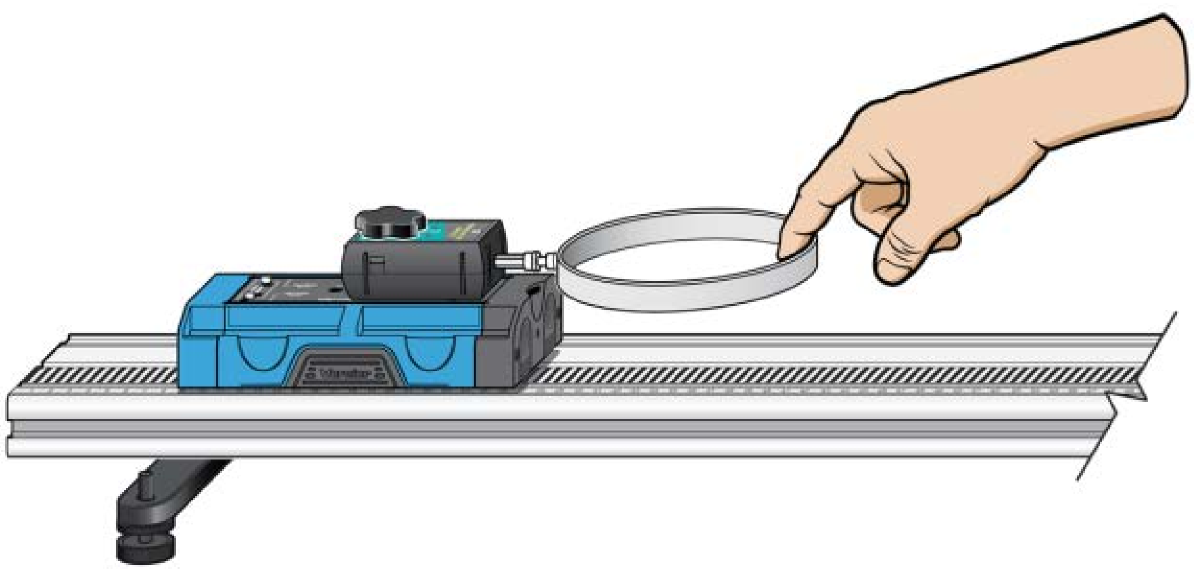

Figure 1

2. The hoop spring can be used to change the direction of motion of a moving cart. Observe.

3. The hoop spring can be used to stop a cart that is moving. Observe.

What is the role of the hoop spring? How can we quantify what the hoop spring does? Discuss with your class and the instructor.

What happens to the cart as a result?

Can you also use the hoop spring to speed up or slow down a moving cart?

PROCEDURE

Part I

1. Discuss and decide how to quantify the effect of the force on the cart.
   - Consider how you have dealt with force in the past and how this investigation may be different.
   - Discuss your method with your classmates and instructor.
2. Practice applying force to the cart in different ways, and make note of what the effect on the cart is.

Part II

1. Discuss and decide on what variable(s) you will measure to model how the applied force affects the motion of the cart.
   - Consider previous models of motion you have developed.
   - Remember there can be only one dependent variable.
2. Develop a purpose and a procedure for your investigation.
   - Your purpose should ask a question or propose a relationship between variables.
   - Include the measurement equipment you will use.
   - Decide how much data to take in order to have enough information to satisfy your purpose and stand up to questioning by your peers.
   - Remember to change only one independent variable at a time.
3. Carry out the investigation.

ANALYSIS

Part I

Examine your graphs and look for commonalities and differences. What distinguishes a force graph that reverses a cart's direction of motion from a force graph that merely speeds up or slows down a cart? Can you quantify the difference?

Part II

Is the graph of variable(s) you measured a linear graph? If not, you may need to perform one or more mathematical operations on your data. Develop a mathematical model for your data and discuss with your group how your variables fit into the model. When you discuss the results with your class, be sure to share your model and ideas. You may wish to do some research.

EXTENSIONS

1. Roll a bowling ball and hit it with a rubber mallet to change its motion. Use video analysis to estimate Δt and determine the average force applied.

2. Explore the effect of changing the Δt on the maximum force for a given Δp. **Hint**: Bringing a cart to a stop from a consistent velocity will be a consistent change in momentum

Current from a Changing Field

OVERVIEW

Students doing this investigation should investigate the factors that affect the amount of current arising in a coil of wire due to the motion of a magnet. In the Preliminary Observation, students will observe an ammeter connected to a coil of wire as the instructor passes a magnet into and out of the coil. Students will then investigate factors that affect the amount of current that is generated.

This investigation can be qualitative or quantitative, depending on the equipment available. Some variables may be challenging to control, such as the speed of a magnet being moved relative to a loop of wire.

WHAT SHOULD STUDENTS KNOW BEFORE DOING THIS ACTIVITY?

The goal of this activity is to get students to relate induced current to changing magnetic flux. They do not have to understand the concept of flux, but they do need to understand the concept of magnetic field, and that magnetic fields arise from moving electric charge. Doing the previous activity, "Magnetic Field of a Current" prior to this activity is recommended, or at the least there should be an activity in which students measure or detect the magnetic field produced by electric current.

