Um CARTS WITH A SPRING BALANCE
Exploration

Problem

What relationship can you discover between mass, force, and acceleration?

Materials

Carts and spring balance or bungee cord (stopwatch and meter stick if requested). Gym carts or mat carts work well.

Procedure

1. You will conduct this activity in an area designated by your teacher. In this activity you will be studying the effect that force and mass have on the motion of a cart. While one or more students are sitting on a cart, another student will apply a force on the cart by means of pulling on the bungee cord or a spring scale, which is held by a rider on the cart. If the bungee cord method is used, the force can be measured by the stretch of the cord. The student on the cart can hold a meter stick along the direction of the stretched bungee cord while the puller maintains a constant stretch of the cord. Use the following questions and directions to guide your investigation:

2. Read and discuss the following with your instructor before continuing:
   a) Does all of the force applied to the cart result in motion of the cart?

   b) How much force can you apply before the cart begins to move?

   c) Just before the cart begins to move, what is the net (sum total) of all of the forces on the cart?

3. Increase the force substantially above the force to overcome friction and maintain this force as long as you can possibly apply this same constant force on the cart. Describe this motion.

4. Design a method to compare the acceleration of various trial runs of the cart.

5. Identify the variables that you think will affect the acceleration (rate at which velocity changes) for a cart pulled along a path.

6. Formulate a hypothesis for a relationship between net force and acceleration of the cart.

7. Design an experiment to test your hypothesis. Organize all measured values into a meaningful data table.

8. Does your data support your hypothesis? Please explain.

9. Design another experiment to find how another variable may affect the acceleration of the cart. Again organize your data into a meaningful table. What can you conclude from your data?

Developing and Using Scientific Ideas

1. If you add mass to a car and maintain the same force through the engine, what effect does that have on the rate at which the velocity will change?

2. If a car travels along on a roadway at a constant velocity, what can you infer about the forces on the car?

3. How does acceleration seem to be related to force?

4. How does acceleration appear to be related to mass?

5. If a 3 N force were applied to the cart and rider and no movement results, how would you explain this?

Extending the Activity

Suppose a new Olympic event called the “5 Meter Sprint” were introduced. What would be the most important attributes of an athlete most likely to win the event? Defend your answer based on your observations in this activity. If we were to conduct this event among students in this class, who do you think would win and why?

CAN YOU CHANGE YOUR MOTION?
Concept Development

Problem

What factors do you think might affect the acceleration of an object?

Materials

Dynamics cart, laboratory masses or bricks, timing device, string, spring scales if needed

Procedure

1. You have described motion in your previous studies in terms of displacement, velocity, acceleration, and time. Think of some object like a bicycle, car, or a motorcycle. Identify the variables you think might influence the acceleration that these objects could attain.

2. You will attempt to model the factors that may affect the acceleration of this vehicle by using a dynamics cart. For each variable that you suggested may have an affect on the acceleration, conduct an experiment to determine whether it does affect the acceleration. You should run from three to five trials for each different value of this variable and determine and or record the acceleration for each trial in a data table.

Developing and Using Scientific Ideas

1. Using graph paper or a computer program graph your results. Describe the appearance of each graph.

2. What relationships exist between force and acceleration? Mass and acceleration? How do you know these relationships exist?

Extending the Activity

Consider a cart on a horizontal surface as shown in Figure 8.1. The cart is propelled by the falling mass. Construct a free-body diagram for both the falling mass and the accelerating cart. Use the diagram with equations to calculate the acceleration of the cart and the mass. Keep in mind that the falling mass and the cart are connected, which means both objects have the same acceleration. Does the calculated acceleration agree with the experimental value? Show all work.

