CHALLENGE 5
LEADER NOTES

INVISIBLE FORCE

CHALLENGE: Design a setup so that when a steel ball rolls past a magnet, it changes direction and hits a target that's off to the side.

LEARNING GOALS: *Science:* Magnetism, inverse square law; *NASA*: Gravity-assisted travel; *Engineering*: Design process

NASA CONNECTION: Many spacecraft fly close by a planet or moon to use its gravitational pull to change speed and direction. This "gravity assist" also greatly reduces the fuel required to navigate a spacecraft.

GET READY AHEAD OF TIME

- **Magnets**. The best magnets for this activity are the silver, three-inch-long, oblong magnets sometimes called "cow" or "snake-egg" magnets. If you use disc magnets, kids may need to stack a few to produce a strong magnetic field.
- **Steel balls.** Bike stores sell the 60-millimeter (quarter-inch) ball bearings used in this activity. Slingshot ammo is 80 millimeters (5/16 inch) and is also an option. Balls larger than this build up so much momentum that they don't respond well to weak magnetic fields.
- **Make a physical guide.** In Step 2, kids use a rope to guide the ball's motion. Cut a 30-centimeter (12-inch) length of clothesline per team. Wrap the ends with tape to keep the rope from unraveling and forming a flare that interferes with the ball traveling smoothly along the rope.
- **Get the videos.** Go to pbskids.org/designsquad/links/solarsystem. Download the *Invisible Force,* Victoria Garcia, and NASA videos. Be prepared to project them. If you're unable to show videos, review the handout's overview and steps and tell kids about the NASA work described in the overview and in Step 1.
- **Photocopy.** Copy the handout and performance assessment rubric.

MATERIALS (per team)

Invisible Force works well with teams of two.

- Paper cup (6- to 8-ounce)
- Strip of index card (2.5 x 12.5 centimeters [1 X 5 inches])
- 30-centimeter (12-inch) length of flexible rope (e.g., clothesline)
- 1 steel ball (e.g., 60-millimeter [quarter-inch] ball bearing)*
- 1 strong magnet**
- 1 target (e.g., "X" of tape on the table or object to hit [e.g., a glass, coin, cup, etc.])
- Tape (any kind)

** Available at bike stores. Slingshot ammo from sporting-goods stores works, too.*

*** Available at toy, dollar, craft, and office supply stores.*

1 INTRODUCE THE CHALLENGE (10 minutes)

Set the stage and give the NASA context

- Explain that gravity is a force present in all things and that planets and moons exert a gravitational pull on spacecraft that pass close by.

- Spacecraft use small onboard rockets to make minor course corrections. Big corrections require a lot of fuel, which is heavy to carry. Instead of using rockets, NASA engineers use a planet's or moon's gravity to increase a spacecraft's speed and "steer" it by changing its direction. This process is called a "gravity assist."
- Tell kids that today they will do something similar to what NASA does, but instead of using gravity to steer a ball, they'll use a magnetic force. Then show kids the *Invisible Force* video.

Kids roll a ball down a ramp and use a ROPE to guide it over to a target.

2 STEER THE BALL USING A PHYSICAL GUIDE (10 minutes)

- Get a ramp, piece of rope, and steel ball. Place a target right in front of the ramp. Ask: What will happen when I roll this ball down the ramp? *(The ball will hit the target.)*
- Next, place the target 15 centimeters (6 inches) to the right of the ramp. Ask: What will happen now? *(The ball will roll past the target.)*
- Ask: How can I use this rope so the ball hits the target? *(Curve the rope from the end of the ramp over to the target.)* Follow kids' suggestions to hit the target with the ball.
- Emphasize that kids can change the ball's speed—it goes faster when released from the top and slower when released from the bottom. Release the ball from different points on the ramp to show that a ball needs a certain amount of energy to make it to the target.
- Challenge kids to put the target in "wacky" locations around the ramp and use the rope to guide the ball to the target. By trying different speeds and rope shapes, how creative can they get?

