SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

918

Newton's Second Law

October 1996
Adapted by: Stephen Druger

Contents

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

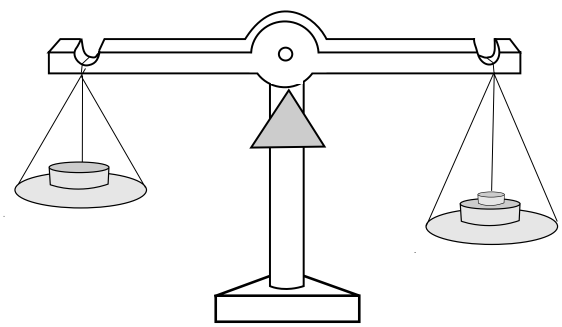
Science as Inquiry

Weighing the Masses

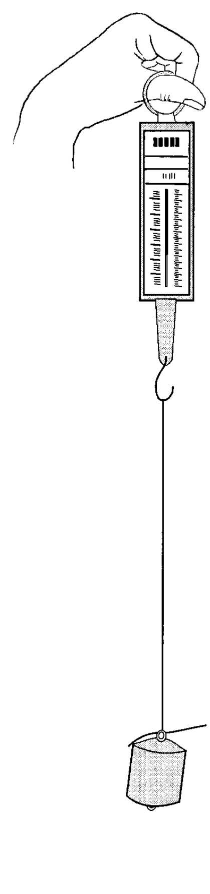
How is weight related to mass?

Overview:

In previous activities you used a balance to measure out different amounts of a particular substance. If you used a balance of the kind illustrated here, the amount of material was determined by comparing the force gravity exerted on the material with the force gravity exerted on a set of carefully constructed metal objects (referred to either as "masses" or more carelessly as "weights," depending on careful you are with your choice of words).



When we refer to the weight of an object in physics we mean how strong a force gravity exerts on it. Clearly, when using the beam balance the weight of a substance (meaning the force of gravity on the substance) is related to how much is being weighed. The question we will examine here is in what sense the weight of an object, the gravitational force it experiences, is related to the amount of the particular substance that forms the object. Some of what you see in this activity is exactly what you would expect, but there is something to be learned by thinking about why we see what we do.



Procedure:

Carefully adjust the spring balance so that the scale reads zero with the string attached. If the spring balance you are using is not adjustable in this way, then take its reading when only the string is attached and subtract that reading from any other readings to get the added force. Suspend a 0.1-kg mass from the spring balance. Note the reading on the scale in newtons and use a ruler to measure how far the indicator moved in centimeters. Now attach an identical mass so that twice as much matter is supported and record the scale reading and how many centimeters the spring inside the balance has been stretched by doubling the mass. Cut the string, allowing the masses to fall onto a newspaper or other cushioning beneath them. Note the new reading and whether the masses reach the ground at the same time if released together.

Questions:

1. When you doubled the “amount of matter” of the same kind supported by the spring balance, how did that change the length of the stretched spring? How did it change the reading on the scale?

2. What conclusions does this suggest about how stretching the spring depends on the force exerted on the spring?

3. What does this suggest about how the gravitational force on an object, meaning its weight, depends on the “amount of matter” making up the object, if the matter of the object is all of one kind?

4. How did the force the spring exerted on the masses to hold them in place compare with the force of gravity acting on the masses (or, in other words, their weight)? How do you know this?

5. When you released the mass by cutting the string, did the masses fall at the same rate or at different rates?

6. How does the force that speeds up the falling 0.1-kg of mass at the acceleration of gravity on Earth ($g = 9.8\ m/s^2$) compare with the weight of the mass?

7. Suppose you were trying to do an experiment involving two chemicals reacting with each other and you needed to measure out precise amounts of each one. If you used a beam balance and a set of masses to measure each substance, would the amount measured out be different if the force of gravity were changed (for example, by measuring it on the moon, whose gravity is weaker?) Why? And would it be changed under those circumstances if you used a spring scale? Why?