Students should be familiar with the idea that the amount of magnetic field is quantifiable. You may or may not want to discuss how to quantify the change in magnetic flux, which is generally a topic reserved for students who have already taken calculus.

It is not necessary for students to have encountered the term electromotive force or emf before doing this investigation, but you may want to introduce the term in post-investigation discussion.

It is NOT expected that students will derive the equation $\mathcal{E} = \frac{d\Phi_B}{dt}$, however they may relate increased current (or potential difference) to more loops of wire, a smaller diameter wire loop, increased magnet speed, or a greater magnetic field.

LEARNING OUTCOME

Relate the current (or voltage) generated to one or more factors related to magnets moving near or through a coil of wire.

NEXT GENERATION SCIENCE STANDARDS

Disciplinary Core Ideas	Crosscutting Concepts	Science and Engineering Practices
PS3.A Definitions of Energy PS3.B Conservation of Energy and Energy Transfer	Cause and Effect Energy and Matter	Planning and Carrying Out Investigations

ESTIMATED TIME

Students should be able to complete the Preliminary Observations, planning, and data collection in the space one 40-minute class period. Reaching a conclusion and class discussion can take an additional 20 minutes or more of the next class period.

MATERIALS

Make the following materials available for student use. Items in bold are needed for the Preliminary Observations.

coils of wire
magnets
analog ammeter or galvanometer
computer, Chromebook, or mobile device
data-collection program
data-collection interface (if needed)
current sensor
voltage sensor
magnetic field sensor
Instrumentation Amplifier
Power Amplifier (extensions only)
other materials as requested by students

PRELIMINARY OBSERVATIONS

The Preliminary Observations can be done as a whole class demonstration or in small groups. Collect several coils of wire with different diameters and/or different numbers of turns of wire. Connect one coil to a galvanometer and move one pole of a magnet into the coil, then stop with the magnet partway through. Turn the magnet around and repeat with the other pole. Students should observe that the needle on the galvanometer moves when the magnet is entering the coil of wire, but not when it is still. They should also observe that the galvanometer needle moves in opposite directions, depending on the magnetic pole.

Do several more demonstrations by moving a magnet into the coil of wire slowly or quickly. Connect a coil of wire that is larger or that has more turns of wire, and repeat the demonstration. Use a stronger or weaker magnet (if available) for the same demonstration as well. Continue to elicit student observations.

After the Preliminary Observations and discussion, frame the investigation. Challenge students to investigate one (or more, if you have time) factor that they believe affects the motion of the galvanometer needle and come up with a model for the measured behavior.

IMPLEMENTATION

Students may choose to examine any of the following factors:

- the number of turns of wire
- the diameter of the coil
- the speed of the magnet
- the strength of the magnet

What they choose should take into account the available materials. Decide whether to guide students to investigate only one factor or several factors. Also, consider having all groups in a class investigate one factor while groups in another class investigate a different factor.

Students may need to be reminded that while they investigate one independent variable, all other possible independent variables must be kept constant. This includes the speed of the magnet, so students will have to decide how to control for a reproducible speed. One option is to always drop a magnet from the same height above a coil. Another is to pull the magnet through a tube using a motor.

Since it will be impossible to generate a constant current with this type of experiment, students should measure the maximum current (or maximum voltage) generated. It is also a good idea to take multiple trials and average the maximum values.

ANALYSIS

Students will find a more or less linear relationship for maximum current vs. number of turns of wire in the coil. The relationship between the maximum current and the diameter (or radius) of the coil will be approximately inverse. The maximum current will also increase with the speed of the magnet and with the strength of the magnet.

SAMPLE RESULTS

Here is a sample graph obtained using a Go Direct Current Sensor connected to a 60-turn coil of wire with a 3.5 cm diameter. Two neodymium disk magnets were taped onto the end of a dry-erase marker, which was dropped through the coil from a position 2.5 cm above the coil. The Go Direct Current Probe was used on the ±0.1 A setting, and data were collected at 1000 samples/second in order to capture this shape.

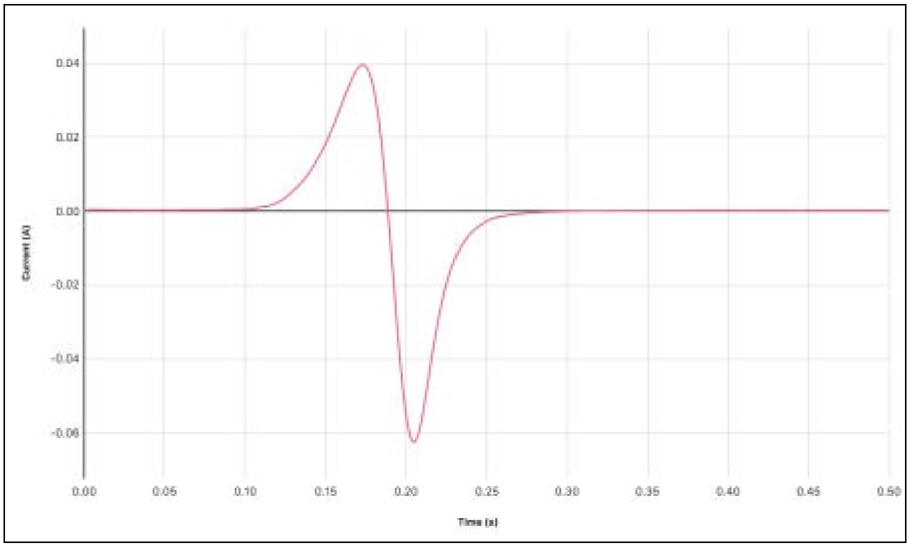

Figure 1 Current rises and then reverses direction as a magnet falls through a coil of wire

Students should find that the more coils of wire they have, the greater the average maximum current is. Ideally, a linear trend will emerge from the data, but this is unlikely to actually happen. Students may try to manipulate the data to linearize the data.

