MISSIONMakers

Simple Machines Shoebox Rover

You are a born engineer! Human beings have always found ways to help us work and explore. Our earliest machines were simple, but key to our survival. A spoon, a hammer, an arrow. As technology evolved, we invented more complex machines. Plows, wheelbarrows, bicycles. Eventually, we designed machines that perform amazing jobs. Now we even explore the outer edges of our solar system. Yowza!

YOUR CHALLENGE

Design a Shoebox Rover!

1) envision the world you want to investigate
2) decide the science questions you want to answer
3) design the tools & instruments you need

What do you need? Craft materials. Time. Curiosity.

- Explore
- Create
- Collaborate
- Problem-solve
- Build a Rover!

THE SIX SIMPLE MACHINES

- Lever
- Wedge
- Screw
- Pulley
- Wheels & Axle
- Inclined Plane

Combine these six simple machines and do more complex jobs!

- **Lever + wedge = shovel arm**
- **Wheels & axle + inclined plane = mini-rover ramp**

Every NASA spacecraft incorporates simple machines in its design.

WHEELS & AXLE: Locomotion

Robotic spacecraft help us explore distant worlds. We design them to interact with their surroundings and gather data. Moving parts and locomotion can be key.

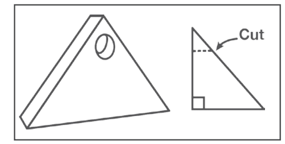
A wheel (or two) is placed on a shaft called an axle. The axle goes through a bearing, in our case, a straw. This structure supports the axle and allows it to spin freely.

1 LOCOMOTION DESIGN:

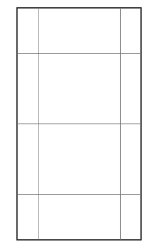
For smooth rover locomotion, axles & bearings are parallel to the ends of the box. Struts are perpendicular to the box ends.

Skewers = Axles
Plastic lids = Wheels
Straws = Bearings
Triangles = Struts

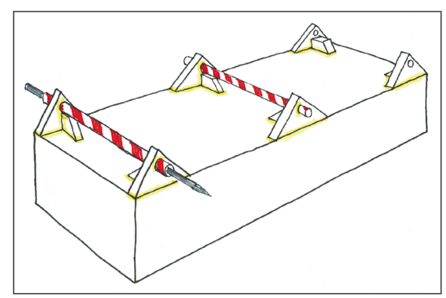
- For 3 sets of wheels & axles:
  - Struts: cut 6 cardboard right triangles
    - Use regular punch for hole
  - Braces: cut 6 small right triangles



- Attach struts to bottom of box, as shown
  - Measure and draw lines on box bottom
  - Glue struts with centers on horizontal line, parallel to box sides



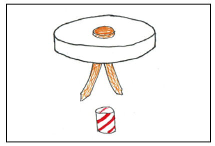
- Attach axle
  - Glue braces to inside of struts
  - Slide straw bearing through strut holes & glue
  - Slide axle through straw bearing. Do not glue! Axles must spin freely.
- Attach wheels
  - Poke a skewer through center of each wheel
  - Attach 2 wheels to each axle
  - Trim axle
  - Glue wheels to axle



WHEELS & AXLE: Move, Pivot, Turn!

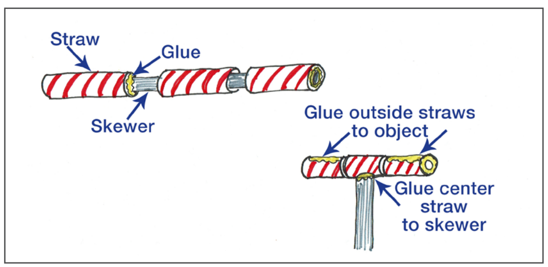
Wheels and axles can make other instruments move, pivot and turn! Customize your rover design with detail and creativity. Swivel mounts hold instruments on the bus. Hinges allow solar panels to pivot toward the sun.