Science as Inquiry

Moving the Masses

How does a force affect an object free to roll?

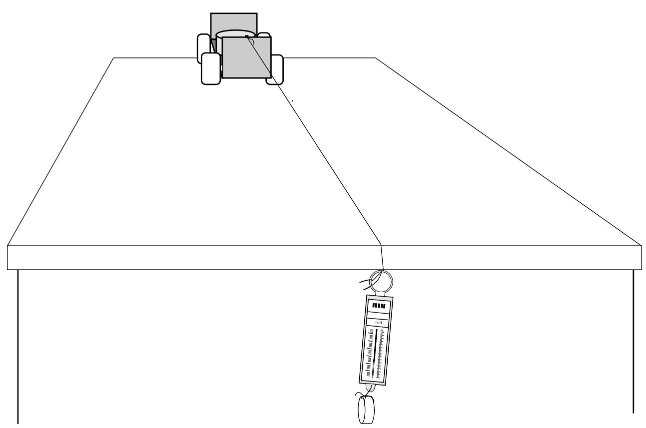
Overview:

It's a lot harder to push some objects to get them moving than others. Sometimes this may be because the frictional forces are different. A block of ice, for example, is much easier to slide along a smooth floor than an equally heavy piece of iron.

But there is also another reason that objects respond differently to a force. We saw in previous activities that objects tend to resist changes in their motion. It takes a force to get an object moving in a straight line, to make it stop moving, or to make it move in a different direction. In the present activity we will look at this particular kind of resistance to changes in motion, or "inertia," in greater detail.

Here we examine how a laboratory cart reacts to a force applied to it, depending on whether it has some large objects added to it as cargo or not. Since we will be looking for effects other than friction that may control the cart's response to a force, and since as far as we know the friction in the wheels could be different if the cart is carrying a heavy object, we will also have to check for changes in frictional forces as part of the experiment.

Procedure:



Tie a spring balance to the cart with a string and measure what force it takes to pull the cart at a steady rate against the friction opposing it. Be sure the string pulls horizontally. Then add an extra 1.5 kg and try again. Is there a significant difference? Record the forces you measure.

Next, tie a string to the cart and suspend the string over the end of the worktable. Hold the cart in place by hand, or by placing an object in its path, and hang a spring balance supporting a much smaller mass from the dangling end of the string (see figure). An obstacle should be placed near the end of the table to stop the cart from rolling over the edge.

Release the cart, letting the hanging spring balance and attached mass set it in motion. Watch carefully to see whether the reading of the balance appears to change significantly when the cart is allowed to roll. Is the force being applied to the accelerating cart about the same as or substantially different than the force measured with the stationary cart?

Now remove the scale and allow the cart to be pulled by the string and its attached mass. Time how long it takes the cart to reach the obstacle at the edge of the table. For the second trial, add an extra mass to the cart and time it again.

To get more meaningful results corrected for friction, calculate the slight extra force, if any, that was needed (in addition to the force for the empty cart) to pull the cart carrying the cargo. Use the spring balance to measure the right combination of small extra masses whose weight is equal to this extra force.

Then do a third trial with this extra weight also pulling the cart with cargo. Skip this last trial if you could not find a significant difference in friction opposing the motion of the empty and cargo-bearing carts.

Questions:

1. Unless you had very high-quality wheel bearings on the cart, you probably found that it took some applied force to keep it moving. But an object moving on a smooth sheet of ice seems to keep moving in a straight line without anyone having to keep applying a force. Why would a small force be needed now just to keep the cart moving?

2. How significant is the force needed to keep the cart moving at the same speed compared to the force exerted by the hanging weight that sets the cart into motion?

3. If there were no friction within the wheel bearings or elsewhere to oppose the motion of the cart, how would that affect the force needed to keep the cart moving at a steady rate?