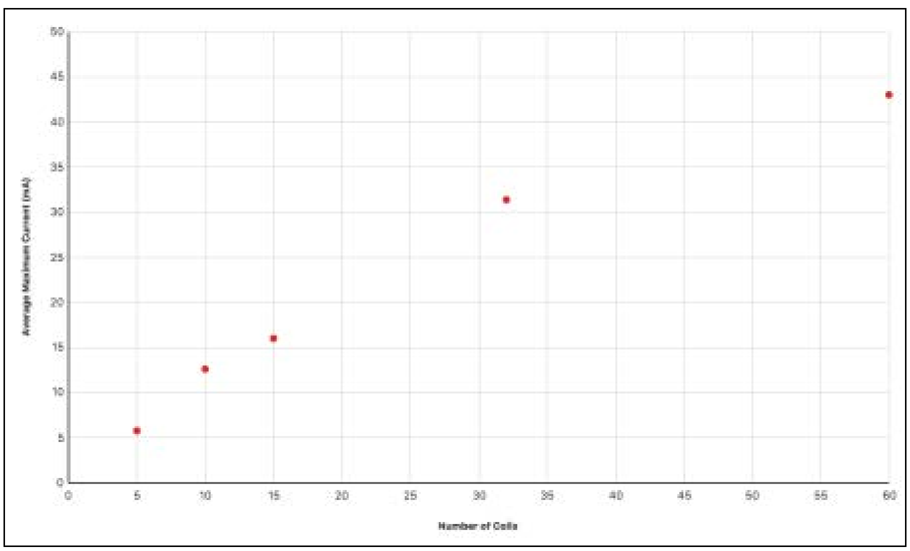

Figure 2 Average maximum current (from 5 trials per number of coils) increases with number of coils, but not quite linearly

When the size of the coil is increased, the maximum current from the moving magnet decreases. The relationship may be an inverse proportion. It may be difficult to collect enough data for this experiment, as it depends on having enough different diameter coils of the same number of turns of wire. The sample data were collected by wrapping 32 turns of wire around two rolls of tape and two cardboard tubes, and dropping the magnet and marker combination from the same height above each coil multiple times. In this case, we measured induced potential difference instead of current.

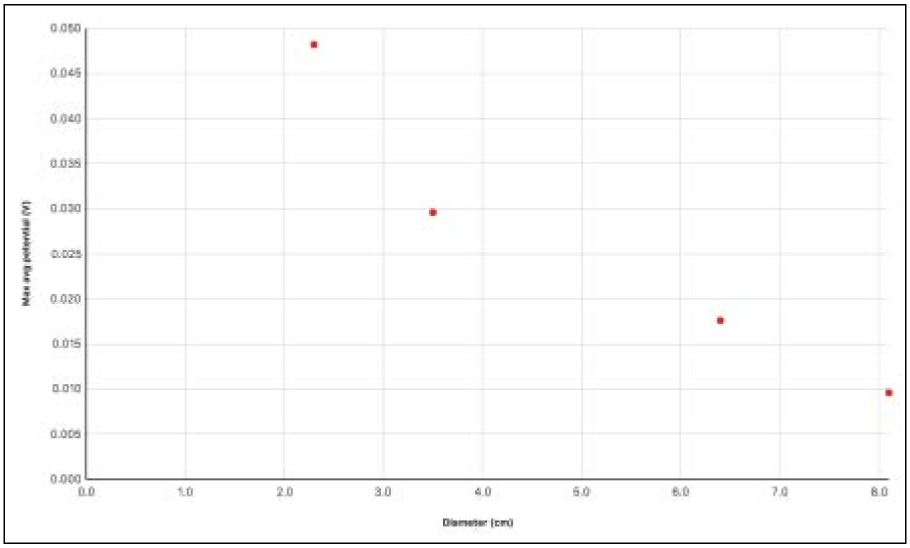

Figure 3 In this sample graph, the maximum voltage decreases as the coil diameter increases.

We did not collect sample data for the effect of the speed of the magnet as it passes through the coil, nor did we collect sample data for different magnetic fields.

TIPS

1. In the Electronic Resources you will find many useful files, including sample program and a PDF of the student pages so you can print the activity for your students or distribute the file to them electronically. Sign in to your account at **vernier.com/account** to access the Electronic Resources. See Appendix A for more information.

