SCOPE, SEQUENCE, and COORDINATION

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SCOPE, SEQUENCE, and COORDINATION

Student Materials

Learning Sequence Item:

1012

Impulse, Momentum, and the Conservation of Momentum

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Science as Inquiry

When Ball Bearings Collide

How do balls behave in collisions?

Overview:

Suppose one object exerts a force on another for a very short time, for example, by colliding with it. When we have a few such objects of equal mass all in a row, interesting things can happen. Here we examine just what happens and how it depends on mass and speed. We use a set of five ball bearings mounted in a row from strings so that each one is capable of swinging into the next one in line.

Procedure:

Part A. First, use two neighboring metal balls, moving all of the others out of the way. With one of them hanging at rest, pull the other about half the way back, release it to let it swing. What happens? Now release it from even further back. How does the height reached by the other ball compare to the height from which the first mass was released? How does the speed just before the collision compare to the speed after collision for each ball?

Part B. Try this with all but one ball at the end hanging in line at rest. Pull this single ball at the end back and release it to swing into the others. How many balls move strongly? How does the speed appear to compare roughly before and after the collision?

Part C. Try releasing two balls from the same end together to crash into the line of remaining balls at the same time. How many balls do most of the moving after the collision? How does their speed compare with their speed before the collision?

Part D. With all the balls except one at each end at rest, let the two on opposite ends swing through essentially the same distance by releasing them both to collide with the rest at the same time. What happens now?

Questions:

1. For Part A (with the moving ball crashing into the stationary one), draw a diagram showing the locations immediately before and immediately after the collision. Near each ball in the diagram, draw in arrows to indicate the speed and direction of motion just before and just after collision. What did you observed in terms of the degree of motion being transferred from one ball to another?

2. Two of the balls collide and the first one is exerting a force F on the second at some instant. How does this compare with the force that the second ball exerts on the first? How do the directions of these forces compare? The balls used here have equal mass. What does that mean in terms of their inertia? How much force must be acting on ball #2 as compared with how much force must be acting on ball #1?

3. How can you explain what you observed when one ball collided with the second in Part A?

4. For Part B, draw "before and after" diagrams labeling each ball with an arrow indicating its *velocity* (the speed and direction of motion). Do the same for Part C. Did the balls that reacted the most strongly to the collision move about as fast and as far as the one before collision in both Parts? How does the total amount of mass that moved afterwards compare with the total mass moving before collision in both Parts? How does the "amount of motion" transferred depend on mass?

5. Imagine that you have 20 identical steel balls lined up in a row and suspended. Suppose that one ball, three times as massive as any one of the other balls, is allowed to swing into the column from one end. How would the line of suspended steel balls move?

6. The quantity that reflects the "amount of motion" (*momentum*) available to be transferred during a collision is usually taken to be the mass multiplied by the velocity. Explain how what you observed suggests that this definition of momentum is a more meaningful indicator of the "amount of motion" than the velocity alone would be.

7. For Part D, draw a sketch showing the "before and after." Keep track of directions of motion by using a plus sign for the numerical value of the momentum to the right and a minus sign for motion to the left. What is the sum of every "mass x velocity" before collision, and the sum after collisions with directions taken into account in this way?

8. What result would you predict for two balls at rest if three balls are allowed to collide into the first two?

Science as Inquiry

Tabletop Collisions

How do colliding balls behave?

Overview:

When one object collides and bounces off another, the two exert forces on each other over a short time. Some interesting things happen when the masses of different objects have the right values and when the objects are very resilient, acting more like perfect springs when bouncing back than the way a mushy underinflated basketball might behave. Here we see just what happens and how to understand it in terms of momentum. We use a set of ball bearings or marbles of equal mass free to roll in the groove of a ruler, and also try various combinations of coins (or of hockey pucks if available) colliding into each other on the surface of a smooth table.

