MINI CATAPULTS

Lesson Type: Engineering / Construction/ Take home
Target: Elementary School
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Side view


Back view


Another design
(see first link in Refernces for instructions)

Challenge:

• Build a mini Popsicle stick catapult to launch mini marshmallows.
• There is no real "challenge" except to build the catapult. There is no predetermined way for the mentees' catapults to compete against each other. You can modify this to make knocking cups down the objective.
• This will be done as a take-home project, so every mentee should try to build their own to bring home.

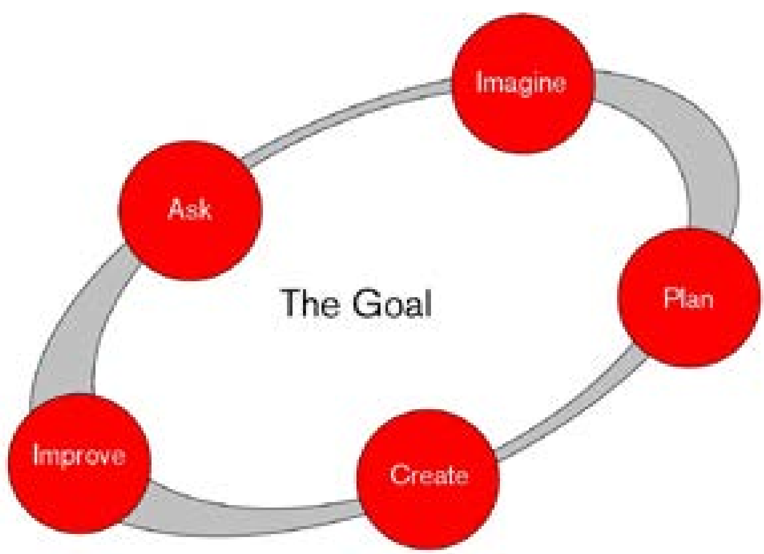
Teaching Points

• The 5-Step Design Process.
• The rubber band stores energy.
• How to increase the magnitude of the torque created by the catapult.
• Building structurally sound things by adding supports and reinforcement.
• The object launched follows projectile motion.

Agenda

Introduction (10 min)

• Introduce what they'll be building.
• Discuss levers and torque
• Show an example of a catapult (built during the DeCal) and materials they will be using.
• Discuss the Engineering Design Process.
• Give mentees paper to sketch out their ideas *before* giving them materials. Have them point out lever components in their drawings.



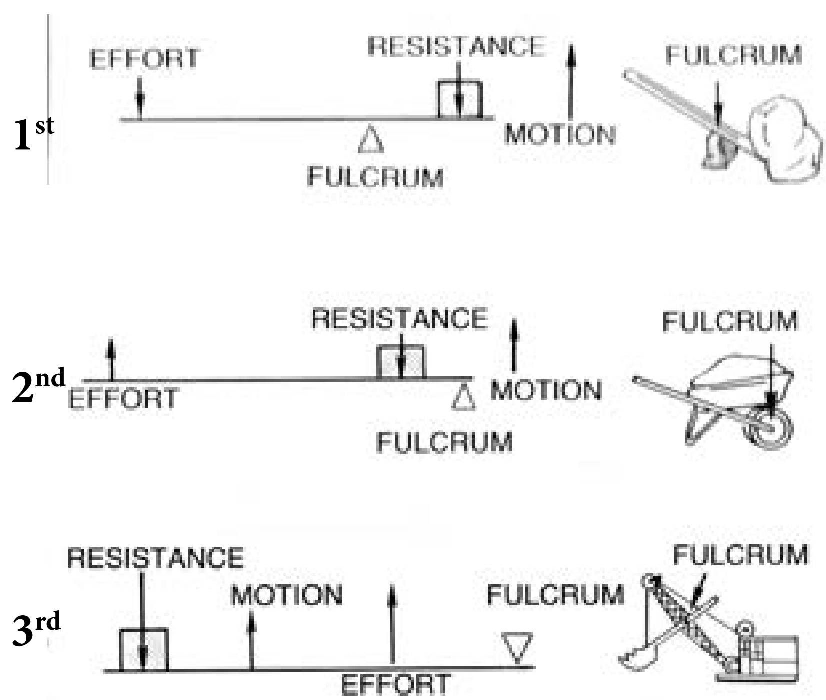
Build (30 min)
• Set up the materials bar and allow unlimited access.
• You will need to help your mentees out a lot since building 3D structures with Popsicle sticks is farily difficult.
• If they get their catapults working, try to have them improve their designs.
• Have students identify lever components (load, force, and fulcrum) on their catapults.
• When they get to the rubber bands, discuss how they store energy.