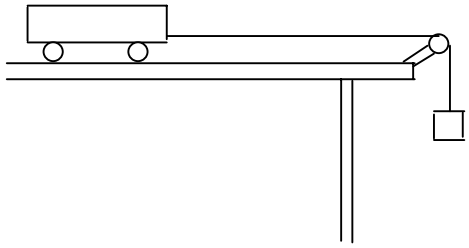

Figure 8.1

CONCEPT ENHANCER- NEWTON'S 2ND LAW

Variables that are Proportional

In the activity CARTS WITH A SPRING BALANCE, you explored the relationships between force, mass and acceleration in order to develop Newton's Second Law. In these activities you discovered the variables that affected acceleration. We call acceleration the dependent variable because it depends on the value of other variables such as force and mass. Force and mass are independent variables because we can change them by manipulating their values. In this activity when you pulled hard enough, the cart changed velocity. It accelerated. When you pulled still harder the cart accelerated again, but the rate at which the speed changed was increased (you got to a high velocity faster) or you could say you had a greater acceleration. You knew this by the way your feet had to move faster and faster so that you could keep the force constant. So force is directly related to acceleration. You also found that if you pulled on a more massive person that the acceleration was less. So acceleration is inversely related to mass. This can be summarized as

$$a = F/m,$$

which is a form of Newton's Second Law of Motion. The force in this equation is actually the net force acting on an object, which means that you have to add up all the forces on the object that you are trying to accelerate. This relationship is often solved algebraically for force and written as

$$F_{net} = ma$$

Acceleration is Directly Proportional to Force

This might appear to be a simple law but it has dynamic implications. In, CAN YOU CHANGE YOUR MOTION, when you began the experiment you had a small mass on the end of the string, which resulted in a force of tension acting on the cart. The cart (and the hanging mass) accelerated according to Newton's Second Law. As you added more mass to the string you increased the force due to the weight of the hanging mass that acts on the system of the cart and the hanging mass. The mass of the cart remained constant so the acceleration of the system increased.

$$F_{net} = ma$$

And as you added still more mass on the end of the string (and thus more force as weight on the end of the string), the acceleration got even larger.

$$F_{net} = ma$$

This is what is meant by a direct relationship. If you doubled something on one side of the equation, the other side also doubles. Triple one side – the other side also triples. Reducing one side by one half reduces the other side by one half.

Acceleration is Inversely Proportional to Mass

When you started adding more mass to the cart but keeping the force on the string (the weight of the hanging mass) the same, the acceleration reduced. Therefore mass and acceleration are inversely proportional. If one quantity goes up and the other goes down, the product can remain the same as in the case of mass and acceleration

$$F_{net} = ma$$

Net Force Revisited

Now lets look at net force again. Did all the force with which you pulled produce acceleration of the cart or skater? When you pulled on the cart you applied a force. If you pulled harder the cart would begin to move but at a steady or constant speed. A constant speed means the acceleration is zero. Doesn't this violate Newton's Law? Aren't you supposed to be accelerating? Zero acceleration means that the net force is zero, which means the sum of all forces on the cart is zero and therefore, any forward force has to be balanced with a retarding or negative force. This negative force is known as friction ($F_{friction}$), which opposes or acts in the opposite direction to motion. By definition

$$F_{net} = F_{friction} + F_{applied}$$

Be careful how you handle the signs. When you substitute a value for friction, it will be negative and therefore the net force will be the difference of the applied force and friction. The net force could also be called the accelerating force since it is the amount of force left over to accelerate you after you subtract friction from your applied (or pulling) force. So not all of the spring scale force (pulling or applied force) goes in to the acceleration. There will only be one unique value of the applied force that will cause zero acceleration and that is when the value is equal to friction.

Net Force and Terminal Velocity

Lets take another example – a rock falling downward. When the rock begins to fall it accelerates. Initially the only force acting on the rock is gravity or the gravitational attraction between the rock and Earth. This force of gravity on the Earth is defined as weight. So when you measure your weight, you are measuring the Earth's attraction for you.

As the rock speeds up air resistance becomes significant. Think about going for a ride in a slow moving car with your arm out the window what do you feel? Air friction. What happens to that air friction as you go faster and faster? It gets larger and larger. The same thing happens to the rock. For a falling object, the force of air friction pushes the object upward and the force of gravity pulls it downward. You can define up or down positive as you wish, but the forces will be in the opposite direction and when values are substituted into the equation you will be taking the difference in the two values to calculate the net force.

$$F_{net} = F_{weight} + F_{friction} = ma$$

As friction increases the net force decreases and therefore the acceleration decreases. Notice that the force of gravity doesn't change but yet the rock has a lower acceleration and the net force (accelerating force) is also smaller.

