DIY Drawing Machine

Objective:
Create a drawing machine to make complex mathematical patterns. Explore the science on how gears move.

Have you ever played with a Spirograph? These drawing devices can create beautiful patterns and are fun to tinker with. If you have patience and some time, you can build your own drawing machine just by using just cardboard, glue, and paper. You can use the drawing machine to investigate the math of curved figures!

Difficulty to build: Challenging (ages 10-12)/Medium with help (ages 8-12)
Difficulty to use: Medium (ages 8-12)/Easy with help (all ages)

Materials:

- 10” Paper plate or something else circular
- 14 x 14” Cardboard pieces (2)
- A large piece of corrugated cardboard - You can make your own corrugated cardboard by carefully separating the flat layer of a corrugated box from the bumpy inner layer. The size you will need will vary slightly, but it will be roughly 3 times as long as the distance around the rim of each of your circles.
- Glue - craft glue, school glue, or hot glue (be sure an adult knows if you are using hot glue, be careful of burns)
- Scissors
- Pen, pencil, or marker
- Paper
- Cardstock or plastic lids of assorted sizes
- Awl, hole punch, or nail

Note: You can use different sized objects than we list here. If you do, that will affect the size and circumference of your circles, and the length of the corrugated cardboard strips that you need to put around them.

Procedure:

Part One: The drawing machine base

1. Trace around the outside edge of a paper plate onto two separate pieces of cardboard. If you don’t have a paper plate, you can use a coffee can or other round object.

2. Cut along the lines you traced so both pieces of cardboard wind up having a circular hole cut through them. These will form the inner ring of your drawing machine base.

3. Place the two pieces of cardboard with circular cutouts side-by-side, and spread glue on one of them. Then sandwich them together so the circular cutouts are aligned.

4. Cut a strip of corrugated cardboard long enough to encircle the inner cut out circle, and slightly higher (wider) than the height of the two pieces of cardboard that you glued together. The dimensions will vary depending on what you used to trace your circle onto the cardboard.

5. Glue the corrugated cardboard strip along the interior of the circular cut out so that the smooth side is attached to the cardboard template and the bumpy side points toward the middle of the circle, like the teeth of a gear.

6. If you used craft glue or school glue, you will need to let your project dry thoroughly. If you use hot glue, you will not need as much drying time. (Always be sure an adult knows you are using hot glue, and be careful, since it can cause severe burns).

Part Two: The drawing machine inner gear

1. While your template is drying, you will make the additional parts of your drawing machine. Take a smaller square of cardboard, and an object with a circular surface that is smaller in diameter than the paper plate, or whatever you used to make the template for the inner ring.

2. Trace around the object, so you have a circle that has a smaller **circumference** (outside measurement) than the first two circles you drew and cut out. Cut out this circle.

3. Cut another strip of corrugated cardboard, long enough to go around the outside of this smaller circle. Glue it onto the edge of the circle, with the smooth side attached to the circle's edge and the bumpy side pointing out. Try different materials, and see what works best. Is it easier to cut out two circles and attach the corrugated cardboard between them, like an ice cream sandwich? We had the best luck using a large, screw-on plastic lid from a jar of mixed nuts, and

attaching the corrugated cardboard to the outside rim. This will be your inner gear.

4. Poke a hole slightly off-center in the top of the inner gear. The hole will need to be big enough to fit the tip of a marker, pen or pencil through it. Experiment with the size until you are able to fit a writing instrument through the hole and make marks on paper underneath. This might take a few tries. Keep tinkering, and don't give up!

5. Tape a large piece of paper to the underside of your drawing machine base. You may want to tape or weight down your drawing machine base to the table.

6. Place the inner gear inside the inner ring on the drawing machine base. Put a pen, pencil, or marker into the hole in the top of the inner gear, and move it so the corrugated cardboard lines up with the corrugated cardboard on the interior of the drawing machine base circle template (like the teeth of a gear).

7. Use one hand to hold your writing implement steady, while using the other hand to move the smaller circle around the inside of the larger circle template. What do you notice happening on the paper?

8. Keep tracing your smaller circle around and around the larger circle template, until you have created a geometric design. Then you can use different colored markers or pencils and trace around the template again, making even more complex patterns.