Procedure:

Part A. Place six or seven steel ball bearings, each nearly touching the next, in the groove of a ruler lying on a flat table. Flick one additional ball bearing along the groove so it collides into the end of the column. How does the column react? How many ball bearings are knocked off at the other end? Now reset everything in place and try to flick two ball bearings together into the end of the column, and see what happens. Try this also with three.

Part B. Try this with coins of equal mass (or pucks of equal mass if available) on a smooth table: First line up two meter sticks parallel to each other on the table—slightly more than one coin-width apart (so that they guide the path of the coins). Flick one coin so that it slides directly into another on center. It may take a few tries to aim right. What happens immediately after collision? Now line up two similar coins and flick a the third coin directly along the line from the center of one to the center of the other. What happens?

Test whether this really depends on the mass of the initially moving object by trying either Part A or Part B, (or both), using a ball bearing or a coin much heavier than the ones it is aimed at.

Questions:

1. For Part A, draw a diagram based on your observations of the moment before and the moment after collision. Label each ball that was strongly moving with an arrow indicating its *velocity* (speed and direction of motion) by making the *length* of the arrow indicate the relative speed and the *direction* of the arrow indicate the direction of motion. What did you observe in terms of the amount of motion being transferred between colliding objects?

2. How did the total mass that was moving strongly and its speed appear to compare before and after collision?

3. When one object collides into another, the first object is exerting a force F on the second object. How does this compare with the force that the second ball exerts on the first? How do the directions of these forces compare? The balls used here have equal mass. What does that mean in terms of their inertia? How does the force acting on ball #2 compare with the force acting on ball #1?

4. The single ball flicked into the column of balls exerted a force on the balls at the end by pushing on the whole column. How can your explain what you observed when one ball collided with the second in the first part of this activity?

5. Imagine that you have 20 identical steel balls lined up in a row in the same way. One of these steel balls is three times as massive as any one of the others. This massive ball is flicked into the column from one end. What happens at the other end and why?

6. The quantity that reflects the “amount of motion,” which is partly transferred in a collision, is the mass multiplied by the velocity. How does this definition of *momentum* indicate the “amount of motion” better than just the velocity alone?

Science as Inquiry

Motion (almost) Without Friction—the Air Track

How do colliding carts on air tracks behave?

Overview:

It would be a lot easier to see just how the laws of motion work if we could avoid having to deal with the extra complication of frictional forces. A way to do this is to use a specially designed hollow track with small holes along its length. A motor-driven pump forces air into the track, and the escaping air suspends specially designed carts very slightly above the track surface so that they ride with very little friction on a cushion of escaping air. A piece of springy steel is usually mounted on the carts or ends of the track or both so that the cart at each end rebounds and continues its motion in the opposite direction.

We can then study what rules apply when the carts collide. Two kinds of collisions of special interest are those in which the carts bounce off each other as close to perfectly as possible (which we call *elastic*), and collisions in which the two carts stick to each other (which we call *completely inelastic*.)

Procedure:

Measure the mass of the carts with a balance or scale. They should have equal mass.

Elastic collision. This takes a coordinated effort by three students. With the Velcro sides facing away from each other so the colliding carts will not stick, set one cart in motion and let it collide with the other. Note the motion of each cart before and after collision. Next, repeat this, with one student timing how long it takes a single cart to move between the tape marks used to indicate locations on the track, with the second student quickly placing the second cart at rest on the track to allow collision and quickly removing the first immediately after it collides, and with a third student then timing how long it takes the second cart to move through the same distance between tape marks.

Completely inelastic collision. Turn the carts with Velcro sides facing so the carts will stick when they collide. Place the second cart at rest toward the far end and set the first in motion. Observe how the speed seems to compare before and after they latch onto each other. Then do an actual measurement. Place the second cart at rest beyond the second tape mark. Start the first cart in motion before the first tape mark. A student should time how long it takes to move from one mark to the second. A third student waiting for the right moment should time once again how long it takes the coupled carts to go from mark #2 back to mark #1. Record the times and the distance between marks and compare the two times and speeds.