3 DISCUSS THE GAME'S KEY POINTS (5 minutes)

Stop kids' play by asking them to stick the ball to the magnet and come over to a demo area.

- **Path shape.** Without a guide, how will the ball travel once it leaves the ramp? *(Straight)*
- **Off-center positions.** What were the "wackiest" target positions that your ball hit?
- **Speed and energy.** How was the ball's speed affected by where you released it? Why is the ball's speed important? *(The greater the speed, the greater the momentum. Momentum gives the ball energy to roll to the target.)*
- **Consistent results.** It's helpful to tape the ramp in place and release the ball cleanly (e.g., hold it back with the tip of a sharp pencil).

Set the ball on the magnet. It will move to the pole—the strongest part of the magnetic field. Make a loop of duct tape and stick it at 90 degrees from the pole. Have kids tape their magnets to the table so the pole is in the same plane as the rolling ball.

4 STEER THE BALL USING A MAGNET (5 minutes)

Tell kids that their new challenge is to replace the rope with a magnet that will guide the ball. Set the rope aside. Tape down a strong magnet.

- Ask: How does this system compare to the one with the rope? *(The magnet replaces the rope. Its magnetic force will change the path of the ball. Otherwise, the setup is similar.)*
- Ask: How big is the zone around the magnet that can affect the ball? *(Small)*
- Ask: How are the ball's speed and distance from the magnet related? *(A slowly moving ball has less energy than a fast-moving one, and the magnet can capture it more easily. A faster ball can travel closer to the magnet without crashing.)*
- How is this small zone like the Goldilocks story? *(Too close and you crash. Too far and you get lost. Just right and the ball curves and hits the target.)*

5 BRAINSTORM AND DESIGN (5 minutes)

- How will you control how fast the "spacecraft" travels? *(Change the release point on the ramp.)*
- What will you do if the spacecraft always crashes into the "planet?" *(Aim farther from the magnet.)*
- What will you do if the spacecraft zips right by the planet? *(Aim closer to the magnet.)*

Kids roll a ball down a ramp and use a MAGNET to guide it over to a target.

6 BUILD, TEST, EVALUATE, AND REDESIGN (15 minutes)

If any of these issues come up, ask questions to get kids thinking about how they might solve them.

- **If kids can't consistently launch a ball…** Stabilize the ramp by taping it to the table. Also tape the ramp to the cup.
- **If the ball rolls in random directions…** Crease the ramp's index card more. Too wide an opening lets the ball go in different directions.
- **If kids can't find the "zone" around the magnet…** Tell them that a magnet's strength drops off quickly with distance. Also have them experiment with the ball's speed.

7 DISCUSS WHAT HAPPENED (10 minutes)

Emphasize key elements in today's challenge by asking:

- **Engineering:** How did testing help you decide how to change to your setup? *(Answers will vary.)*
- **Science:** Why did your ball change direction? What did you have to do to get it to change direction? *(The ball passed through a magnetic field. To change the path, the ball has to pass close enough to the magnet so the magnetic force affects the path of the ball.)*
- **NASA:** What part of the model represents the launch pad, spacecraft, gravity, and the planet or moon? Is the rope or magnet a better model of how spacecraft travel? *(There are no physical guides in space, but there are invisible forces. The magnetic field is a stand-in for gravity.)*
- **Career:** Show kids the engineer profile featuring Victoria Garcia. As an aerospace engineer, she uses virtual-reality tools to design effective spaces for astronauts living and working on a spacecraft. Download the profile sheet for fun facts, discussion prompts, and extension ideas.

EXTEND THE CHALLENGE

- **Sharpest turn.** Which team can consistently achieve the largest change in direction of the launch path? Can anyone do better than a 90° bend? Which team can consistently hit the target?
- **Go longer.** Find a large, level area. Challenge teams to hit a target that is at least 30 centimeters (1 foot) away. Next try 60 centimeters (2 feet) away.