2. The Current Probe and Go Direct Current Probe work very well for this investigation. However, in the event that these are not available, students can use a voltage sensor such as the Go Direct Voltage Probe or the Instrumentation Amplifier. The Voltage Probe and Differential Voltage Probe will work also, but without the same resolution as the other sensors. For more information, see **vernier.com/current-sensors** and **vernier.com/voltage-probes**

   The existence of a difference in potential between the two ends of the coil of wire implies that there must be a current in the coil. If students are familiar with Ohm’s Law, they can determine the resistance of the coil by determining resistance per unit length of wire and applying it to the length of wire in the coil, and determine the current. However, if students simply use the voltage measurement, they will discover the same relationships.

3. Magnet wire (enamel-coated copper wire) is ideal for this experiment, but regular hookup wire works also. Magnet wire can be purchased from a number of science and electronics supply companies. The 28-gauge magnet wire that comes with the KidWind simpleGEN kit is an excellent choice. Remember that the enamel must be sanded off the ends of the wire in order to measure the current (or voltage).

4. A demonstration galvanometer is nice to have for the Preliminary Observations. These are available at some science supply companies. You may also be able to rig a smaller analog galvanometer or milliammeter so that a document camera can display the face. We definitely recommend an analog meter of some kind for the Preliminary Observations, as these meters operate on the same principle they are measuring and can be an excellent source of discussion.

5. A button magnet or small disk magnet may have a tendency to turn or flip as it falls through a coil, while a bar magnet usually keeps its orientation. If you are using a button or disk magnet, tape it to the end of a pencil or marker and drop the pencil vertically through the coil.

EXTENSIONS

Assign one or more of the following extensions once students have concluded their investigations. While we provide guidance for what to expect from students in response to the extensions, we do not include sample data or conclusions.

1. A current in a wire generates a magnetic field. A changing magnetic field induces current in a wire. Use these principles to transfer energy wirelessly between two circuits, demonstrating that it works by lighting a small bulb or LED, or transmitting a sound signal.

A source of changing current can be a closed circuit that is opened suddenly (or closed suddenly) or it can be a low-voltage AC source such as the Power Amplifier. A small flashlight-type light bulb or an LED can work for this. Each circuit will need a coil of wire.

To transmit a sound signal, an easy way is to connect a mono phone plug to a coil of wire. Connect a second coil (approximately equal in diameter and number of turns) to an amplifier/speaker and bring the two coils near each other. An example can be seen in the YouTube video MIT Physics Demo–Inductor Radio.

2. Investigate flashlights and emergency radios that are charged by turning a crank or shaking. Explain how this works and build your own flashlight that works this way.

Students need to research capacitors as energy storage in order to make this work. The principle is the same as a generator.

3. Research the role of transformers in electric power transmission, and build and demonstrate a small transformer. **CAUTION**: Do not work with household (mains) current. Use only a regulated laboratory power supply.

Students may use two coils of wire and a piece of iron or steel to place both coils on. The steel core does not have to be a square donuts shape to work. A bundle of nails will work. The Power Amplifier is useful as a low-voltage AC source, and adding a resistor can keep the current low.

Impulse and Momentum

OVERVIEW

The goal of this activity is to relate impulse and momentum, and to determine that the impulse is equal to the change in momentum. The investigation is set up in two parts. First, students will evaluate how to quantify the event that causes a change in motion (i.e., impulse). The second is to develop a model for how impulse changes the velocity or momentum of an object.

$$m\vec{v}_i + \vec{F}_{net}\Delta t = m\vec{v}_f$$

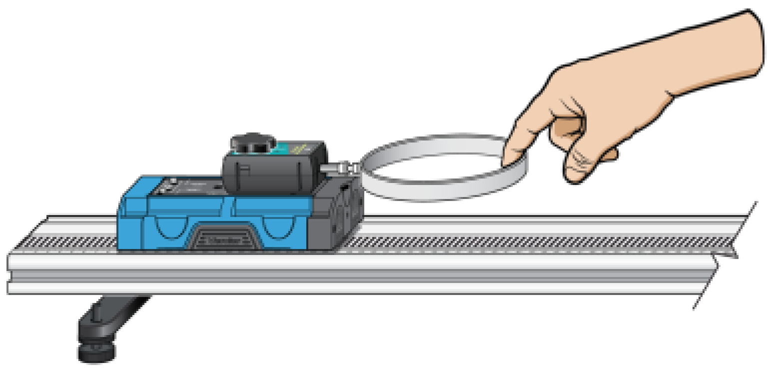

Figure 1 Using a Go Direct Force and Acceleration sensor attached to a cart

In the Preliminary Observations, students observe a cart experiencing an impulse, using a hoop spring on a force sensor to change the momentum of a cart. Students address impulse in Part I of the investigation.

In Part II, students address the question of quantifying the change in the motion state of the cart. Students who investigate the relationship between impulse and change in velocity should find that the constant of proportionality is about equal to the mass of the cart. Students who investigate the relationship between impulse and change in momentum should find that the two values are nearly numerically equal.

WHAT SHOULD STUDENTS KNOW BEFORE DOING THIS ACTIVITY?

If students do not have an operational definition of momentum before this activity, they should develop one by the time all class discussion for this activity has concluded.

Students should be able to determine velocity of a cart and measure force using data collection software and sensors.