Equal speeds. Separate the two carts with Velcro or soft wax sides facing so that they will stick when they collide. Place a meter stick or other light stick on top so that they can be moved at the same speed. Push the stick forward (pressing down lightly if need be so the stick does not slip) to set both in motion at the same speed, lifting the stick without pushing forward on either cart at the end of this motion). One cart then rebounds from the end of the track. Note the specific motion of the combined pair of carts once they collide and stick. Repeat for one cart having twice the mass of the other, setting the carts in motion with the more massive cart in front—note what happens now.

Questions:

1. For the elastic collision, draw a diagram of the carts just before and after collision. Label each with an arrow (when appropriate) to indicate direction of motion. Describe what you observed in terms of the amount of motion, or momentum, transferred. Calculate the momentum as mass times speed before and after. Compare these two momentum calculations.

2. Sketch a “before and after” diagram for the completely inelastic collision with a stationary cart. Describe what you observed regarding “amount of motion” transferred in the collision. How much did the total mass that was moving increase or decrease in the collision? How much did the speed of the moving mass increase or decrease? How did the sum of the mass moving multiplied by speed compare before and after?

3. Discuss (in view of your answers to the previous question) whether regarding the mass times its velocity (*momentum*) as a measure of the “amount of motion” of an object appears reasonable—based on what you observed. See if your explanation is supported by the specific mass-times-speed, or *mv*, values that you measured.

4. Suppose that a cart collided with a stationary cart twice as massive and the two stick together because of Velcro (or soft wax) on the carts. This means that three times as much mass is moving after collision. If the total momentum were to stay the same before and after collision, how much must the speed of the moving object change?

5. Sketch a diagram for the two identical carts colliding into each other at the same speed, indicating with an arrow the direction of the motion of each cart before collision. Taking velocities to the right as positive, and velocities to the left as negative, what would the total momentum be just before collision—and how can you explain what was observed in terms of total momentum changes in view of Question 3 and 4?

6. When two carts, one twice as massive as the other, collide head-on with each moving at the same speed, how do their momenta compare before collision (in both direction and magnitude)?

7. If the two carts in Question 6 have Velcro (or soft wax) between them so that they stick, what motion to you expect after collision?

Science as Inquiry

Stopping a Moving Object

How much force does it take to stop a moving object?

Overview:

When an object is moving, forcing it to stop abruptly sometimes can be difficult. But what determines how hard it is to stop? We examine this question in terms of the mass and speed of a falling object.

Procedure:

Cut off about 1–2 meters of fishing line with the lowest rated test strength and attach one end to the rigid support and the other to the 200 g test mass so that the mass hangs at least 50 cm above the floor. The line should be attached by wrapping it six or seven times around the support bar and adding a piece of tape to hold everything in place. (Tying the line with a knot weakens the line at the knot and may cause breakage.) Measure the height from the floor when the test mass hangs freely, and drop the mass from increasing heights above where it hangs at rest, for example from about 15 cm greater height, then about 30 cm, then 45 cm, etc., to find the approximate distance of fall for which the string breaks. After determining the approximate drop distance to break the line, repeat the final test drop with a freshly cut length of line to verify and fine tune your results.

Remove all leftover broken fishing line each time a new piece of line must be used. You will need to know each time from the string remnants that the string really broke rather than the knot merely coming loose. If a horizontal bar clamped to a ring stand is used as the rigid support, press down during each test on the top of the vertical ring stand shaft near the clamp to help keep it in place on impact, trying to do this in about the same way each time.

Try this with at least one other kind of fishing line of greater strength. Now, repeat using a 400 gram mass for at least two different strengths of fishing line.