2 SWIVEL MOUNT

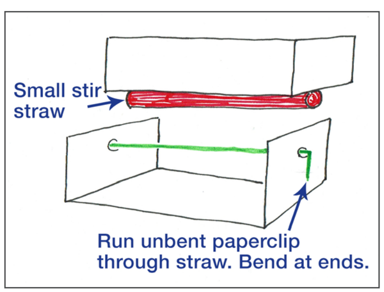


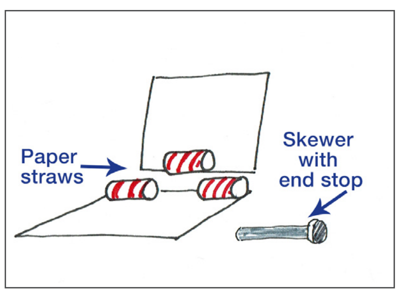
- Punch a hole on the rover top
- Punch hole in the center of a cardboard circle (wheel)
- Connect wheel and top with a large brad (axle)
- Glue instrument to wheel, but not to the axle—allow it to move freely!

3 HINGES



A hinge is a movable joint made with an axle and bearing attached to two separate objects. This allows them to pivot and turn. Paper or small stir straws can be used for your bearings. Skewers or paper clips make great axles.





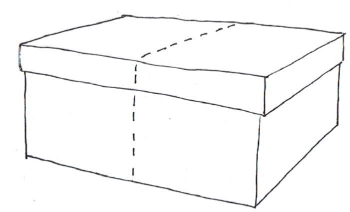
GO! The Spacecraft Bus

Think of your body as a spacecraft. Food, oxygen & water provide fuel. The skeleton offers structure. Skin gives protection. Outside sensors—eyes, ears, nose, tongue, skin—gather information. Inside, your brain is mission control, processing all that data!

Think of a spacecraft like a robot. A human-like robot, going places hard for people to visit. It needs a lot of the same things that a person does. The spacecraft body is often referred to as a “bus” or a “chassis.” Its structure is the skeleton. It carries all the working parts of the mission, from engine to camera to spacecraft antenna. It protects instruments from the harsh space environment.

A spacecraft’s shape and construction is driven by its mission. Where is it going? What does it want to explore? What questions does it hope to answer?

1 GETTING STARTED:



A shoebox will be your rover’s bus. It will house your mechanical parts & instruments.

- Collect all materials
- Use box templates or measure to find the center line around the top and bottom, as shown.

Note: *Remember, the lid will be slightly larger than the box when you make your measurements.*

WHEELS & AXLE: Automata

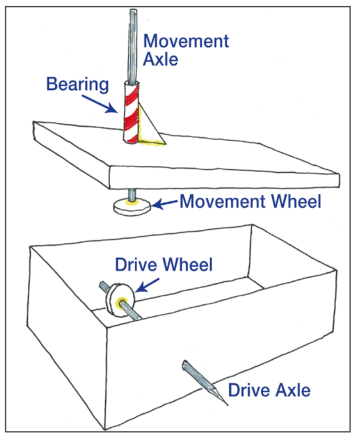
ADDING MOTION

Rotating parts allow an instrument on a NASA spacecraft to make best use of its position. You will make two "automata" (ah-TOM-a-tah)—moving instrument mounts—for your rover. An automaton uses wheels & an axle inside the shoebox to transfer movement to the outside. Cardboard circles intersect at a 90-degree angle, like gears, to make your instruments move.

NOTE: *Read all automata directions before beginning.*

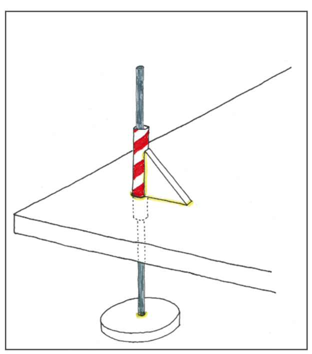
1 PUNCH YOUR HOLES

Each automaton (set of motions) needs two aligned holes on the long sides of the box, and one hole through the lid.



