Over Your Feet, Part 2 (Science of Dance)
Things don't fall when their center of mass is over their base

Recommended Grade Level:
6th- 12th grade

NGSS Science & Engineering Practices:
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations

Time: 30 minutes in class; 2 hours to make the first time

Materials Needed:
(per group)

- One each: rectangular piece of 2 x 4, trapezoidal piece of 2 x 4, irregular piece of 2 x 4 (see below)
- 3 pushpins with flat heads
- 3 pieces of string approximately 10 cm long
- 3 heavy nuts
- 3 12 x 24 x ¾ inch plywood boards

Background Information:
An object's center of mass is defined as the average position of the mass of the object, weighted by how far it is from a reference point.. For many purposes, the force of gravity on an object can be considered to arise from the center of mass.

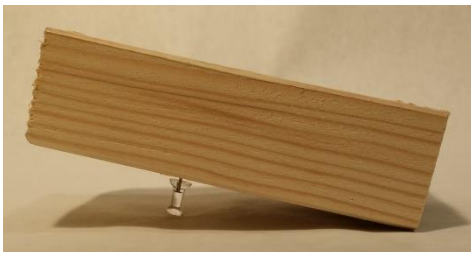
If an object starts with its center of mass at rest over its base (footprint) then it is stable. If the object is rotated around an edge, it will fall back onto its base as long as the center of mass doesn't get past the edge.

To Do and Notice:

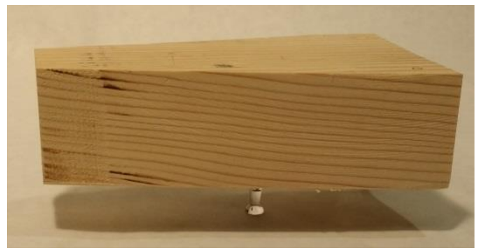
1. Cut three pieces of 2 x 4 (actually closer to 1½ inches x 3½ inches) into a rectangle with approximate dimensions of 3½ x 5 inches, an isosceles trapezoid with one base of 3½ inches and another base of 1½ inches, and

another into an irregular convex shape.

2. Find the center of mass of each object. One way to do this: guess the center of mass and put a pushpin in that location. Turn the object over and try to balance it on the flat side of the pushpin. If it balances, you are done. If not, you'll need to move the pin. Move the pushpin a little towards the lower side.

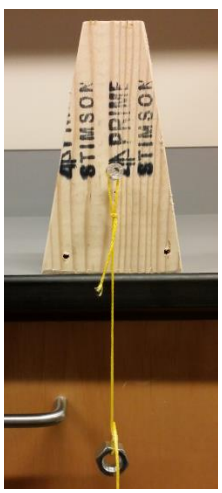


Move the pin to the right.

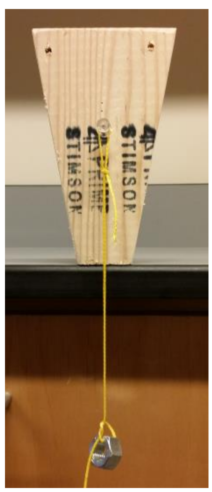


Now it's balanced.

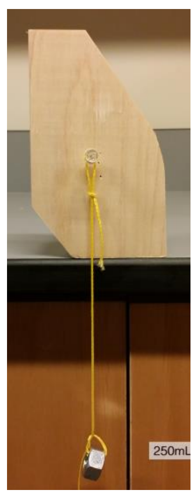
3. Tie a nut to one end of the string and tie the other end to the pushpin. Place on the edge of the table. Allow the string to hang down.

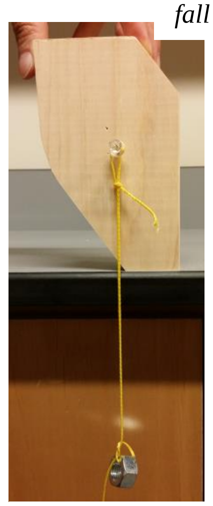


Balanced.