Students should have already learned Newton's laws of motion. Reviewing these in the context of the Preliminary Observations may be useful for students.

The third law, regarding equal forces in opposite directions on the two bodies involved in an interaction, allows the use of only one force sensor in the investigation, either mounted on the cart or held by hand. Students using a force sensor and hoop spring held by hand should realize that the force on the hoop spring is equal in magnitude and opposite in direction to the force on the cart.

Vectors are extremely important in this activity. In each trial, students will need to keep track of the direction of motion of the cart and the direction of the force. Students should be able to establish a coordinate system applied to their experimental setup and familiar with using positive and negative to indicate directionality.

LEARNING OUTCOMES

- Identify variables, design and perform investigations, collect and analyze data, and draw a conclusion.
- Determine impulse and change in momentum based on measurements of force and velocity.
- Create a mathematical model of the relationship between impulse and the change in momentum.

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Disciplinary Core Ideas	Crosscutting Concepts	Science and Engineering Practices
PS2.A Forces and Motion	Patterns Cause and Effect Systems and System Models	Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions Science models, laws, mechanisms, and theories explain natural phenomena

ESTIMATED TIME

Students should be able to complete the Preliminary Observations, planning, and data collection in the space of two 40-minute class periods. Reaching a conclusion and class discussion can take an additional 20 minutes or more of the next class period.

MATERIALS

Make the following materials available for student use. Items in bold are needed for the Preliminary Observations.

computer, Chromebook, or mobile device
data-collection program
data-collection interface (if necessary)
cart
track
force sensor
hoop springs
masses to place on carts
motion detector
Motion Encoder
Go Direct Sensor Cart
video analysis software (e.g., Logger *Pro* or Video Physics)
other materials as requested by students

PRELIMINARY OBSERVATIONS

The Preliminary Observations for this investigation are focused on using the hoop spring to change the state of motion of a cart on a track. Students should observe that the hoop spring deforms (stretches or compresses) when a force is being applied. These Preliminary Observations work best as a whole class activity with group discussion.

Set up the demonstration as in Figure 1: Attach a hoop spring to the force sensor of a Go Direct Sensor Cart or use a wireless force sensor mounted on a regular cart. If the force sensor cable will drag on the track or table, an alternative is to hold the force sensor in your hand and use the hoop spring to apply force on the cart. A sample rate of 50 samples/second works well for this demonstration.

Display a graph of force *vs*. time for students to see. Use the hoop spring to apply forces to the cart and change its motion. You can either push on the spring or pull on it, or both.

Ask students to make observations of the hoop spring, the motion of the cart, and the force *vs*. time graph. Displaying several runs at the same time will allow easy comparisons.

Examples include

1. Stationary cart receiving positive impulse (see tips) and negative impulse.
2. A moving cart changing direction
3. A moving cart being brought to a standstill.

Students should notice that there are "humps" or "dips" in the force *vs*. time graph that correspond to the changes in slope of the position *vs*. time graph. They should observe that these correspond to the hoop spring being compressed (dips) or stretched (humps). If students do not bring it up, ask how they might assign a value to each hump or dip. Determining this value will be the Part I investigation.

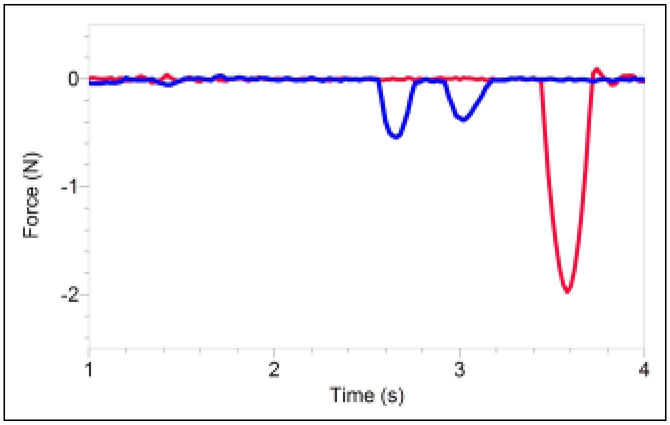

Figure 2 Dips in the force graph

If desired, you can complete Part I of the investigation and discuss it with students before doing observations and experiments for Part II.

The next set of observations should involve a series of events with more force each time (or less force each time). For example, use the hoop spring to slow the cart down, to bring it to a stop, to reverse its direction, and to reverse direction and rebound faster. Invite students to combine observations of the hoop spring and observations of the cart motion.

Students should observe that more dramatic changes in motion are observed with greater impulses (though you may choose to not introduce the term impulse until later). The investigation of this phenomenon will be the Part II investigation.

Frame the investigation for the students by asking how they would quantify what the force does to the cart? Is it enough to simply use the maximum force from the graph? Students should come up with ideas relating to the dips and humps from the force *vs*. time graphs, such as size, shape, or duration.