- Measure your box or use the templates provided for hole placement.
  - A horizontal skewer through the box sides parallel to the floor is the drive axle. It should spin freely.
  - A vertical skewer through the top of the box is the movement axle.

2 BRACE YOUR INSTRUMENTS



- Glue a 3" paper straw through each top hole with one end sticking down about 1/4" inside the box. This will be the bearing for the axle.
- Glue a right triangle to your straw & the top of your box. This braces your vertical axle.

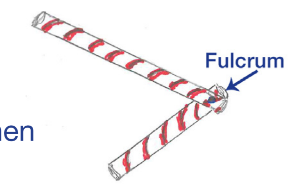
LEVERS

In ancient Greece, Archimedes once said: "With a long enough lever, I can move the world!" Levers are simple machines we use everywhere. Our earliest inventions were levers. Sticks. Brooms. Spears. Many have another simple machine on them, like a wedge. This helps them dig, cut and do work. You even have levers in your body. Think joints and limbs. Move some of your body levers!

When robotic spacecraft explore new destinations, we often equip them with levers. Robotic arms are complex machines that use a series of levers. They perform a range of tasks, from collecting samples to moving science instruments.

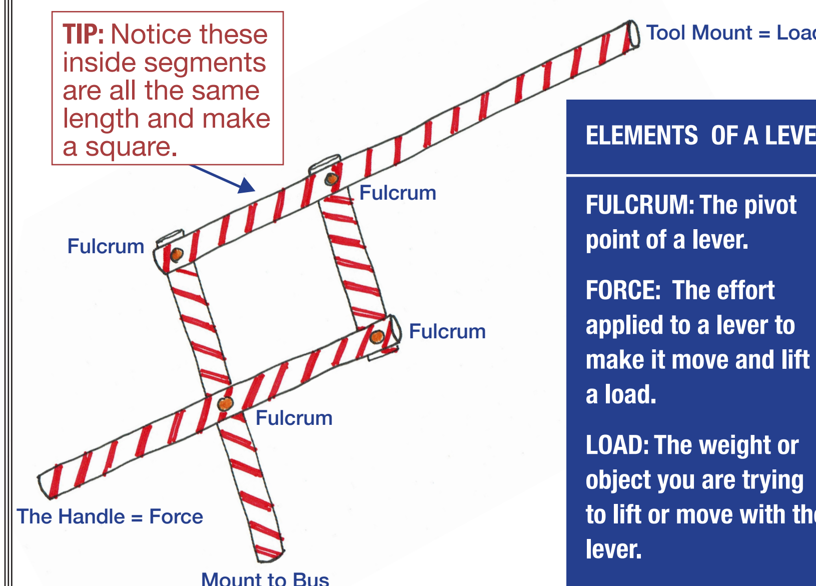
1 BUILD LEVERS

Make a lever out of two straws:



- Put a dot of glue in one end of each straw & squish to strengthen
- Punch a small hole in that end
- Connect with a small brad—this is your fulcrum
- Make another!

How might two levers combine to make a robotic arm?



ELEMENTS OF A LEVER

FULCRUM: The pivot point of a lever.

FORCE: The effort applied to a lever to make it move and lift a load.

LOAD: The weight or object you are trying to lift or move with the lever.

LEVERS: Pivot, Turn, & Touch

DESIGN CHALLENGE: Make a robotic arm! What work do you want it to do? Collect soil, air or liquid samples? Rotate an instrument—a solar panel or a drill? Open a hatch? Its purpose will help you decide the best design.

