Western Engineering Outreach

Combination Lock

Grades 6-8

Meet Today's ENG HERO!

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To learn more about Dr. Asokanthan visit:
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Learning Goal:

- Explore simple machines by building a combination lock.
- Curriculum Connections: Grade 7 - Form and Function; Grade 8 - Systems in Action

Materials Needed:

- Ruler
- Cardboard
- Large paper clip
- 2 new pencils
- 1 pencil for writing
- Something to draw a good circle e.g. compass, lid to trace, etc.
- Scissors
- Skewer or something to help poke holes
- Hot glue
- Box cutters (optional)
- Single hole punch (optional)

Engineering and Science Connections:

Mechanical Engineering

Mechanical engineers use science and engineering principles to develop new devices, materials, processes, and systems. Mechanical engineers often work with things that move, so that includes transportation like cars, trains, etc., but it can also include things that have moving parts like the hands on an analog clock. Today you will be acting like a mechanical engineer and designing a combination lock, which has moving parts.

What are simple machines?

Simple machines are basic machines that make our lives easier. They use few or no moving parts that change the amount of motion or force needed to do work. Work is how much energy is needed to move an object.

There are six simple machines: pulley, wheel and axle, screw, inclined plane, lever, and wedge. Simple machines can be thought of as the building blocks for more complicated machines. For example, a bike is made up of a combination of simple machines: wheels and axles for the wheels and pedals, levers for steering, and pulleys for the chain.

The 6 Simple Machines

Pulleys - a pulley is a rope wrapped around the rim of a wheel. Pulleys change the direction of the force that is used on the rope. At one end of the rope is the object that is intended to be lifted, and a person (or motor in more complex machines) at the other end who will use the pulley to lift the object. Pulling one end of the rope will lift up a heavy weight on the other end of the rope.

Pulleys are used to more easily lift heavy objects than just lifting the object from the ground. They do this by changing the direction of the force needed to lift the object. It is easier to pull the rope down than to pull up on a rope. Using one pulley decreases the amount force needed to do the work but using a system of pulleys (more than one) decreases the force required even more! When two pulleys are used, more rope is needed so the object will need to be pulled a further distance, but less force will be needed. Pulleys are used to move elevators up and down or to hoist a bucket of water out of a well or even on a flagpole.

Wheel and Axle - a wheel is made up of a circular frame that revolves around an axle like a rod or shaft. If you tried to move a bookcase by pushing it along the floor, it would be a lot harder than if you put the bookcase on wheels and just rolled it across the floor. The wheel and axle are actually considered to be one of the most significant inventions in the world because it allowed transportation of goods easier, especially for people travelling large distances.

An important part of a wheel and axle is a gear. Gears are like a wheel and axle except that the wheel has teeth on it so that multiple gears can be used together. Gears can be used to change the direction of a force or to increase force or speed (speed is changed by changing the size of the gear). Common examples of gears are in analog clocks

or in car engines. If you have a manual can opener at home, take a look at the inner workings, you should see a gear or two!

Screw - a screw is a cylinder with a long, inclined plane wrapped around it. A screw transforms rotational motion into linear motion. Screws are often used to exert a force that is larger than the force needed to turn the screw, like when a lug nut gets tightened on a car. The most common example would be drilling a screw into a piece of wood to hold something together.

Inclined plane - an inclined plane is a sloped surface that helps people move heavy objects. The force needed to move the object up an inclined plane is less than the force that would be needed to raise the object. The idea is that you have to use a smaller force for a longer distance. Inclined planes are used in lots of places that you may be familiar with, like ramps.

Lever - a lever is a bar that rests on a support (a fulcrum). When you push one end of the lever down, it can lift a heavy weight that is on the opposite side of the bar. This allows you to use a smaller force to lift a heavy weight. Common examples of levers are a crowbar or a teeter totter.

Wedge - a wedge is an object that is thicker on one side but becomes thinner towards one edge. When the wedge is driven between two objects or parts of an object, it can be used to split, lift, or tighten. Examples of a wedge could be an axe, which is used to split things, or a doorstop, which is used to secure the door.

Today's activity uses a lot of wheels and axles for the rotors, washers, and dial that are included in the combination lock.

How Combination Locks work
Combination locks typically use a set of wheels called a wheel pack. When you know the combination for the lock, the notches on each wheel line up unlocking it. In a padlock, that is where the lock can release the one end.