IMPLEMENTATION

Part I Quantifying a variable force impulse

In their investigation, students should qualitatively relate the values they come up with to the behavior of the cart. For example, investigate how to get the cart to slow to a stop, using only the hoop spring as a force. Students will find that holding the sensor/hoop spring still (or holding their hand still for the hoop spring to run into) simply reverses the cart's direction when the cart runs into the hoop spring. But if they move their hand along with the cart to apply a small force over a longer time, they can bring the cart to a stop, and they will see a distinctly different graph for force *vs*. time than they see when the cart bounces off the spring and reverses direction.

The pair of graphs in Figure 3 illustrates the difference. A double bounce of small amounts of force brings a cart to a stop, as seen on the position *vs*. time graph. But a single, high-force bounce reverses the cart's direction.

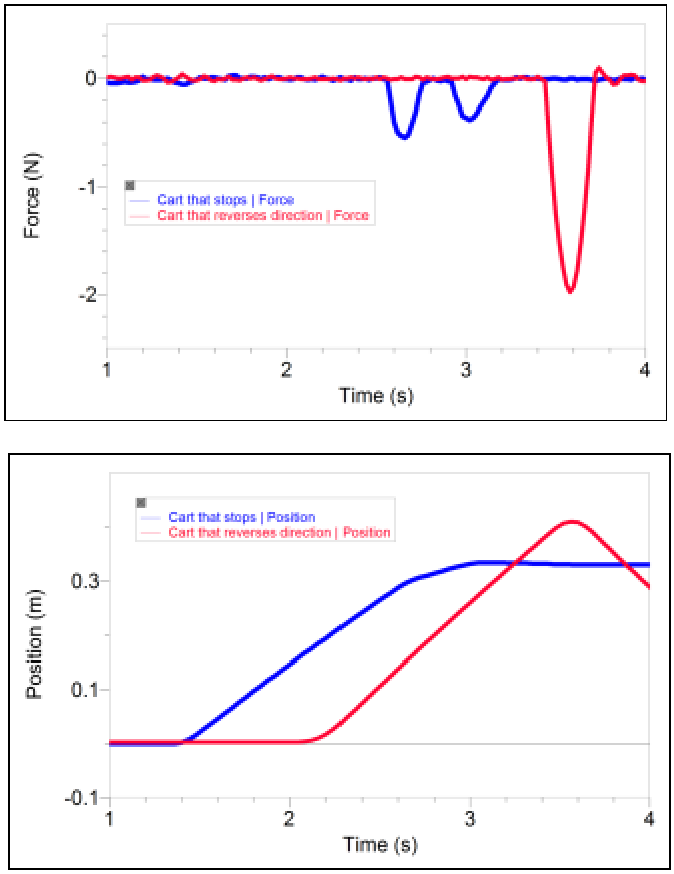

Figure 3 Different impulses for a cart that changes direction and one that comes to a stop

Part II Impulse changes momentum

Once students are comfortable with quantifying impulse as a way to describe the effect of a force acting for a time period, they should investigate how the impulse affects the motion of the cart, in particular quantifying the change in the motion.

Students will have to make clear before and after measurements of velocity, using the slope of a position *vs*. time graph or using a velocity graph. Students may need guidance for determining the change in velocity (e.g., If a cart is moving one direction at 1 m/s and its motion is exactly reversed to 1 m/s in the other direction, the total change in velocity is 2 m/s and the sign depends on whether the cart's motion changes direction from positive to negative or from negative to positive). Remind students that the change in any quantity is always found by subtracting the initial state from the final state, and that velocity is a vector. It may also help for students to put a tape mark on the track to denote the positive direction for motion and force.

If students don't think to mass the cart during the experiment, that is okay. They can use change in velocity just as well as change in momentum if the mass of the cart is kept constant.

ANALYSIS

Part I

Students will find that when using the hoop spring on a force sensor, the force *vs*. time graph will consist of a "hump" shape (or a "dip"). They should notice that the hump represents a force which is not constant. They will need to think of a way to quantify the amount of force being exerted on the hoop spring.

There are in general two ways to determine impulse using software: calculus-based and non-calculus-based. The calculus method involves selecting the hump on the force *vs*. time graph and integrating as in Figure 4. The impulse is calculated in N•s. The non-calculus method involves selecting the hump on the force vs. time graph and using the statistics function to determine the average force and shown in Figure 5, then noting the total time interval Δt for the force on the sensor and multiplying average force by Δt. Both ways give a good results in most circumstances.