What happens if the frictional force equals the force of gravity? Wouldn't the net force become zero as well as the acceleration?

$$F_{weight} + F_{friction} = 0$$

So with no net force there is no acceleration. This is defined as terminal velocity. The rock still has forces acting on it but the forces are equal and opposite so there is no more speeding up (acceleration) for that rock but the rock is still moving. The average skydivers terminal velocity equals 63 m/s (227 km/hr or 141 mi/hr) downward before the parachute is opened. Once they open their parachute, their average terminal velocity is around 3 - 4 m/s (7 - 9mi/hr) downward

Weight and Mass

Is there a difference between mass and weight? Weight is a force and can be calculated using Newton's Second Law

$$F_{weight} = ma = ma_{gravity}$$

where a is the acceleration due to gravity (g).

If John's mass is 60. kg what would he weigh?

$$F_{weight} = (60.\ kg)(9.8\ m/s^2) = 590 \text{ but what is the unit?}$$

The unit for weight and for all forces is a Newton (N) so John would weigh 590 N. Since 4.4 N = 1 lb, John's weight in pounds would be about 134 lbs. Since force is a vector quantity, direction must also be included. Since the acceleration of gravity is directed downward, John's weight would also be directed downward. As a result, the force of gravity (or weight) acting on John would be 590 N or 134 lbs directed downward.

In the application activities, WHO HAS THE PULL AROUND HERE? and WHO PUSHED THAT SPEEDING CAR?, you will be provided with experiences to apply Newton's Second Law in situations that involve friction.

CONCEPTUAL PRACTICE

1. Galaxy Weight Loss Company had a great offer – lose 5/6 of your weight in two days. All you need do is travel to and live on the moon where gravity in 1/6 that of the Earth. What is wrong with this idea?

2. If an object is not accelerating, can you conclude that no forces are acting on it? Explain.

3. If we say that one quantity is proportional to another quantity does this also mean they are equal to each other. Explain using mass and weight in you example.

4. With your knowledge of Newton's Second Law, sketch graphs for the following scenarios:
   a. John is comparing the force on his bicycle pedal with acceleration while his mass remains constant in Figure 8.2.

   b. What is the likely relationship between the number of cars and mass of a train and its acceleration if the force delivered by the engine remains constant in Figure 8.3?

   c. Heather compares the weights of laboratory masses in Figure 8.4.

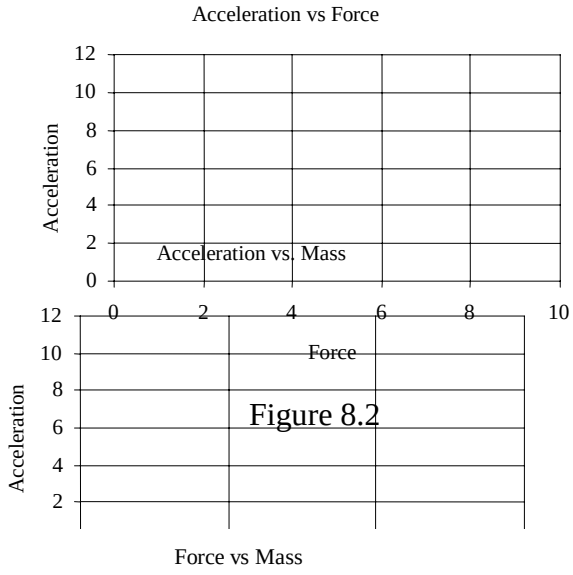

Figure 8.2

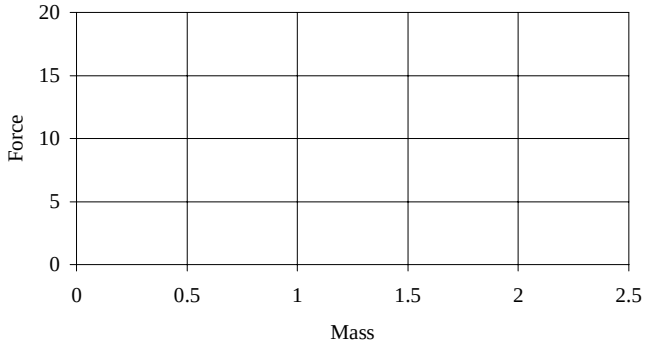

Figure 8.4

WHO HAS THE PULL AROUND HERE?
Application

Problem

How can you calculate the applied force and net force needed to accelerate a cart to a given final velocity? How can you determine the forces of friction that act on a cart?