DESIGN YOUR LEVER ARM:

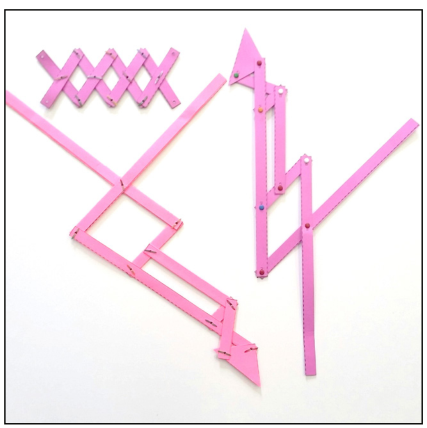
- Design your robotic arm (sketching ideas helps)
- Construct it
- Mount it to your rover

See Wheels & Axle: Swivel Mount

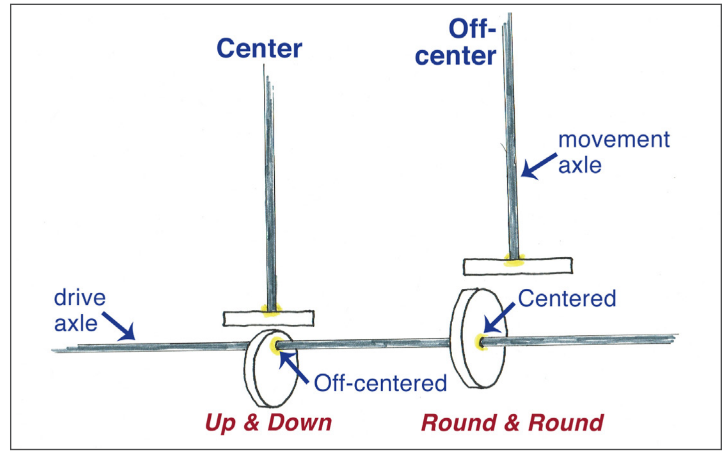
LEVER PRACTICE

Improve your skills with the lever templates.

- Print template on cardstock or paper
- Cut on solid lines
- Score dashed fold lines with skewer or push pin
- Fold & glue
- Punch holes
- Match hole numbers
- Connect with tiny brads



AUTOMATA: Choose Your Movements



3 CHOOSE YOUR MOVEMENTS: Instruments (camera, antenna, etc.) on the top of your rover can go round & round or up & down. Look at the sketch to understand where to place the axle on the drive wheel for the desired movement.

4 PUTTING IT ALL TOGETHER

- Glue wheel to end of movement axle
  - Slide through straw bearing in lid
- Poke axle through drive wheel
  - Round & Round is centered
  - Up & Down is off-center
- Place drive wheel on axle so the movement wheel rests on it perpendicularly
  - Round & Round is off-center
  - Up & Down is centered

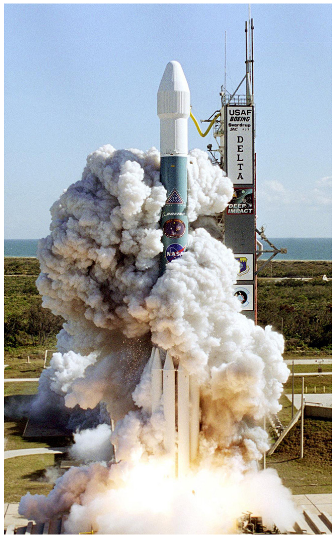
TIP: Cut a little door in your shoebox to help you see. It can become an opening for a mini-rover!

TEST MOVEMENT

When you are satisfied with the movement on rover top:

- Stabilize drive axle ends using a spool or binder clip
  - Glue stabilizer to one axle end
  - Make it snug to rover, limiting side to side movement
  - Trim axle and glue 2nd stabilizer snug to other side
- Glue drive wheel in place on axle

WEDGES



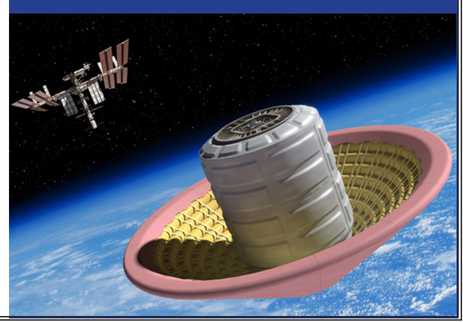
Wedges are simple machines that help us cut, scoop and collect. Look around your kitchen or garden to see many examples. Push pins. Spoons. Rakes. A knife's cutting side. A wedge is often combined with other simple machines. With a handle as a lever, it digs. Two wedges that meet in a point can be an inclined plane, as in a ramp. Two wedges combined with a lever makes scissors.