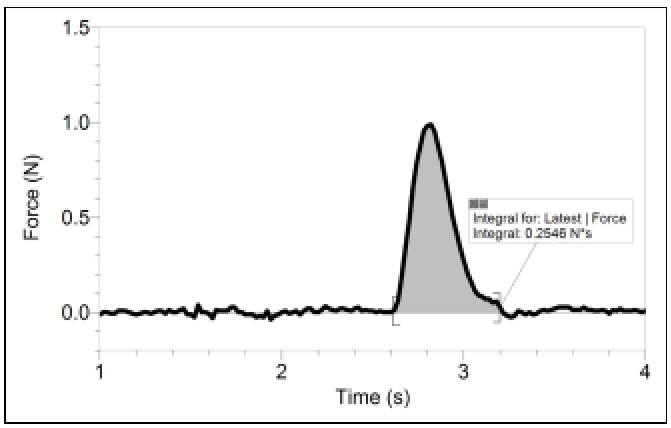

Figure 4 Using the integral function to quantify impulse

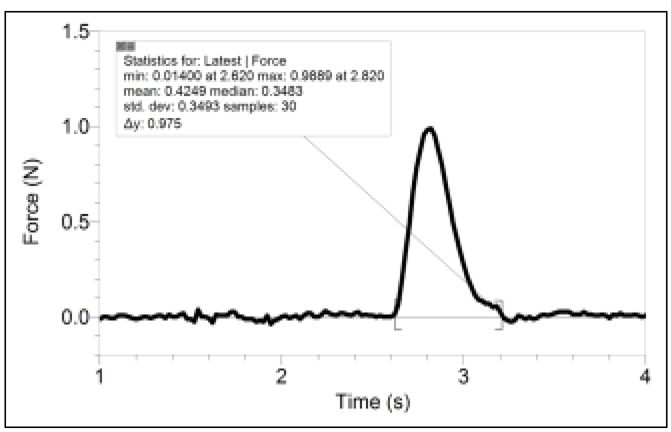

Figure 5 Using the average force to quantify impulse

Part II

Students will need to determine the impulse and change in velocity or momentum for a number of trials. They may graph their results as impulse *vs*. change in velocity (or vice versa) or as impulse *vs*. change in momentum (or vice versa). In any of these cases, the graph should be linear.

While the slope of a graph with change in momentum *vs*. impulse should be close to 1, using change in velocity instead will bring out the mass of the cart. This can be determined using the units (kg or 1/kg, depending on how the students graphed the data).

SAMPLE RESULTS

One way to determine the change in velocity is to use the position *vs*. time graph and the linear fit function. A second way is to use the velocity *vs*. time graph and record the velocity values immediately before and after the impulse.

Figure 6 shows an example of a negative change in velocity and a negative impulse. Note that the velocity after the impulse is not constant, so the velocity very nearly after the collision is measured rather than the average velocity for the entire time interval shown.

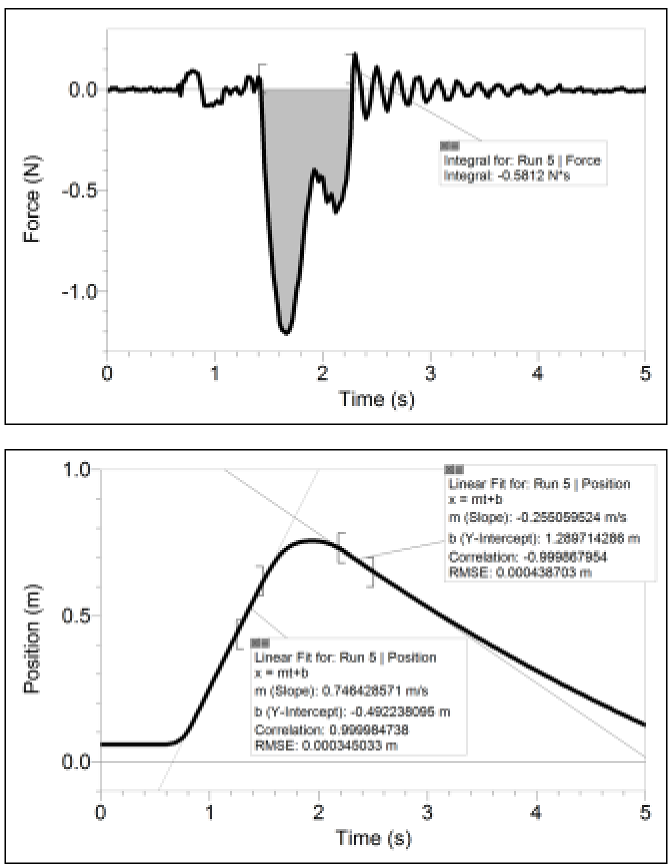

Figure 6 Determining impulse using the integral function and change in velocity from the slopes on the position graph

Here is a collection of sample data using a cart with a mass of 0.5310 kg:

Impulse (N•s)	Velocity 1 (m/s)	Velocity 2 (m/s)	Momentum 1 (kg•m/s)	Momentum 2 (kg•m/s)	Change in Momentum (kg•m/s)
0.1583	0	0.281	0	0.1492	0.1492
–0.1720	0	–0.3168	0	–0.1682	–0.1682
0.2774	–0.2837	0.1978	–0.1506	0.1050	0.2557
–0.1447	0.2734	0	0.1452	0	–0.1452
0.2291	–0.4332	0	–0.2300	0	0.2300
–0.5998	0.5764	–0.4907	0.3061	–0.2606	–0.5666
0.3986	0	0.671	0	0.3563	0.3563
0.2013	0.1733	0.5263	0.0920	0.2795	0.1874
–0.2502	–0.2035	–0.6778	–0.1081	–0.3599	–0.2519
–0.1724	0.4041	0.162	0.2146	0.0860	–0.1286
0.08118	–0.4598	–0.2849	–0.2442	–0.1513	0.0929
–0.4722	0.2147	–0.6089	0.1140	–0.3233	–0.4373

These data produce the following graph with a slope of 0.9358, which has no units.