Materials

Low friction dynamics carts, three 20 N spring balances, meter stick, two stopwatches

Procedure

1. In this activity you will push and accelerate a cart on a level surface. You are expected to determine the force that is required to produce the constant acceleration of the cart. From the definition of net force,

$$F_{net} = F_{applied} + F_{friction}$$

By pushing on the cart, you can cause the cart to accelerate and perhaps make measurements to calculate this acceleration. By knowing this acceleration and the mass of the cart and rider you can determine force. Which of the above forces would you be calculating? Explain your reasoning.

2. When you stop pushing on the cart it will coast, slow down and come to a stop. Which force is causing this negative acceleration? How could you determine the value of this force?

3. How can you find the value of the third force in the above equation?

4. Design a method of collecting data to determine the F_{net}, $F_{applied}$, and $F_{friction}$. On a separate sheet of paper show all of your original data in a well-organized table. Make sure to show all of your calculations.

5. Repeat the experiment using the same skater/puller team with 5 N to 10 N of additional force.

Developing and Using Scientific Ideas

1. What is the relationship between frictional force, accelerating force and the measured force?

2. Does it appear that frictional forces act during the first 10 m? Explain.

3. Derive an equation that will predict acceleration if mass, accelerating force, and frictional force are all known.

4. If an average net force of 50 N delivered by a bicyclist produces an acceleration of 1.5 m/s^2, what acceleration would you predict for the same cyclist on the same bicycle if she applied a net force of 75 N?

Extending the Activity

Observe various types of motion outside of class and return with descriptions of the events in terms of forces, velocities, changes in velocity, acceleration, and mass.

WHO PUSHED THAT SPEEDING CAR?
Application

Problem

How can you calculate the applied force and net force needed to accelerate a car or pickup truck to a given final velocity? How can you determine the forces of friction that act on a car?

Materials

Car, pickup truck or school van with operating horn and speedometer, two stopwatches, and a smooth level roadway or parking lot approximately one-city block long

Procedure

1. In this activity you, with the help of other students, will physically push and accelerate a car on a level area. You are expected to determine the force that is required to produce the constant acceleration of the car. From the definition of net force,

$$F_{net} = F_{applied} + F_{friction}$$

By pushing on the car, you can cause the car to accelerate and perhaps make measurements to calculate this acceleration. By knowing this acceleration and the mass of the car you can determine force. Which of the above forces would you be calculating? Explain your reasoning.

2. When you stop pushing on the car it will coast, slow down and come to a stop. Which force is causing this negative acceleration? How could you determine the value of this force?

3. How can you find the value of the third force in the above equation?

4. Design a method of collecting data to determine the F_{net}, $F_{applied}$, and $F_{friction}$. On a separate sheet of paper show all of your original data in a well-organized table. Make sure to show all of your calculations.

5. What was the average F_{net} per person pushing the car?

6. What was the average $F_{applied}$ per person pushing the car?

7. Does the value for the average $F_{applied}$ per person pushing the car seem reasonable? You might push on a bathroom scale on an appropriate wall space with the calculated force. Does it still seem reasonable?

8. Repeat the activity with another group of students as passengers in the car to increase the cars mass.

9. Predict how the accelerations will compare. What was the basis for your predictions?

10. Predict how the forces will compare. What was the basis for your predictions?

11. How did the accelerations compare? Discuss any differences from your predictions.

12. How did the forces compare? Discuss any differences from your predictions.

Developing and Using Scientific Ideas

1. Compare and interpret the magnitude of the net force with the frictional forces.

2. What are the measurements in this lab that might produce results with significant errors? How could you improve these measurements?

3. If an average net force of 50 N delivered by a bicyclist produces an acceleration of 1.5 m/s^2, what acceleration would you predict for the same cyclist on the same bicycle if she applied a net force of 75 N?

4. Sally, with her roller blades, has a mass of 50 kg. If there is a frictional force on Sally of 15 N, what applied force must Sally exert to provide her with an acceleration of 0.60 m/s^2?

Extending the Activity

Observe various types of motion outside of class and return with descriptions of the events in terms of forces, velocities, changes in velocity, acceleration, and mass.