Many wedges are used on NASA spacecraft. Mars Sojourner Rover had rows of wedge teeth on its tractor-like treads to give it traction as it moved on the Red Planet's surface.

Wedges can be found in the form of scoopers and shovels on the Spirit, Opportunity and Curiosity Mars rovers. The Mars lander, InSight, has a wedge-shaped projectile carrying a thermometer probe. It will be deployed beneath the Martian surface to take its temperature.

SPACE WEDGES

Wedges in the form of nose cones, fins, wings and heat shields are used in spacecraft to make them aerodynamic. Their angled shape helps them cut through the atmosphere. Projectiles, from spears to jets to rockets, use wedges to assist with flight. NASA is designing an inflatable heat shield to protect spacecraft entering the Martian atmosphere that is a mushroom-shaped wedge!

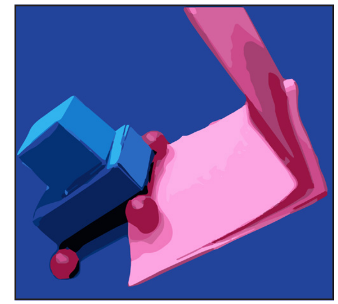


INCLINED PLANES

Inclined planes are flat surfaces tilted at an angle, like a ramp. They help workers get heavy loads into and out of trucks. They are wheelchair ramps and pedestrian walkways. Hiking trails, bike paths and roads become inclined planes as they zigzag up a hill or a mountain.

The inclined plane's angled surface is key to its usefulness. It reduces the force needed to lift a load straight up by distributing it over distance. But there is a trade-off. A steeper incline or slope means a shorter distance to go, but more effort to get there.

The Mars Pathfinder spacecraft deployed a ramp for NASA's first Mars rover, called Sojourner.



TRIANGLES, BRACES, & SUPPORTS:

Because inclined planes are great at distributing force along their angled surfaces, they make good supports. Braces secure your rover's engineering components.

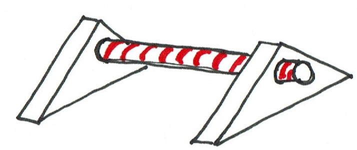
AXLE SUPPORTS:

A paper straw with cardboard or foam core right triangles are used to support your vertical skewers.

AXLE BRACES:

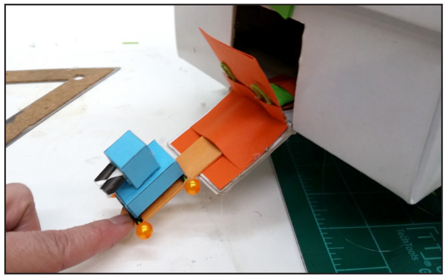
Cardboard or foam core triangles can position and stabilize your wheels & axles. A bearing made out of a straw is attached to hold your axles.

See Wheels and Axles



INCLINED PLANES: Move & Brace

DESIGN CHALLENGE:
Design an inclined plane ramp for your rover.
Be creative!



Ideas:

- A trap door that opens down to make a ramp to deploy a mini-rover
- A system with a retractable arm or levers to move an instrument in and out of a trap door or hatch

1 MAKE A MINI-TOOL:

Design an instrument to utilize your inclined plane ramp. This example is a mini-rover, housed in a secret compartment inside the spacecraft bus.

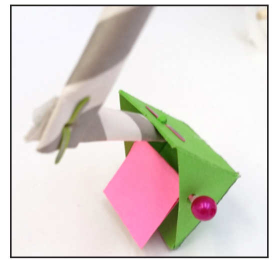
The mini-rover has a 3-D body constructed from the prism templates and paper straw cameras. It uses stir sticks for bearings, paper clips for axles, and beads for the wheels. There's even a lever latch!