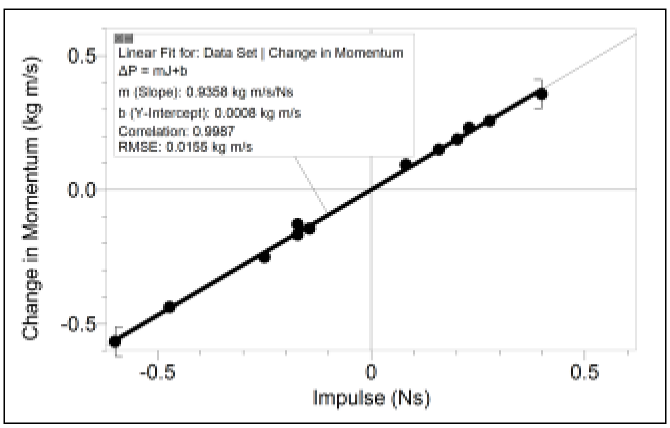

Figure 7

Post-experiment discussion is the time to formulate that if the impulse or average force multiplied by time interval is equal to the change in momentum, then the momentum of a system is equal to its previous momentum, plus whatever impulse has occurred

$$\vec{P}_f = \vec{P}_i + \vec{F}\Delta t$$

TIPS

1. In the Electronic Resources you will find many useful files, including sample program and a PDF of the student pages so you can print the activity for your students or distribute the file to them electronically. Sign in to your account at **vernier.com/account** to access the Electronic Resources. See Appendix A for more information.

2. The Go Direct Sensor Cart is ideal for this experiment. Attach a hoop spring directly to the cart's force sensor and you are set to go. However, any force sensor and cart combination should work for this experiment.

3. Hoop springs are essential for this activity. If you do not have them, you can purchase them from Vernier (order code: HOOPS-BLK) or make your own. You can make hoop springs from spring steel such as 1095 spring steel or blue-tempered spring steel. You will need about 18 cm of spring steel for each hoop. Drill a hole in each end, and overlap the holes. You can use the hook that comes with the force sensor to secure the loop to the force sensor.

4. If you have only wired force sensors, holding the sensor in your hand rather than mounting it on the cart will prevent drag from the wire from affecting the motion of the cart. In this case, it may not be obvious how to apply a pull using the hoop spring. It can be done by hooking the hoop spring onto the spring release pin of the plunger cart, or use the cart hardware to put a post on the cart that can be pulled.

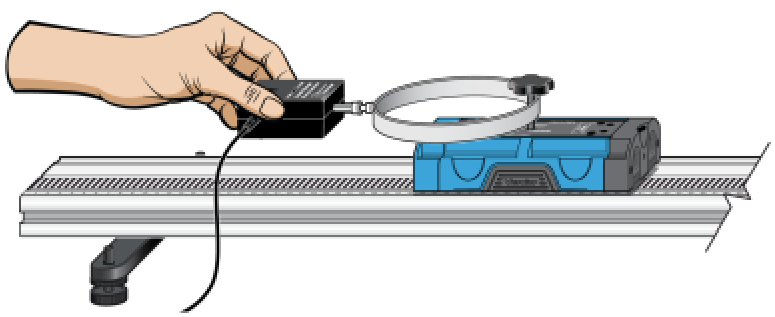

Figure 8 Using a Dual-Range Force Sensor to pull a cart

5. The force reading may oscillate for a short time after the impulse. This is clearly seen in the force *vs*. time graph in Figure 6. If students are concerned about this, you can reassure them that the average force during that time is 0 (because the oscillations are about equally above and below zero). If they include this part of the graph in an integral, their impulse value will not be affected. However, if students are determining the average force and multiplying by the time interval, they should avoid selecting the oscillating portion of the graph, as this will reduce the average force determined by the Statistics function.

6. You may wish to have students consider the units for the slope of the line. This can be especially helpful if they did not consider the mass of the cart, but only the change in velocity.

7. Newton's second law of motion relates force and acceleration. The relationship between impulse and momentum is essentially a restatement of the force and acceleration relationship. This is a good topic for discussion after the students share their results.

EXTENSIONS

Assign one or more of the following extensions once students have concluded their investigations. While we provide guidance for what to expect from students in response to the extensions, we do not include sample data or conclusions.

1. Roll a bowling ball and use a rubber mallet to change its motion. Use video analysis to estimate Δt and determine the average force applied.

This extension will work better with high-speed video, as that will allow a better estimate of the time the mallet is in contact with the bowling ball. If you don't have a way to accurately determine the mass of the bowling ball, this can turn into an exercise in error propagation for students: how many significant figures is in 14 pounds, and what is the uncertainty in that value? When converting to kilograms, what is the uncertainty in the mass? What is the uncertainty in the time measurement for the impulse.

2. Explore the effect of changing the Δt on the maximum force for a given Δp. **Hint**: Bringing a cart to a stop from a consistent velocity will be a consistent change in momentum.

The easiest setup will involve bringing a cart to a stop, perhaps at the bottom of a mild incline. With a consistent release point for the cart. The different time intervals can be accomplished with different materials between the force sensor and whatever applies the force. Hoop springs are likely to make the cart bounce, so the challenge is to bring the cart to a stop without bouncing.