CURRICULUM CONNECTIONS

Use *Invisible Force* to engage, explain, and extend student understanding of the following topics:

- **Inverse square law.** For an explanation, see page 26.
- **Newton's 1st Law.** Unless acted upon by an outside force, objects in motion tend to stay in motion, and objects at rest tend to stay at rest. This law is key to understanding how spacecraft move and navigate from Earth to their targets billions of miles away. Newton's 1st law says that a spacecraft will travel in a straight line and at the same speed forever unless an outside force acts on it. NASA often uses gravity assists to supply the force necessary for changing a spacecraft's direction and speed.
- **Newton's 2nd Law.** As with the magnet, the closer the spacecraft passes to the planet or moon, the more force will be exerted. As more force is applied to spacecraft, its acceleration—its speed and/or direction—changes. There is a direct proportion between the two quantities.

INVISIBLE FORCE

To make changes in a spacecraft's speed and direction, NASA often uses gravity. To get what's called a "gravity assist," NASA passes a spacecraft close to a planet or moon. The strong gravity changes the spacecraft's speed and direction.

CHALLENGE 1

Roll a ball down a ramp and use a ROPE to guide it to a target that's set off to the side.

1. BRAINSTORM AND DESIGN

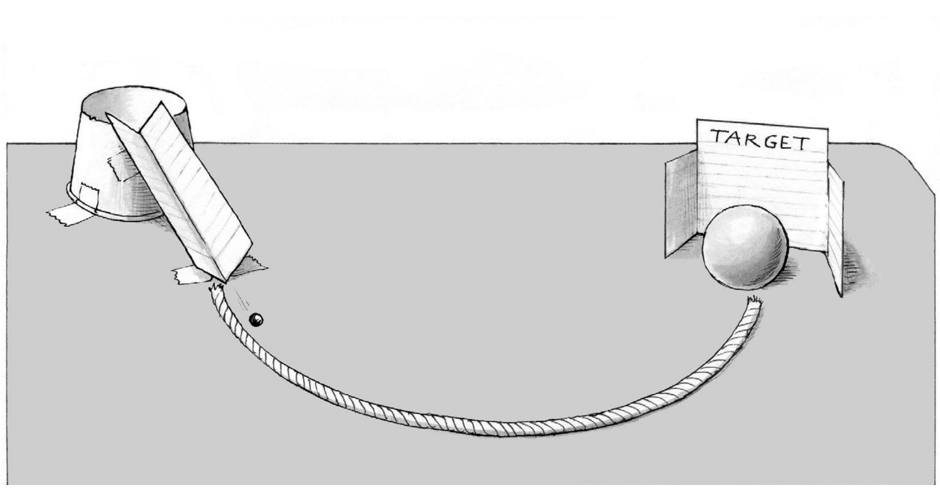
- How should you line up the rope with the end of the ramp so the rope can guide the ball?

2. BUILD AND TEST

- Taping the ramp in place is very helpful for consistent results.
- You can change the ball's speed by launching from different places on the ramp.

3. EVALUATE, REDESIGN, AND RETEST

- What were the "wackiest" target positions that you could hit with your ball?



MATERIALS

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- 1 strong magnet
- 1 target (e.g., "X" of tape on the table or an object to hit)
- Tape (any kind)

WORDS TO USE

- **magnetic field:** *The area around a magnet where a magnetic force can be detected*
- **gravity assist:** *Using a planet's or moon's gravity to change a spacecraft's direction and speed*