4. Did the force that was applied by the small hanging weight, as measured by the spring balance, change significantly when the cart (and cargo) was accelerated by the weight on the string compared with when it was stationary?

5. What then can you conclude about the force exerted on the cart with the heavy cargo compared with the force exerted on the empty cart? Is one force much greater than the other or are they both about the same? How do you know this?

6. Which cart gained speed more rapidly, the empty cart or the cart with the extra cargo?

7. In the sense that the term “massive” is commonly used, which cart was more massive?

8. The concept of “mass” as used by Newton was, in the same sense as the everyday word “massive," a measure of the “amount of matter,” so that if we placed one cart on top of another as cargo the mass being moved would be doubled. What does this activity tell you about how the acceleration of an object in response to a force depends on its mass? Does an initially stationary object speed up faster in response to a force if its mass is large or small?

9. A more precise meaning of “mass” in physics is how much an object reacts to a force by changing its motion. So then how does the force needed to speed up an object in a particular way depend on its mass? Is the force greater for the large or small mass?

Science as Inquiry

It’s a Downhill Battle

How do changes in mass affect rolling down an incline?

Overview:

Suppose a small lab cart is placed on a road that slopes down a hill. You would expect to have little trouble holding the cart with one hand to keep it from rolling. But you would expect plenty of problems trying to use the same one-handed method to keep a tractor-trailer truck with no brakes from rolling down the same hill.

In this activity we will examine what determines how much force is needed to keep objects of different masses from rolling down an incline. This will tell us what force is acting to make an object start rolling and how that force depends on the mass.

The previous activity suggests that even if the force were the same for two different masses free to roll downhill, the effectiveness of the force to set them in motion would also depend on the mass of each object. So really there are two ways in which mass is a factor. The force of gravity changes if the mass is changed, but for any particular force its effectiveness in making the cart roll changes as the mass of the cart (and therefore its inertia) changes.

Observing how quickly carts of different mass gain speed when allowed to roll then leads to information about certain laws of motion.

Procedure:

Place a cart on an inclined plane. This may be a worktable with its legs propped up on one side. The plane should be tilted enough so that the initially stationary cart will roll, but not so much that the time it takes to reach the end of the surface is too short to measure.

Start with the cart held by a string, which in turn is held by a spring balance, and thereby measure the force being exerted by the spring balance along the direction of the incline to keep the cart from rolling. Also measure the mass of the cart. Repeat the procedure with an extra 0.1-kg mass added.

Now place the empty cart at a mark on the incline and time how long it takes to reach a lower marked point. Repeat the experiment a few times, averaging your results. Then repeat the entire process with the extra mass added to the cart.

Questions:

1. Based on the previous activity, would you expect the cart with the greater mass to have more, less, or about the same resistance to being set into motion by the same force?

2. How did the force needed to keep the cart from rolling downhill change when the mass was increased? Did it increase or decrease, and by what precise factor?

3. How does your answer to the previous question compare with the ratio of the two masses involved (that of the empty cart and that of the cart with the extra mass)?

4. Was the average speed of the cart with the extra mass greater or less than that of the empty cart, or was it about the same?

5. If the force causing the cart to roll down the incline changed in the way you described when its mass was changed, and the average speed of the carts was affected or unaffected as you observed, what can you conclude about how resistance to changes in motion because of mass depends on the value of the mass? Explain your reasoning in your answer.

6. More precisely, what was the ratio of the two masses (empty and cargo-bearing carts) rolling down the incline and what was the ratio of the forces you measured for the two cases? How do they compare?

7. Assuming that the pattern in the previous question always holds, by what factor would you expect the force pushing the cart along the incline to change if the mass of the cart plus its cargo is tripled? Suppose that such a change in force produces no change in acceleration and speed for the cart. What does that mean for how the acceleration for a particular force changes if the mass is tripled? How would that explain what was seen in this experiment?