Design a Catapult: Grades 11 to 12

YOUR MISSION

Today you will design, build, and test a catapult made from common household items and craft materials. Your catapult will launch a projectile, in this case a ping pong ball, as far as possible using the energy stored in a stretched rubber band.

Catapults demonstrate many important concepts that mechanical engineers use every day for designing many different types of machines. These concepts include kinetics, kinematics, and ballistics.

WHAT'S GOING ON

Engineers are problem solvers and they come up with solutions to problems to better the lives of everyone around them. They do this by coming up with designs, products, technologies, innovations, procedures, and systems to make the world a better place.

Mechanical engineers design components, systems and procedures for machines and other systems with moving parts. Aerospace, automotive, industrial, and materials are just some of the different mechanical engineering fields. Some of the very first inventions that demonstrate the fundamentals of mechanical engineering date all the way back to the Middle Ages. Back then, catapults were built, along with trebuchets and ballistae, to launch projectiles into the air.

Though catapults are not as frequently used today, slingshots, airplanes who use aircraft catapult to assist on take-off from aircraft carriers, as well as the Olympic athletes who compete in the sport of Archery using bows and arrows, all utilize the exact same principles of physics and engineering as the catapult you will be building today.

How exactly do these catapults work and how will we design one? Before we get to that, here are some key terms that you need to know and will learn about while you are doing this activity and that are essential to building your own catapult.

KEY TERMS

- **Kinetics:** The branch of mechanics focusing on how the various forces applied on an object result in motion; also known as dynamics.
- **Kinematics:** The branch of mechanics that does not focus on the forces acting on an object, but rather purely the motion itself such as displacement, velocity, and acceleration, both linear and rotational.
- **Ballistics:** The study of projectiles.
- **Tension:** The stress of an object when being pulled apart.
- **Deflection:** The difference in length of a spring from its original unstressed position.
- **Force:** The measurement of a push or pull on an object.
- **Energy:** The capacity of an object to perform work.
- **Work:** The product of force and displacement.
- **Potential Energy:** The stored energy in an object or system because of its position or the way it is configured.
- **Kinetic Energy:** The energy of an object due to its movement - its motion.

Now that you are familiar with these terms, let's find out how catapults work to make our own!

The main feature in a catapult is its quick release mechanism of potential energy that is stored in its elastic, rope, or spring, before being transferred into kinetic energy of the arm and thus the projectile.

The more one pulls back the arm, the more tension there is in the elastic, and thus more energy being stored in the system. And of course, the more energy the catapult has, the further the projectile will travel. This activity is a great example that demonstrates both kinetics (dynamics) and kinematics.

MATERIALS NEEDED

Before you design your catapult, here are the materials you will need.
Ask a parent or teacher to help you gather and/or use these materials if needed.

- Metal Spoon
- Popsicle Sticks
- Rubber Bands/Elastics
- Any type of strong craft glue
- Masking Tape
- Scissors
- Ping Pong Ball, or other similar object such as a cork or silly putty that will be projected safely in the air

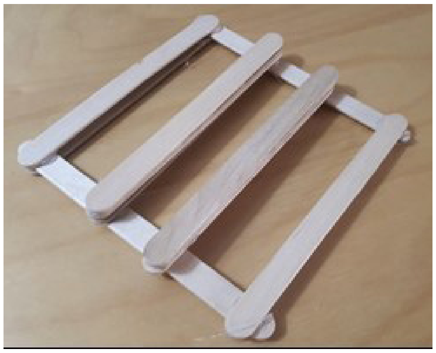
WHAT YOU NEED TO DO

To build your catapult, we will break our design into 4 parts: the base, tower, arm and launch.