Test (15 min)
• Set up cups to knock down or to fire into.
• Show how the marshmallow follows standard projectile motion and that they can reliably hit the same target because of it.
• Mentees can keep their catapults when they are done.
• Encourage them to improve their design based on their tests.

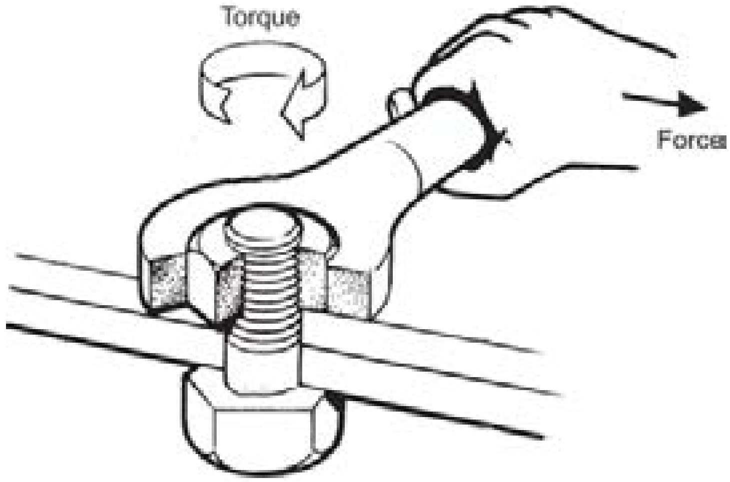
<u>Materials</u>
• Popsicle sticks (10-15 per catapult)
• Rubber bands (1-2 per catapult)
• Masking tape
• Plastic utensils (preferably spoons)
• String (cotton, or something else easy to tie and manipulate, optional)
• Paper (construction and/or printer)
• Plastic or paper cups (as targets, optional)
• Mini marshmallows (or another suitable projectile)

<u>Background for Mentors and Mentees</u>
5-Step Design Process
• Imagine → Plan → Create → Improve → Ask → etc.
• Cyclical process, so never truly stops.

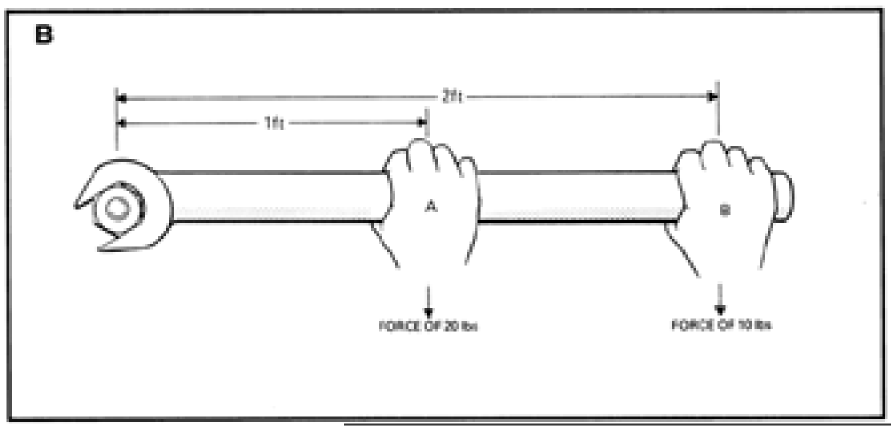
Levers
• "Give me a place to stand and a lever long enough and I will move the world" – Archimedes
• **Levers** are a simple machine consisting of a beam attatched to a fulcrum.
• They are used to transmit and amplify force to do useful things.
• The three lever components are:
1. Fulcrum.
2. Input force, or effort.
3. Output force, or load.
• Common levers are:
1st class: Crowbar, scissors
2nd class: Wheelbarrow, bottle opener
3rd class: Tweezers, the catapult
• A good example to use is a seesaw. A lighter person can launch a heavier person up if he is farther from the fulcrum than the heavier person is.
• The design shown several pages below is a 3rd class lever because of how the fulcrum, load, and effort (force F) are positioned along the lever arm (distance between fulcrum and load in this case). Force points up because of the rubber band's tension. Load points down because that is where the force due to gravity points.



