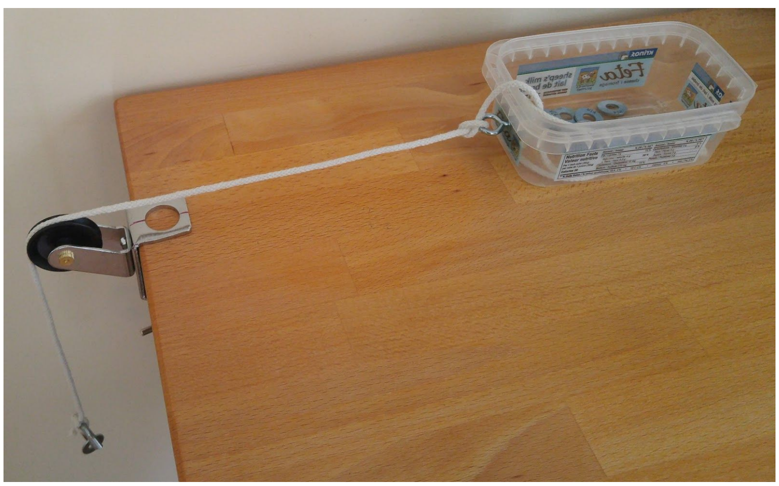
Forces and Friction Facilitator guide

Learning objectives

- Forces affect the motion of objects. The larger the force, the greater the effect on the motion.
- Friction is one type of force.
- Two forces can both be acting on an object at the same time. These might cancel each other out, or they might cause the motion of the object to change.

Materials



Setup with pulley

Per group:

- Plastic box (e.g. a recycled container) with eye hook attached
- Cord tied to an s-hook
- Washers (around 10)
- Table clamp pulley (optional - can also let the cord hang over the edge of the table or a book placed at the edge of the table)

Note to Physics Matters volunteers: some of the boxes have an additional eye hook on the opposite end of the box to allow for two competing forces from different ropes. See extensions for ideas on how to use this for a longer activity.

Alternate setup without pulley - let the cord hang over the edge of the table. Use a book with a slippery cover to further reduce friction between the cord and the surface it’s in contact with.

General tips

- Help the students tie to the cord to the box.
- If using pulleys, help students attach the pulley to the table.
- If not using pulleys, students may need to use more washers on the hook in order for the box to move. If friction between the cord and the table is too high, a smooth book can be placed on the edge of the table (see picture of alternate setup.)
- Use hot glue on the inside of the box to hold the eye hooks in place. Cover the sharp end of the s-hook by gluing a water or juice cap to the inside of the box.
- If possible, test out the experiments ahead of time, and specify the appropriate number of washers on the hook or in the box for each experiment.

Experiment 1: what is a force?

1. **ENGAGE** Probe students on what they already know about forces.
    a. Questions to ask include: What is force? How do forces cause things to move?
    b. Ask students if they have ever been pulled in a sled. What forces are acting on the sled?

    c. Show an example of how a physicist draws a model of a force acting on a box. Ask students to draw a picture that shows the force(s) on a sled. (See worksheet.)
2. Help students set up the first experiment. Ask them to make a prediction about what will happen when more washers are added to the hook.
3. **EXPLORE** Have students test their prediction by adding washers to the hook and circling or writing their observations. Have them describe how the number of washers on the hook affects the strength of the force.
4. **EXPLAIN** that a force is a push or a pull. In this case the cord is pulling on the box forward, and friction is pulling the box backwards.
5. If not brought up by a student, ask whether the speed of the box changed, or if it was constant. Forces cause changes in motion: the box went from not moving, to moving because of the difference between the pull of the cord forward and the pull of friction backwards.
    a. One subtlety that may come up: objects that are moving and have no net force acting on them will remain moving, but it's possible that a force is what caused the object to start moving in the first place. For example, if I have a friend push me while I'm wearing ice skates, it will cause me to go from not moving to moving, but once I'm moving I'll remain moving for a long time because the ice has low friction and so the net force is small.

Experiment 2: can you get the box to move more slowly?

1. **ENGAGE** Ask students how they can make the box move more slowly when there are a set number of washers on the hook (use the highest number of washers from the first experiment) using the materials available. Have them brainstorm ideas as a group.
2. **EXPLORE** Ask them to choose one or two ideas and test them, writing their observations in the table. Have them to explain their observations.
3. **EXPLAIN** Ask students to describe their observations, and collect the results for the entire group on a blackboard.