Attach a length of the weakest line to the 200 g test mass, and observe once again that a drop through the height you determined or slightly greater will indeed break the line. Repeat with a freshly cut piece of line of the same kind—however, this time attach the line and test mass to a heavy rubber band and then attach this assembly to the rigid support. Measure the rest height from the ground, and drop the test mass through the same distance of fall that previously broke the string. Did the line break this time? How did the distance over which the line actually pulled to stop the test mass compare?

Questions:

1. How does the height of the fall affect how fast the falling object is moving?

2. When was the speed greater for a given mass—when it broke the weaker line or the stronger line?

3. How does increasing the momentum of an object by changing only its speed affect the force needed to stop it abruptly?

4. How does the force needed to abruptly stop the falling object depend on its mass?

5. What effect does increased momentum have on the force needed to stop the test mass abruptly? How did your results show this?

6. Compare the distance over which forces act to stop the falling object with and without using the rubber band. Compare the strength of the force, compare the length of time the force must act, and compare the momentum that must be reduced to zero (by indicating whether each is smaller, larger, or about the same) with and without the rubber band between the string and the rigid support—being sure to justify your answers in terms of what you observed.

7. The change in momentum produced by a force over a short time is often called the "impulse" imparted by the force. If the same force acts longer, would you expect it to produce a greater, smaller, or the same velocity change?

How would you expect having the same force acting longer to affect how much it changes the momentum?

How then would allowing the same force to act longer affect the impulse it produces? Why?

For a greater force to produce the same impulse, must it act for a longer or shorter time? Explain.

How then would the force change to produce the same impulse over a longer time?

Use the ideas of impulse being equal to the momentum change, and being related in this way to the average force and time it acts, to formulate an explanation for the results observed when the rubber band was used instead of the rigid support holding the string directly.

Science as Inquiry

The Water Rocket

What makes a rocket work?

Overview:

What makes a rocket work? Exhaust gases fire out the back of the rocket, but why does that mean the rocket will be propelled forward? Analyzing the behavior of a simple device provides some answers.

Procedure:

Fill the water rocket partially with water to the lowest mark indicated on the rocket (no more than $^1/_5$ full). Clamp the pump in place on the rocket and pump about six thrusts of the pump handle to pressurize the inside (or just enough to feel the pressure resistance on the pump). In a location clear of overhead lights or other breakable objects, aim the rocket upward and (with the unit held over a catch basin or sink if done inside), slip the latch mechanism to unclamp the rocket, releasing it to let it launch. Then repeat the entire operation with exactly the same number of thrusts of the pump handle plus one or two extra to make up for the missing water. Observe what happens now when you follow the same procedure to launch the rocket.

Questions:

1. What is the initial momentum of the system (meaning the rocket together with the water in it) when it is pressurized but not yet released?

2. Draw a diagram illustrating the rocket with the spurt of water after having been ejected. Label your drawing with an arrow showing the direction of the momentum of the water.

3. Now, in your diagram, draw a second arrow to indicate the direction of the momentum (mv) that the rocket of mass m moving with velocity v had after the water was ejected.

4. What is the precise relation between the momentum of the rocket in flight and the momentum of the water ejected if the total momentum is to remain the same as before the launch?

5. Suppose someone in a row boat throws a large rock (weighing 100 lb) overboard. What effect do your observations and answers to Questions 1–4 suggest this would have on the motion of the boat? Explain.

6. Justify your conclusions in Question 5 about the way the boat would behave directly in terms of the relation between the force the first exerts on the second, compared with the force the second exerts on the first. Does this apply also to the rocket? If so, how (considering the forces exerted on the water and rocket by the compressed gas)?

7. Suppose someone claimed to you that a rocket works because the exhaust from the rocket pushes

against the air behind it. What arguments would you offer to convince the person that such an explanation is not correct?

8. The answers to these questions describe propulsion of the water rocket in terms of momentum being "conserved" (that is, staying the same). It also describes it in terms of the forces exerted by the compressed air inside on the rocket and on the water. Which description better explains what actually makes the water rocket move?