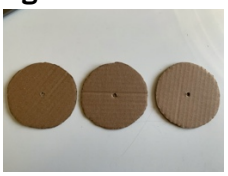
Video Recommendation:

Simple Machines for Kids: Science and Engineering for Children - FreeSchool
https://www.youtube.com/watch?v=fv0maf2GfCY

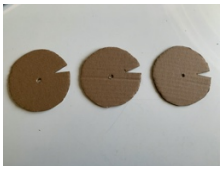
Activity:

Part 1: Make the Rotors

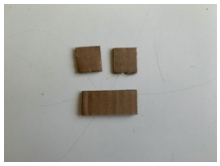
1. Cut out 3 cardboard circles that are each about 10 cm in diameter. Each of these circles is a rotor.
2. Poke a hole in the center of each circle using the skewer or a pencil or a hole punch.



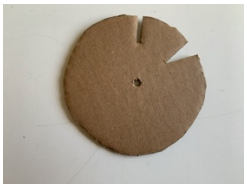
3. Draw a notch/pizza slice in each rotor about 1 cm wide at the top that goes about halfway to the center of the cardboard circle.
4. Cut out the notch from each of the 3 rotors.



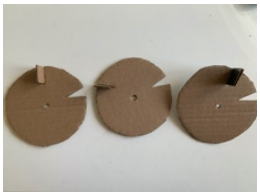
5. Cut out 2 cardboard squares that are 2 cm x 2 cm.
6. Cut out 1 cardboard rectangle that is 4.5 cm x 2 cm.



7. Make a cut out in one of the circles that is about 2 cm deep and about as wide as your cardboard is thick. Repeat for the 2 other circles. Make sure to adjust where the cut outs are on your circles because otherwise the combination will be the same number three times in a row.



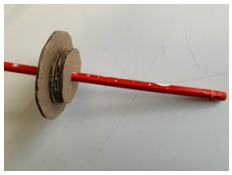
8. Attach the cardboard squares and rectangle cut outs into the cut in the rotors using hot glue. The rectangular cut out should be centered in the notch, the squares should be sticking out on only one side. See picture for clarification.



Part 2: Make the Dial

1. Cut out 3 cardboard circles that are about 4 cm in diameter.
2. Cut out 1 cardboard circle that is about 7.5 cm in diameter.
3. Poke a hole in the center of each circle using a skewer or a pencil or a hole punch.

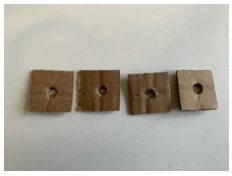
4. Push them all onto a pencil against each other.



5. Hot glue them together but don't glue them to the pencil. This is going to be the dial that you turn to enter the combination to unlock the lock.

Part 3: Make the Washers and Supports

1. Cut out 4 cardboard squares that are 3 cm x 3 cm.
2. Poke a hole in the center of each square. These will be the washers.



3. Cut out 2 cardboard strips that are about 9.5 cm x 4.5 cm. These will be the short supports.
4. Poke a hole in each of the short supports that are about 0.5cm down from the top and are centered on the support.

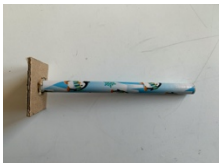
5. Cut out a cardboard strip that is 11.5 cm x 4.5 cm. This will be the long support.
6. Poke a hole in the long support that is 1.25 cm from the top and centered on the support.

Part 4: Build the Independent Rotors (rotors that spin freely)

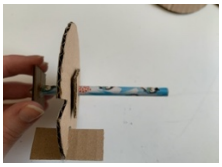
1. Cut the eraser end off of the pencil. The piece of pencil and eraser being cut off should be 3 cm. You may have to do this with box cutters. Save the piece of pencil, you will use it later.
2. On the second pencil, cut a 10 cm piece off of it. It does not need to include the eraser.
3. Gather the materials needed:
    a. 2 rotors built in Part 1, one with the rectangular cut out tab and one with the square tab
    b. The 2 short supports built in Part 3
    c. 3 washers built in Part 3

d. Piece of 10 cm pencil you just cut

4. Hot glue one of the washers to the end of the 10cm pencil piece.

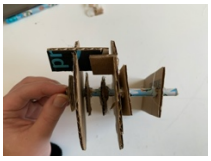


5. Slide the rotor with the rectangular cut out tab onto the pencil but don't glue it down. You want it to be able to spin freely.



6. Slide another washer onto the pencil and against the rotor.
7. Glue the washer onto the pencil. Make sure the rotor can still spin freely.
8. Slide the other washer onto the pencil to about 2.5cm from the second washer. Don't glue it yet.
9. Slide the second rotor (one of the ones with the square cut out tab) onto the pencil with the cut out tab pointing towards the other rotor. Slide the rotor to a position where the cut out tabs will touch each other but not so close that the rotors can't move.

10. Glue the third washer to the pencil.
11. Glue one of the short supports next to the second rotor. Make sure the rotor can still spin freely.
12. Glue the second short support about 5 cm away from the first one on the pencil.