Torque



- $\tau = r \times F = rF\sin\theta$ is the tendency of a force to rotate an object about an axis.
- To increase the magnitude torque, you can do three things:
  1. Increase the force applied.
  2. Increasing the length of the lever arm.
  3. Change the angle at which the force and lever arm cross each other (if they aren't perpendicular)
- The direction of torque can be found using a right hand rule. Point hand along lever from fulcrum to force. Curl fingers in direction of force. This makes your thumb point in direction of torque.
- Don't try to teach torque as described above to elementary school students since they don't have the mathematical/ physical background to understand cross products.
- Instead, teach torque as the "twisting force" that a lever can produce.
- Teach how to increase the magnitude of the torque (three ways above), but not its directionality.
- You can explain torque by describing how much "twisting force" a wrench can transmit from a hand to a nut.

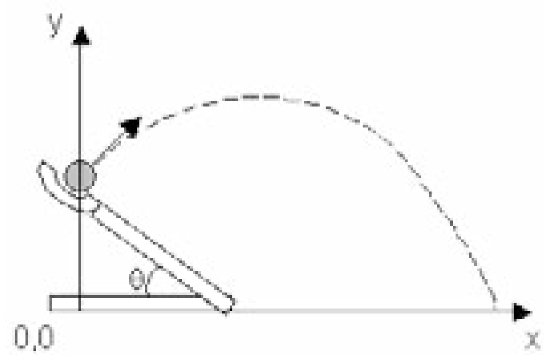


Projectile Motion

- The marshmallow follows projectile motion, governed by the equations

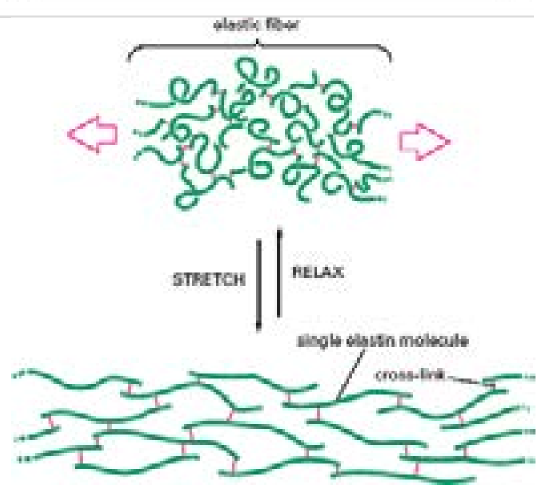
$$d_i = v_i t + \tfrac{1}{2}a^2$$
$$v_f^2 = v_i^2 + 2ad$$
$$v_f = v_i + 2at$$

- You would solve these by solving for the y-direction first for time, then plugging that into the x-direction to find the final horizontal displacement, which is where the marshmallow should land.
- For elementary schools, you should not try to teach the equations, but describe the parabolic flight path of the marshmallow and show how it is similar.
- Barring air resistance or wind, the marshmallow should follow the same path due to this "physical determinism."



