LIGO Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

Fan Cart (Modified from Exploratorium's Teacher Institute)

Grade[a](s): Upper elementary to middle school

Topic: Newton's Third Law
(and aspects of force and motion)

Standards:

Disciplinary Core Ideas: Physical Science – Forces and Interactions

For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). **(MS.PS2A.a)**

The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion (acceleration) **(MS.PS2A.b)**

Science and Engineering Practices:

Asking questions and defining problems
Planning and carrying out Investigations
Engaging in argument from evidence

Objective: Learn how Newton's Third Law applies to different conditions.

Materials:

2 plastic drinking straws
Hot-glue gun and glue sticks
Four beveled faucet washers (1/4L, 19/32 O.D.)
Two 3/16 wooden dowels (14 & 16.5 cm long)
Styrofoam plate
Electric drill and bits (1/8" and 5/64")
1.5-3.0 V DC hobby motor
A two-blade 6-inch plastic propeller
Safety goggles
10 x 26 cm project board,
Four CDs for wheels
One 1/8-inch wooden dowel (about 28cm long)
Wood block (5 x 5x cm)
Cable with with mounting head for screw (19 cm)
Two wood blocks (1 x 3 x ¾" & 2 x 3 x ¾")
Phillips pan-head sheet-metal screw (#8 x ¾")

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Materials (continued)

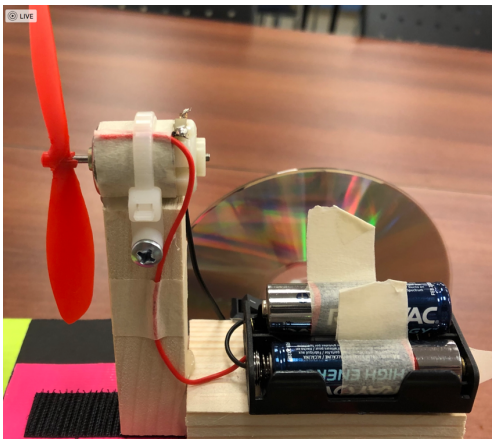
Phillips screwdriver
Two AA batteries
Ruler
One mini alligator clip (optional)
Battery holder for two AA batteries
Sticky-back Velcro (about 10 inches)
Scissors
Needle-nose pliers (optional for the alligator clip)

Advanced Preparation:

Cut straws to 11.5cm and 14.5cm lengths. Carefully hot glue straws to the project board about 2.5cm (or 1 inch) from each end that will act as bushings for the wooden axles. Hot-glue can and may melt the plastic straws, so put the glue on the poster board instead of the straws.

Insert the wooden-dowel axles into the straws and carefully assemble the washers and CD wheels onto the dowel axles. Check to make sure the wheels turn freely in the straw bushings.

Drill a 1/8-inch hole in the center of the 5 x5 cm square wood block for the mast-and-sail assembly. Insert the 1/8-in dowel into the square block for the mast and add the Styrofoam plate for the sail. (Optional: draw a design on the sail while waiting)



Tighten the cable tie around the motor. Cut off the excess. Use the 1/8 drill bit to drill a pilot hole for the sheet-metal screw 1-cm down from the top of the 1 x 3 x ¾" block.

Use caution when you hot glue the 1 x 3 x ¾" wood block to the 2 x 3 x ¾" wood block making sure the sheet-metal screw hole is on the side of the 1 x 3 x ¾" vertical wood block and not facing the front or back side.

Use caution when you hot-glue the battery holder to the 2 x 3 x ¾" horizontal wood block.

Wrap a long piece of masking tape around each AA battery so that you have an extra length of tape to give something to help removing the batteries from the holder.

Motor and propeller assembly:

The combination of the motor and propeller shape determines which direction the propeller pushes the air. If air is being pushed backwards when you turn on the motor, reversing the connections (wires) should reverse the direction the motor spins so that the propeller pushes air forwards. (*You can also try to reverse the direction of the batteries!).*

Optional: If you have an on/off switch that you want to attach to the circuit (we are using the alligator clip and or pulling the battery out as an on/off switch), See Safety Precautions on page 5 for correct way to install switch.

Activity[A]: To do and notice

Investigation 1: Attach the sail to the cart, attach the fan so it blows air toward the back of the cart away from the sail. Before turning on the fan, predict what you think will happen and then observe what happens.

Investigation 2: Adjust the fan so that it is attached to the cart but blows air towards the front of the cart (where the sail is). Remove the sail assembly (or pull the sail all the way up so when you turn on the fan, the air is not blowing on the sail. Make your prediction before you turn on the fan and observe what happens!

Investigation 3: Replace the sail back onto the cart (or move the sail down the wooden dowel) and this time remove the fan assembly from the cart, and hold it in your hand while it blows air toward/onto the sail. Make your prediction and observe what happens.

Investigation 4: Attach the fan assembly back onto the cart so that it blows air toward/onto the sail. Predict what will happen before you turn on the fan and observe what happens.

Investigation 5: Similar to Investigation #4, with the fan and sail both attached to the cart and the fan blowing air towards the sail. Hold a file folder (or a stiff piece of paper) between the fan and the sail (but not touching either one!) and observe what happens.

Underlying Science:

Here is a summary of the results to be expected for the investigations above:

1. Cart moves forwards.
2. Cart moves backwards.
3. Cart moves forwards
4. **Cart does NOT move!** (You did nothing wrong here…)
5. Initially the cart doesn't move, but when the file folder (or stiff piece of paper) is in place, the cart moves backwards!

The behavior of the cart is a classic example of Newton's Third Law:

For every action, there is an equal and opposite reaction.