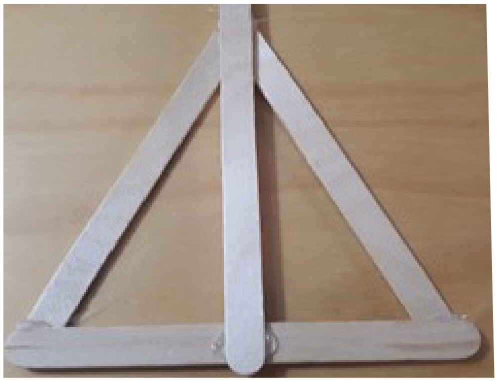
Each section and all steps, along with accompanying pictures, are listed below. Remember, feel free to experiment and customize your catapult with your materials if you'd like. Engineers are very creative when coming up with solutions to problems!

- Base - Make a square base out of popsicle sticks that is 1 stick long and 1 stick wide. Use glue to connect the ends of the sticks. You may add a second layer of sticks to reinforce the base.

- Tower - Glue two separate stacks of 4 popsicle sticks. Glue these two stacks to the middle of the base adjacent to each other, with a small 1 cm gap separating them. Make sure this is centered on the base.



- Make two equilateral triangles out of popsicle sticks. Then, glue a stick from the middle of the base to the top vertex of each triangle.



- Glue each triangular support to the outer sides of the two stacks that are already glued to the base.

- Solidify the triangle supports by connecting them with popsicle sticks. You may glue these wherever you like except for the rear half of your design as you'll need space to pull back and release your arm when using your catapult.

- Arm - Tightly wrap the handle of a metal spoon to the front side of the popsicle stick you glued in the previous step. The spoon handle should fit in the gap you made between the two stacks of sticks. Use several rubber bands for a tighter connection if you must.

- Glue the popsicle stick to the vertical sticks of the supports below.

- Finally, wrap several other rubber bands around the spoon handle and then around the rear corners of the base, as shown below.

- Launch! Once the glue is done drying, you're ready to test your catapult design! Make sure you do your testing in a wide and open area and away from other objects and people. If you don't have a ping pong ball, you may use another similar sized object such as a cork, or a piece of clay (if you are outside).

FURTHER REFLECTIONS

1. How far did you launch your ping pong ball (or similar object)?
2. Would changing the launch angle affect the throwing distance?
3. How can you modify your design to change the launch angle?
4. If you add another elastic, will it throw further?
5. What can you do to your design to alter the trajectory of your ping pong ball (or similar object)?

ENGINEERING DESIGN PROCESS

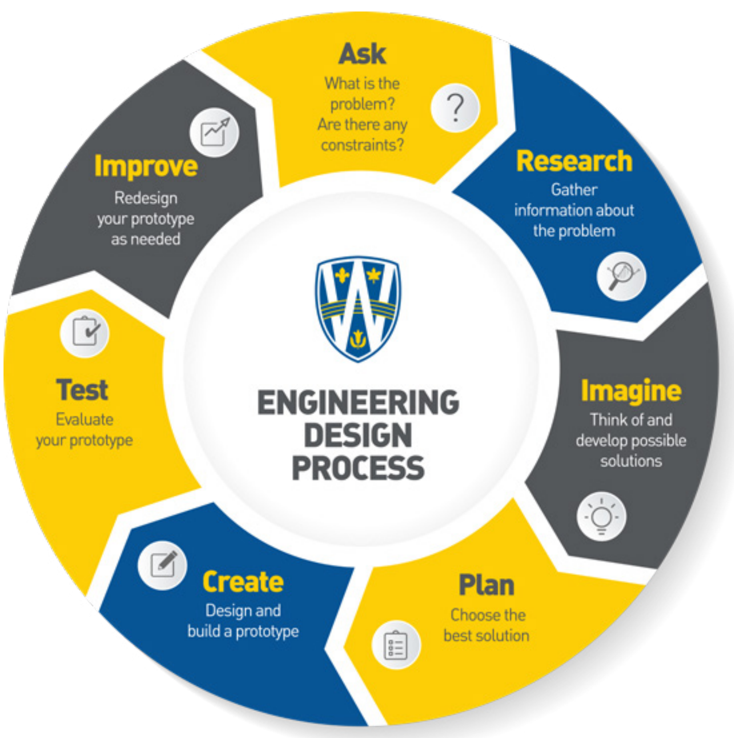
All engineers use the Engineering Design Process to plan, build, test and reflect on their designs and when coming up with solutions to a problem. The steps for the Engineering Design Process are listed below. Use the Engineering Design Process to test and improve your design.