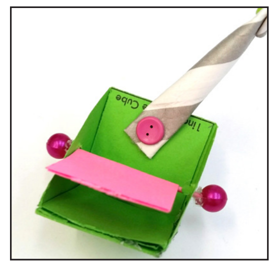
WEDGES: Cut, Scoop, & Collect

DESIGN CHALLENGE: Design an instrument for your lever arm using wedges. If your lever arm is like your own arm, what do you want its "hand" to do? Your tool could be a pick, axe, shovel, or even a temperature probe. Get creative!

Think about:

- The science data you want to collect
- The work you want your arm to do





1 DESIGN WEDGE TOOLS:

This rover's wedge tool is a shovel. We made it by converting a 1" cube. You can experiment with other 3-D shapes. Add special details.

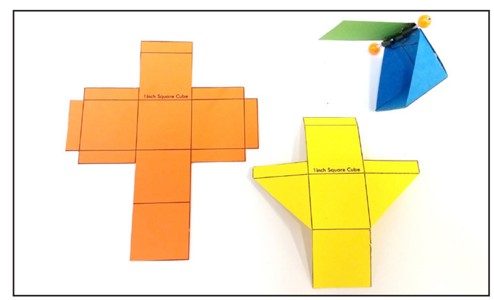
Ideas:

- Create a lens cover with a paper clip axle and 2 beads
- Add a brad or hinge assembly at the end of your arm for range of motion
- Place several instruments on one rotating mount as a turret

TO MAKE A SHOVEL

Choose a 3-D template:

- Cut the side squares at a diagonal (see yellow template)
- Remove the last end square
- Fold and glue tabs

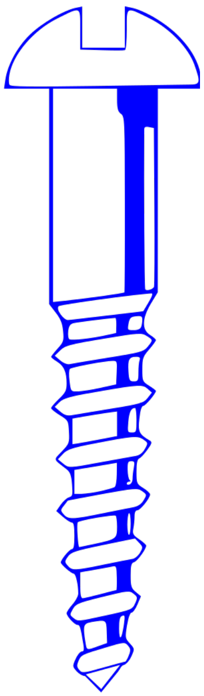


Add a hinged cover.
Use a stir straw as a bearing and a paper clip for an axle.

SCREWS

Screws are ingenious simple machines. They are made by wrapping an inclined plane around a cylinder.

A screw's spiraled edges are called threads. They work to distribute force when turned, twisting them into material like earth or wood. More complex machines like propellers, helicopter blades and fans are also screws that spin around and cut through air or water.



NASA missions use thousands of screws to assemble and connect spacecraft parts. Often, NASA rovers employ a drill system for sample collection and geologic analysis. Space shuttle astronauts used a robotic drill to repair the Hubble Space Telescope. The brilliant engineering behind this unique drill has made space repair missions much safer and more effective for astronauts.

CHALLENGE:
Examine the image above. Draw an arrow to other simple machines you see that are part of a screw's design.

Hint: Think wedge!

ROBOTIC GEOLOGISTS

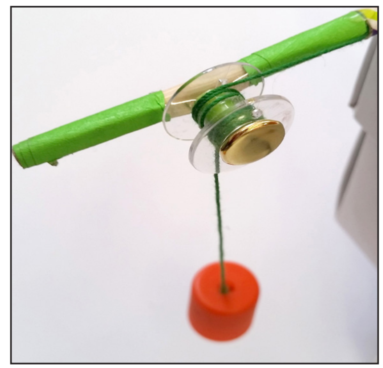
Landers and rovers have simple and complex machines to do the job of a geologist. NASA's Spirit and Opportunity rovers used an instrument called the Rock Abrasion Tool (RAT) on Mars. The RAT was the first instrument to drill into a rock on another planet!

Mars Curiosity has a more sophisticated drill system that works in tandem with a suite of instruments and an on-board lab to analyze the Martian surface.

PULLEYS

A pulley is a simple machine that combines a wheel & axle with a long flexible line or wire, like a rope or chain. It is used to raise and lower a load. Pulleys are important in construction and transportation. Think cranes, large and small. Bicycle gears. Fishing rods. Sailboat rigging.