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More Explanations

Investigation 1: By physically reversing the fan, the fan pushes the air backward and air pushes the fan forward. Since the fan is attached to the cart, the cart moves forward.

Investigation 2: The fan pushes the air forwards and the air pushes the fan backward. Since the fan is attached to the cart, the cart is pushed backward.

Investigation 3: The fan pushes the air forward and the air pushes the fan backward. But the fan is in your hand and not attached to the cart, there is no effect on the cart for this action-reaction pair. The air pushes the sail forward and the sail pushes the air backward. Since only the sail is attached to the cart, the cart moves forward.

***Investigation 4*:** The fan pushes the air forward and the air pushes the fan backward. (A crucial thing to keep in mind is that action and reaction forces, often called an action-reaction pair, do not act on the same object.) If this was all that was happening, the cart would move backward: The fan is being pushed backward, and since it is attached to the cart, the cart is also pushed backward. The sail is set in place, so there is a second action-reaction pair, with the air pushing forward on the sail and the sail pushing backward on the air. In this situation, there are two forces exerted on the cart: air pushing backward on the fan, and air pushing forward on the sail. These two forces balance each other, and the cart **does NOT move!**

Investigation 5: Initially, the cart is in the same configuration as in *Investigation 4*, so it doesn't move. However, when a barrier is inserted between the fan and the sail (without touching either one), then the first action-reaction pair is the same as in *Investigation 1*: The fan pushes the air forward, and the air pushes the fan backward. In the second action-reaction pair, the air pushes the file folder forward, and the file folder pushes the air backward. But the only force in the two reaction pairs that acts on the cart itself is the force on the fan, which is connected to the cart, so the cart moves backward.

Further challenges: What do you think would happen if the sail was moved part way up, so that the fan was only blowing onto half the sail, a quarter of the sail, ¾ of the sail?

Try using a 3-inch double-blade propeller, or a triple-blade propeller.

LIGO Connection: LIGO's interferometer is very sensitive to environmental conditions. Every time a car pushes on the ground it accelerates the ground, which accelerates parts of LIGO, causing things like the mirrors in LIGO to start accelerating. That's why LIGO uses seismic isolation systems in order to keep these forces from getting to the interferometer parts (such as the mirrors). There is even an action/reaction pair with the light! When the light reflects off of the end mirror, it actually pushes the end mirror the opposite direction - just like a ball hitting a pendulum!

Resources: https://www.exploratorium.edu/snacks/fan-cart

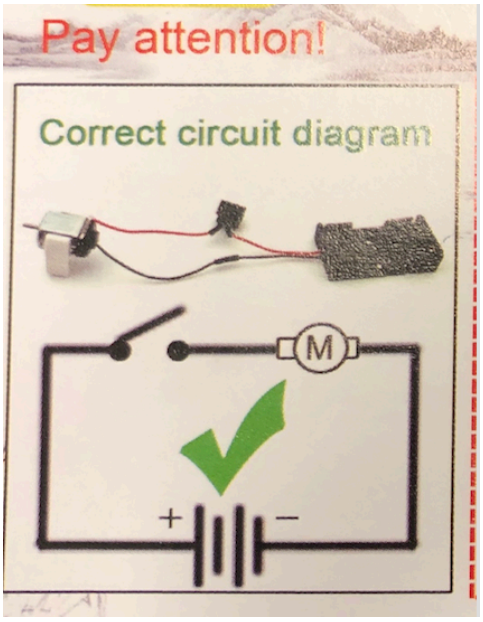
Safety Considerations:

Use caution when working with hot-glue guns (especially the very high-temperature guns!)

Use safety glasses when working with hand-drills.

Avoid any short-circuits by wrapping electrical tape (or use shrink wrap) around exposed wire connections.

*Diagram for inserting a switch correctly to prevent a short-circuit!



‘Harder-to-find’ materials list

(In no particular order)

Cable-ties

Beveled Washers

Alligator Clips

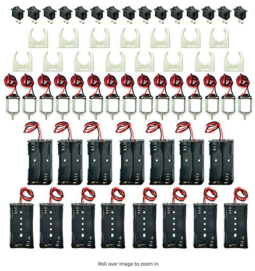
Metal screws

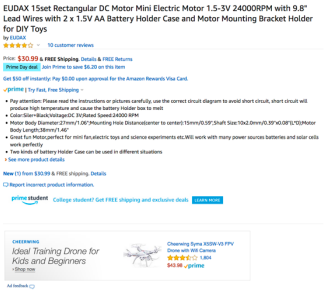
1 x 1 inch square dowels (Lowe’s)

Materials bought off of Amazon or eBay

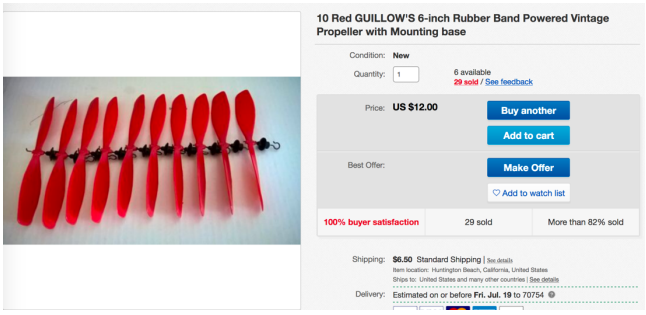
1.5 v motors, AA battery holders and on/off switches

Small print: EUDAX 15 set Rectangular DC Motor Mini Electric Motor 1.5-3V 24,000RPM with 9.8” lead wires with 2 x 1.5V AA battery holder case.





6-inch double-blade propellers



Optional: 3-inch mini CDs