Rubber Energy Storage

- When you pull the rubber band back, you store energy.
- You can feel how much energy it has when you get hit by one. That's the kinetic energy being transfered into your body.
- Teach the students that rubber bands store potential energy when you stretch them and release kinetic energy when you let them go.
- The farther you stretch the band, the more return force you have.
- Aside for mentors: Rubber band elasticity is temperature-dependent. Rubber bands are formed of rubber polymers, which you can think of as long strings that tangle together. Because of the chemical cross-linking of the rubber, stretching it reduces the number of possible states and thus reduces the entropy. Thus, when you add heat to the rubber band, the system will tend towards the direction to maximize entropy; it will tends un-stretching or contraction. So when you heat up a rubber band, it will contract, which is very different from how most materials work. Conversely, if you stretch a



rubber band, you can feel heat; try this with a rubber band between your lips. You can also test this by hanging a weight by a rubber band, then heating it up to pull the weight up. The rubber polymer does not store energy in stretched chemical bonds, but rather in the entropy of the chemical cross-linking. When you stretch a rubber band, the work you put in goes turns immediately into heat energy. The elastic nature that pulls it back in is actually not due to potential energy, but due to its favored entropic state.
tl;dr: Rubber bands aren't springs.

Hints/Tips for Building

• Keep the catapults you make during the DeCal to use as examples during your mentoring session.
• The design and instructions shown are simple, and may not make the optimal catapult. Allow the mentees to have freedom in their designs.
• The simplest possible catapult is a utensil taped on top of a cup.
• Triangles are strong, which is why my design uses them as the sides.
• Sandwich Popsicle sticks and tape them together to make stronger beams.
• The fulcrum of the lever should stay as rigid and static as possible. Do this by reinforcing the area with tape.
• You need the rubber band to be under a lot of tension. To do this, coil it around itself and tape the coil down.
• Building in 3D is difficult for young kids, so make sure to help them with it. I've found it convenient to stay in 2D then fold everything together into a 3D structure as late as possible.

Things to Try

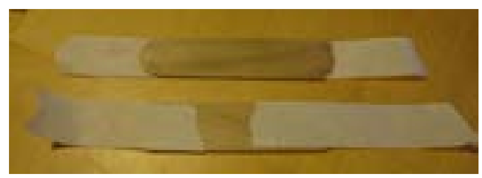
• Vary the number of rubber bands or fold one over.
• Vary the rubber band tension or thickness.
• Change the marshmallow's trajectory to more horizontal or more of a vertical arc. Does the triangluar structure have anything to do with the typical vertical artc?
• Change the length of the lever arm.
• When testing, set out cups at different distances to try to knock down or launch into.
• The catapult design included here acts like a lever. Have students point out lever components on their finished design.
• How does changing how high up along the utensil the rubber band is attached change the projectile's trajectory? If you want your projectile to go in a higher (more vertical) arc then move this stopping bar down closer to the fulcrum. If you want a lower (more horizontal) trajectory then raise the stopping bar so it is farther from the fulcrum.
• What trajectory is best for knocking a cup over? A more horizontal one.
• What trajectory is best for landing a projectile into a cup? A more vertical one.
• Mentors, compete against your mentees to motivate them to think creatively!

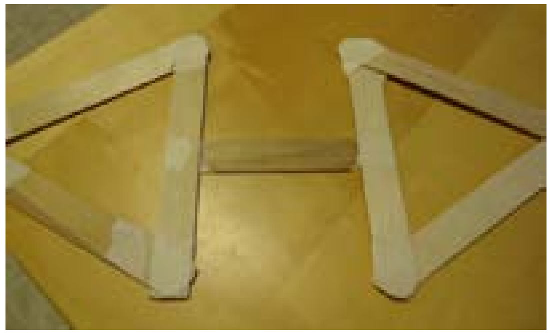
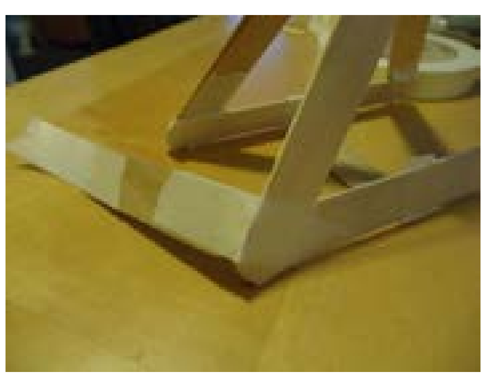
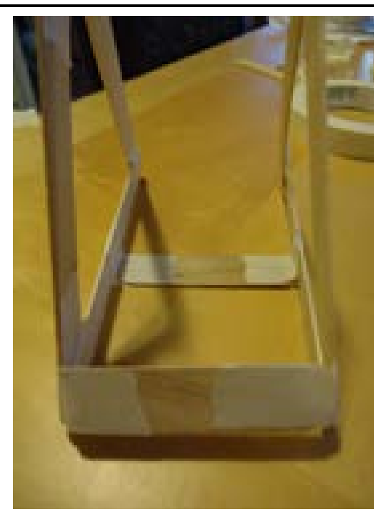
References