CHALLENGE 2

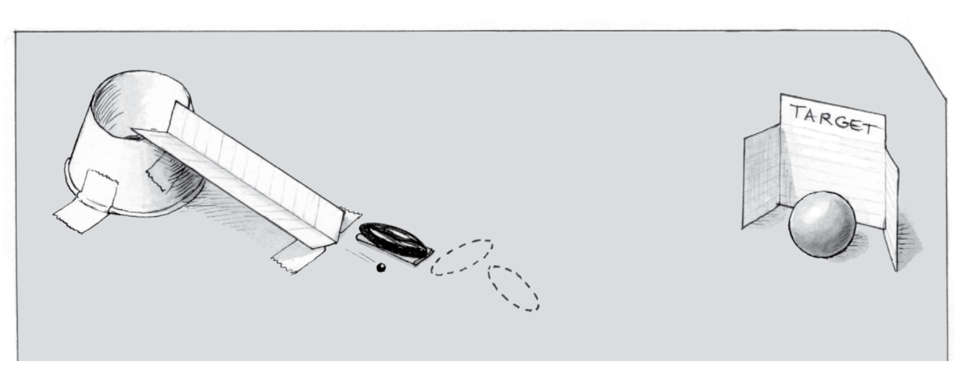
Roll a ball down a ramp and use a MAGNET to guide it to a target that's set off to the side.

1. BRAINSTORM AND DESIGN

- Where should you tape the magnet so the ball's path curves?

2. BUILD AND TEST

- Find the right speed and distance from the magnet so the ball curves over to the target.

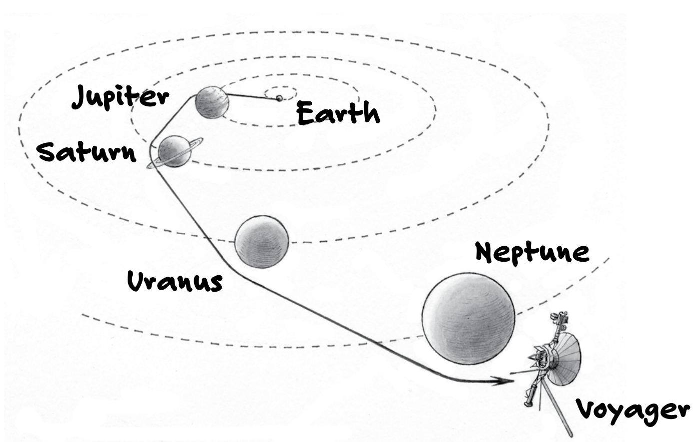


3. EVALUATE, REDESIGN, AND RETEST

- How extreme a turn can your ball make?
- How many times in a row can you get the ball to hit the target?

Check out NASA's missions at nasa.gov

NASA EXPLORES SPACE



For most NASA missions, engineers pass a spacecraft close to a planet or moon. This lets them use the strong gravity to change the spacecraft's direction and increase its speed. For example, NASA's Voyager mission got a gravity assist from five planets to help it on its way!

Visit the *Design Squad Nation* website at pbskids.org/designsquad.

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DESIGN CHALLENGE PERFORMANCE ASSESSMENT RUBRIC

Challenge name: ______________________________

Names of team members: ______________________________

____

Identifying the problem(s) and brainstorming solutions	Showed a clear understanding of the problem(s) to solve. Independently brainstormed solutions.	Needed some teacher direction to define the problem(s) and brainstorm possible solutions.	Needed lots of teacher direction to define the problem(s). Little if any independent brainstorming.	**Points:**
Working as a team member	Worked well together. All team members participated and stayed on task.	Some team members were occasionally off task.	Most team members were often off task and not cooperating or participating fully.	**Points:**
Using the de-sign process	Team brainstormed many design ideas and tested and improved the design. Final design complete or nearly complete and shows creative problem solving.	Some team members were occasionally off task.	Team brainstormed few design ideas and did little testing or redesigning. Final design lacks clear design idea(s).	**Points:**
Processing the science and engineering	Team gave a strong presentation of its solution to the challenge and showed clear understanding of the science concepts and design process.	Team gave a basic presentation of its solution to the challenge and showed basic understanding of the science concepts and design process.	Team gave a weak presentation of its solution to the challenge and showed little understanding of the science concepts and design process.	**Points:**
				Total Points:

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