Experiment 3: How does mass affect motion?

1. **ENGAGE** Tell the students that you are now going to explore two of their ideas from experiment 2 further. First, you will try changing the mass of the box. Ask how the number of washers in the box might affect the motion of the box. For example, what happens if there are more passengers in a sled?
2. **EXPLORE** Have students put a set number of washers on the hook, and try placing different numbers of washers in the box. Have them compare the motion of the box in each trial. Have them explain their observations.

3. **EXPLAIN** If students believe that the force changed, ask them to think back to experiment 1 - how did they make a stronger force? How did they make a weaker force? Alternatively, have them think about pushing a wooden block or a concrete block across the floor. If they push as hard as they can, what will happen to the two blocks?
4. Reiterate that the same force will change the motion of a lighter box more than a heavier box: the force is the same, but the response to the force depends on the mass of the object.

Experiment 4: how does friction affect motion?

1. **ENGAGE** Ask what would happen if a sled hits a patch of grass? If no one brings up friction, ask them what they know about friction? Have them feel the sandpaper and table and compare. Tell them that now we will explore how the surface affects the motion of the box.
2. **EXPLORE** Older kids can choose the number of washers on the hook and in the box (it should be specified for younger kids). Tell them to leave this the same, and compare what happens when the box is placed on the table and sandpaper. Ask them to explain their observations (see worksheet.)
3. **EXPLAIN** that friction is a property of two surfaces which are in contact. The greater the contact, the greater the friction, but it also depends on the roughness of the surfaces.
4. If any student thinks that the total force on the box is larger when there is friction, ask them to think about the motion of the box. In which case was the change in motion greater? What does this tell you about the force? (Greater changes in motion are caused by stronger forces.)
    a. This explanation is getting at the relationship between force and acceleration (F=ma.) Older students may benefit from a discussion about acceleration and the presentation of the equation F=ma.
    b. Some students may understand an explanation based on net force better: There are two forces, the force of the rope pulling on the box, and the force of friction. But the force of friction is opposing the motion, so it points in the opposite direction, and therefore these two forces are subtracted from one another to get the total force. So the total force is smaller when there is a larger force of friction, leading to a smaller change in the motion of the box (or no change in motion at all if the force of friction equals the force pulling the box forward.)

Summarize the activity

1. Have the students revise their force diagram from the first part of the activity. Did they make any revisions based on what they learned?
2. Discuss and summarize findings as a class. Suggested discussion questions:
    a. Did any group encounter a situation when there was a force acting on the box, but the box wasn't moving? In this scenario, what forces were acting on the box?

Why didn't it move? (Was one force bigger or smaller (which one) or were they the same size?)

b. Did you miss any forces in your diagram of the dog sled from the beginning? If so, which one(s)? Change your diagram to show all of the forces that you know about now.
c. If the angle of the force is brought up (either in the drawing or one of the experiments) discuss how the part of the force that is to the right is what causes the rightward motion. Ask: what is the effect of the upward/downward part of the force? (The upward part of the force on the sled is counteracted by gravity and may cause a bobbing of the sled as the person's arm swings.)
d. Students may have encountered a situation where the cord is dragging on the table and caused the box not to move. Ask them if they think this is a type of friction? Why or why not?

Extensions

- Test student understanding with a **discussion** of snow and ice. Questions to ask: Does snow have friction? Does ice have friction? What kind of experiment could you do to test your ideas about the friction of ice?
- **Discuss** what would happen if there were no friction.
- **Discuss** other situations that might make use of friction and forces. Questions to ask: What other forces do you know about? Why do wheels roll?
- Show **videos** from space to demonstrate a zero-friction situation.
- Show **simulations** with and without friction (e.g. https://phet.colorado.edu/en/simulation/forces-and-motion)
- **Discuss** the difference between kinetic and static friction.
- **Discuss** the conversion of potential energy (of the s-hook and hanging washers) to kinetic energy (of the entire system: washer, hook, rope, and box, as well as the spinning wheel on the pulley, if using.)
- Use the materials in this module (may need extra hardware and pulleys) for another **experiment** on competing forces: For each setup, add a second hook to the opposite side of the boxes and another pulley on the opposite end of the table so that the two ropes are pulling in opposite directions. Have students look at the effect of different numbers of washers on both sides. Is it the total number of washers that makes difference or the difference in the number of washers?

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