First, think of the problem.

How can you fix it? Think of as many ideas as you can that you think will solve this problem.

It might be helpful to first sketch out your ideas on a piece of paper. Make as many different designs as you can!

Test and compare all of your solutions. Which one solves the problem and works the best?



CALCULATIONS

In addition to using their science skills, engineers also use their math skills to help them solve engineering-related problems. Here are some of the calculations you would encounter should you decide to look further into this activity. These calculations can help you determine how effective your design is.

If you wanted to calculate the horizontal distance your ball will travel before hitting the ground, follow in order the **kinetic** and **kinematic** equations in the following table.

Further explanations on how to solve these calculations are also listed below.

Kinetics (Arm)			**Kinematics** (Ball)		
1	$k = \frac{F_{spring}}{x}$	Force applied on the arm	4	$\Delta v_y = v_f - v_i = 2v_y$	Change in the vertical velocity
2	$E_{potential} = \frac{1}{2}kx^2$	Energy stored in the elastic	5	$\Delta t = \frac{\Delta v_y}{g}$	Time of flight
3	$E_{kinetic} = \frac{1}{2}mv^2$	Kinetic energy of the arm + ball	6	$S_x = v_x \Delta t$	Distance traveled

Equation 1 is **Hooke's law**, which means that the force required to deflect the rubber band is the elastic constant "k" times the deflection of the arm "x".

Knowing the force applied and the deflection, "k" can be found and used for the next step in **Equation 2**.

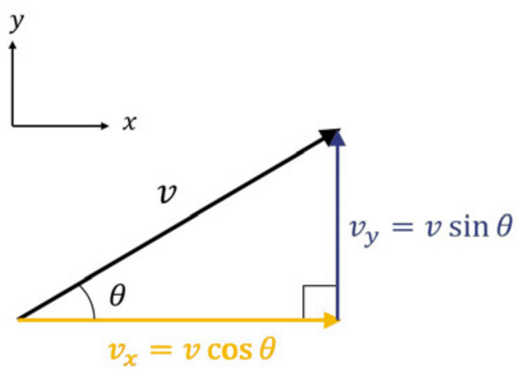
The spring constant might be hard to find in this activity, so here you can assume that **k = 20 N/m** for each rubber band that you wrap around the spoon.

Next, the potential energy stored in the spring is equal to the ball's kinetic energy, which is the energy required to cause the motion of the ball. So, to find the launch speed of your ball, you can equate both **Equations 2 and 3**, and then solve for "v".

The mass of the projectile is "m", and if you're using a recommended size ball for this activity, then use **m = 0.0027 kg**.

Now that you've calculated the speed of the ball, you can move on to **Equations 4, 5, and 6** to find the total throwing distance. However, you'll need to estimate the launch angle "θ", and you can find this by doing a few test throws.

With the speed and angle, calculate v_y and v_x as shown in the picture below, which are the vertical velocity and the horizontal velocity at launch, respectively.



Use **Equation 4** to calculate the change in velocity of the rise and fall of your ball. This is simply twice the value of v_y.

Then use **Equation 5** to calculate the total flight time of the ball by dividing Δv_y by the acceleration due to gravity "g", which is **g = 9.8 m/s2**.

Finally, **Equation 6** is the range or total horizontal distance traveled by the ball "S_x", which is the horizontal velocity "v_x" times the total flight time Δt.

Now compare S_x to the distance measured in your test throws. Do your calculations match your results?

CURRICULUM UNIT CONNECTIONS

Grades 11 to 12 - Kinematics; Forces; Dynamics; Energy and Momentum

SHARE YOUR DESIGNS WITH US!

Tag us on our UWindsor Engineering Social Media Pages and show us your designs!

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REFERENCES

Tuk Crafts. (2014, October 5). How To Make A Spoon Catapult Out Of Popsicle Sticks.(HD). [Video]. Youtube. https://www.youtube.com/watch?v=iKQaTFfhwWo