Explore More:

- Try making holes at different points on your smaller circle or lid. When you put the pencil or marker through different holes, how does that change the patterns you make?

- Try using different sizes of lids or cardboard circles to make your inner gear. How do different sizes of inner gears affect the design?

- Try cutting your inner gears in different shapes. What will happen if you cut the inner gear in an oval shape? Will it work if the inner gear is a triangle or a pentagon?

- Can you design a drawing machine that would let you roll the gear on the *outside* rim of a larger cut-out circle?

- What do you notice about the finished patterns? How are they different? How are they the same?

- If you make ring bases for your drawing machine in different sizes, then if you change the size, you are making the ring base a **variable**. If you change the **circumference** of the ring base, how will that affect the number of bumps on the corrugated cardboard lining? How will it affect the gear traveling inside the ring?

- You can try making different sized ring bases with different amounts of corrugated cardboard lining them. The corrugated cardboard acts like the teeth of a gear. Try using different sizes of ring bases, and see how the smaller gear moves when it traces them, and how it changes the patterns it makes.

What's the Math?

A **variable** is a value that can change. Your drawing machine has two variables:

1.The **radius** of the small gear
2.The distance of the point of your pen/pencil/marker from the edge of the small gear

The radius of a circle is the distance from the center of the circle to any point on the circle (think of the spokes on a bicycle wheel). Imagine we could take a circle and straighten it out into a line. The measurement of that line would be the circle's circumference, or the distance around its edge.

The radius of the ring template cut into your drawing machine base isn't a variable, because it isn't changing. But you can create inner gears with different radii (the plural of radius), and you can make holes in different places on your small gear, to try placing your pen/marker or pencil at different points.

Increasing and/or decreasing the value of any one of these variables affects the results achieved by the tools.

If you make different sizes of inner gears, their circumferences will be different. The number of teeth (bumpy corrugated cardboard edges) will also change. A larger inner gear traveling along the machine base ring will cover the distance in fewer rotations before it comes to its starting point.

We can do this as an investigation. Make three different sizes of inner gears. Count the teeth (bumpy edges) on the outside edge of each one.

Now, put a writing instrument into a hole made slightly off center in the smallest inner gear. Trace it along the inner ring of the drawing machine base. How many rotations will the gear make before it gets all the way around the ring?

Now try the same thing with the middle sized gear. Finally, try with the largest gear. What do you notice? How does this change the patterns you make?

Larger gears have a bigger circumference, so they require more corrugated cardboard. This makes more bumpy teeth.

Because bigger gears have a greater circumference, they can cover more distance in a single rotation when they trace the inner ring. Changing the inner gear's radius will change the number of points in the design that you make on the paper.

Can you design an investigation to see how making different holes for the writing instrument will affect your patterns? What do you think will happen? Make a prediction, and then try it.

Trigonometry is advanced math that gets into the formulas of these special curves. For now, it's fun just to experiment with changing variables and see how this affects the curves and the patterns they can make, but here are some basic trigonometry terms that relate to our drawing machines.

Roulettes are special types of curves that are made when one curve is rotated around another by a fixed point.

Think about when you put your marker or pen into the hole in the smaller gear of your drawing machine. That is the fixed point. As you roll the smaller gear around the inside of the larger circle, the path that the smaller gear takes makes special roulettes called **hypotrochoids**. The drawing machine you made creates these kinds of curves. If you were to create a drawing machine that allows the small gear to roll on the outside of a larger circle, you can create types of curves called **epitrochoids**.

One famous type of trochoid is called a **cycloid**. This is the curve drawn by a point on the rim of a wheel as it rolls along the ground. Galileo studied these curves and named

them-- they are used to shape arches, to design pendulum clocks, and to shape gear teeth.

The painting pendulum at ScienceWorks is a type of drawing machine called a harmonograph. It creates special kinds of curved figures called **Lissajous figures**.

Take a picture and share it with us, so we can see what you made! For more engineering projects and science activities, subscribe to our newsletter! Have an adult send it to online@scienceworksmuseum.org or share it using the hashtag #ScienceWorksOnline