A single fixed pulley is helpful rolling and unrolling a line. Combine more than one pulley and you reduce the effort or force required to move that load. Use two pulley wheels and it takes half the force to do the same amount of work! That's called a mechanical advantage.

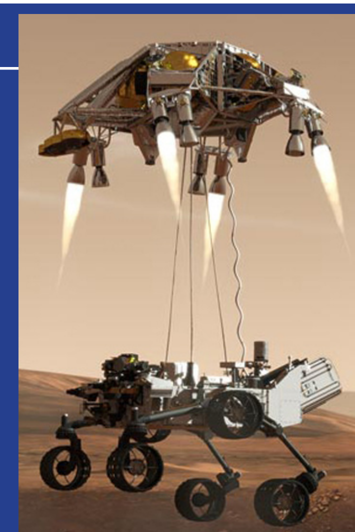


DESIGN CHALLENGE:
Your challenge is to design a pulley system for your rover to do a task. Think about what type of instrument you would like it to lift and move. Experiment with one or more pulleys.

SPACE PULLEYS

NASA has made ingenious use of pulleys in the design of several missions. Mars Science Laboratory used an innovative sky crane to lower the Curiosity rover to the red planet's surface from mid-air (image right).

The Mars InSight lander has a cool pulley system combined with a robotic arm. It will place a temperature probe and seismometer on the Martian surface to measure "marsquakes."

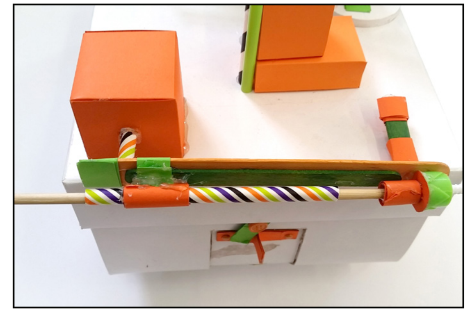


PULLEYS: Move & Lift

ONE PULLEY SYSTEM DESIGN:

1. Pulley
   - Use a bobbin wheel or small spool for the pulley
   - Insert a piece of plastic straw into bobbin for the bearing
   - Place brad through the straw for the axle
   - Open brad tabs and tape them to the end of a skewer (see green tape above)
   - Bobbin should spin freely
2. Pulley Line & Load
   - Create and construct an instrument load (see 3-D templates)
   - Tie load to one end of string (pulley line)
3. Assembly
   - Slip the skewer and string through a straw
   - Glue the straw to your box
   - Glue the skewer to the straw to secure
   - Careful, don't glue string— it should move freely!
   - Wrap excess string around bobbin pulley
4. Experiment
   - Explore using 2+ pulleys to move heavier loads

SCREWS: Drill, Cut & Connect



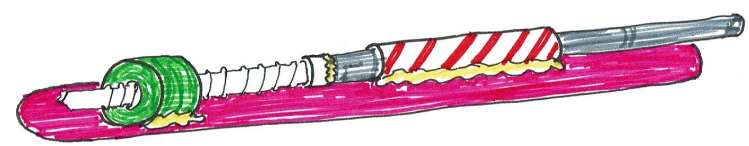
DESIGN CHALLENGE:
Construct an instrument that uses a screw.

Consider:

- The science data you want to collect
- The work you want your instrument to do

Repurpose the insides of an old glue stick or lip balm or use a screw from the family toolbox.

1. **DESIGN A DRILL:**
   For this example, take apart an old glue stick, using the screw and threaded cap parts.
   - Glue a skewer axle to the end of the screw
   - Make a straw bearing
   - Glue the bearing and the threaded cap to a popsicle stick
   - Spin your stick and the screw will move up and down!



Glue threaded cap of glue stick to popsicle stick

2. **ADD DETAILS:**
   Use your simple machine knowledge to add custom details to your assembly. A rotating lever mount and holder increase mobility. Have fun experimenting!