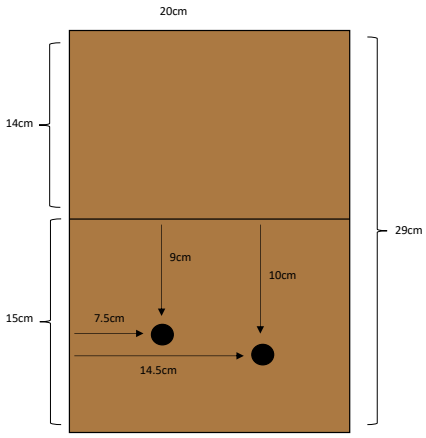
Part 5: Make the Locking Bar

1. Cut out 2 cardboard rectangles that are 2.5 cm x 4 cm.
2. Poke a hole in each one that is about 0.5 cm from the bottom and 1.5 cm from the side.
3. Unbend the large paper clip so that there is a about 10cm long side and 2 perpendicular ends, like a giant staple.

4. Make a shape for the indicator and cut it out. The indicator is what you will turn to unlock the lock so it will get a lot of use. To see a picture of the indicator look at the picture included in Part 7, Step 23. The indicator is a triangle.
5. Glue the indicator onto one end of the 10cm pencil. The rest of the locking bar will be put together in the final assembly.

Part 6: Build the Base

1. Cut out a piece of cardboard that is 20 cm x 29 cm.
2. Fold the cardboard so that the 29 cm side is split into a 14 cm length and a 15 cm length. If you need to, you can use a box cutter or a pair of scissors to gently cut the top layer of cardboard to help you fold.
3. On the piece of cardboard that is 15 cm x 8 cm, poke 2 holes. One of the holes is 7.5 cm across and 9 cm up. The second hole is 14.5 cm across and 10 cm up. See the diagram and picture below for clarification.



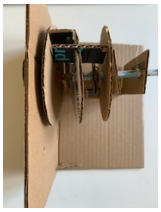
4. Cut out small right triangles from spare cardboard.
5. Glue these triangles at the edges of the base so that the base is square.

Part 7: Final Assembly

1. Slide the dial you made in Part 2 onto the pencil stub you cut (the piece about 3 cm long) and glue it onto the pencil stub.
2. Slide that through the lower hole on the base. The dial should be on the backside of the base.

3. Slide a washer onto the pencil and glue it onto the pencil.
4. Slide the last rotor onto the pencil and glue it onto the pencil. The tab should be facing away from the dial. When you turn the dial, the rotor should move as well.

5. Glue down the rotor assembly you made in Part 4. You want the tabs facing each other, so the supports are at the far end from the dial.



6. Slide the 10 cm piece of pencil into the other hole with about 1 cm sticking out on the dial side.

7. Attach the indicator you chose to the pencil on the dial side of the base.

8. Slide one of the 2.5 cm x 4 cm rectangles onto the pencil, then the long support, then the second 2.5 cm x 4 cm rectangle.
9. Use one of the legs of the paper clip and insert it into the cardboard edge of one of the 2.5 cm x 4 cm rectangles. Repeat for the second one. See picture for clarification. Make sure the staple is at least as long as the rotors. This staple will be the locking bar.

10. Glue the long support down to the base,
11. Move the bar into the lock position. Recommendation is about 45 degrees right of the vertical. Mark the position.

12. Mark where the indicator is pointing as “locked” on the backside (dial side) of the base.
13. Turn the rotors so that all the notches/pizza slices are facing the lock bar.
14. Turn the locking bar into the notches.

15. Mark where the indicator is pointing as “unlocked” on the backside (dial side) of the base.
16. Turn the dial 3 times clockwise. By the third turn, all of the rotors should be turning.
17. Turn the dial so that the farthest rotor notch/pizza slice is positioned directly in front of the locking bar.
18. Mark the dial.
19. Turn the dial once to the left (and maybe slightly more) so that the middle rotor notch/pizza slice is positioned directly in front of the locking bar.
20. Mark the dial.
21. Turn the dial right until the notched on the closest rotor is positioned directly in front of the locking bar.
22. Mark the dial.
23. Using these marks, evenly space numbers out on the dial. Recommend using between 10 and 12 numbers.

Now test out your lock!

What Did You Learn?

- How is the simple machine of a wheel and axle incorporated into your combination lock?
- What are the other simple machines? Could you incorporate any others into your combination lock?

Future Learning

- Where else are simple machines used in your everyday life?
- Do simple machines make your life easier in ways that you were not aware of?
- To learn more about how combination locks work, you can do some research or you can visit this website: https://home.howstuffworks.com/home-improvement/household-safety/combination-lock.htm#:~:text=The%20typical%20combination%20lock%20has,wheels%20and%20a%20drive%20cam.&text=Each%20wheel%20on%20the%20spindle,their%20notches%20line%20up%20perfectly.

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