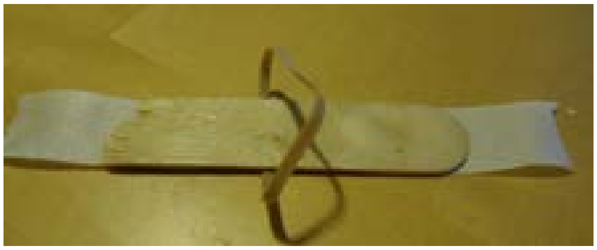
http://www.stormthecastle.com/catapult/popsiclestick-catapult.htm
http://www.squidoo.com/catapult-lessons#module147195911
http://en.wikipedia.org/wiki/Lever
http://en.wikipedia.org/wiki/Torque
http://en.wikipedia.org/wiki/Rubber_band
http://io9.com/5724974/the-thermodynamics-of-rubber-bands
http://mdmetric.com/tech/torqcht2.htm

Material	**Amount Per Group**	**Expected $$**	**Vendor**
Popsicle sticks	10-15	$5 per box	Artist & Craftsman Supply
Masking tape	roll		ACE
Rubber bands	1-2	$5 per bag	Dollar Store
Mini marshmallows	4-5		Dollar Store
Plastic spoons	1		Dollar Store
Paper			
Cups			Dollar Store

A Step-by-Step Basic Catapult

1. Arrange three sticks into triangle on a flat surface. These will form the sides of the catapult.	
2. To tape the corners of the triangles, start by taping along one edge, then the other.	 
3. You should have two triangles now.	
4. To build the cross-supports, break two Popsicle sticks in half. Place two strips of tape on the opposite ends of the half-sticks such that the tape hangs off the end.	 

5. Lay the triangles flat and tape the tape the cross-support between them. Have tape tabs ready for when you fold the triangle sides up into a 3D structure.	 
6. Fold the sides up and tape the bottom cross-support down firmly with the tape tabs. It will still be very flimsy, which is why we want to add another cross-support.	
7. Add a cross-support in the front. Keep in mind that the taping will be a bit awkward because you will be taping at an angle. We now have two cross-supports.	 

8. Attach a small strip of tape to the end of your utensil. You'll use this to attach it to the 2nd cross-support you just added.	
9. Tape the utensil to the support, but give yourself about ½ inch of a gap of empty tape between the Popsicle stick and the plastic so that it can swing freely. Then tape over the empty tape so that you have a two tape-thickness hinge. This part of the catapult acts as a fulcrum.	
10. Add another cross-support on the opposite side. It is below the fork prongs in the image to the right.	
11. A better term for the last cross-support is a stopping bar because it halts the utensil's movement. Make sure to loop a rubber band around the half-stick so that it will stay in place once the stopping bar is taped down.	

12. Tape the stopping bar down, allowing the rubber band to hang freely. The stopping bar is where the force is applied.	
13. Loop the rubber band over the utensil. You'll have to stretch the rubber band to do so.	

14. Twist the rubber band and tape it down to increase its tension. This increases the force that can be applied to the lever.	 
15. Done!	See first page for pictures.