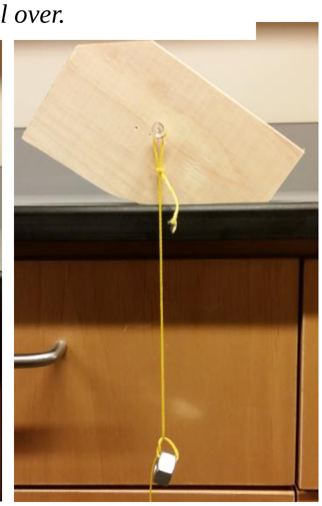
Even upside down.



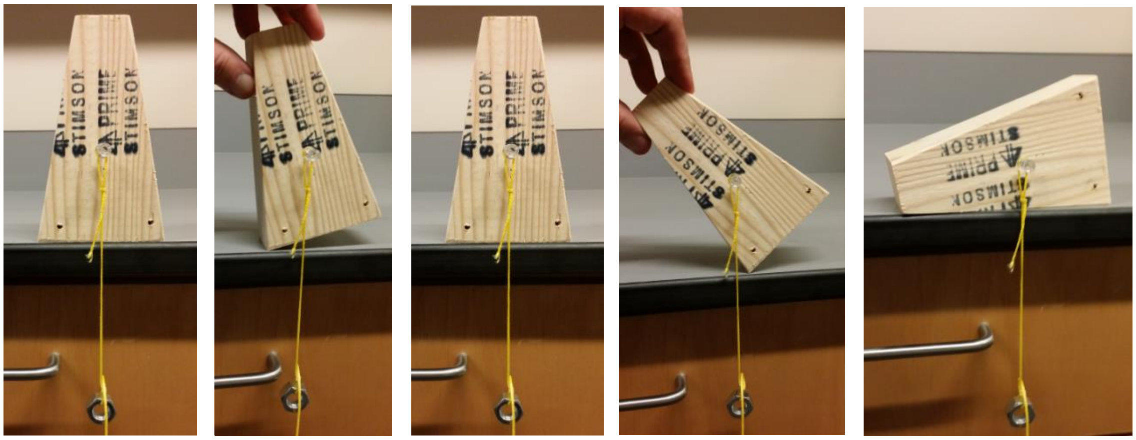


Oops! The center of mass isn't over the base.

That causes the block to fall over.



4. Tilt a block around an edge a little bit and let go. See which way the block rotates.

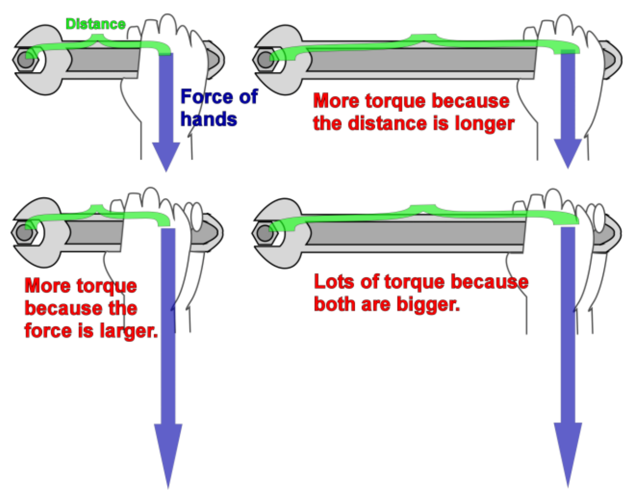


If the block starts like this, *a small rotation around an edge* *won't topple the block over,* *but a bigger rotation* *will.*

5. Where the edge of the block touches the counter acts as an axis of rotation, also known as a fulcrum, sort of like the center of a seesaw. Like a seesaw, the side that has the most mass the farthest from the fulcrum will "win" the battle, and the block will rotate downwards on that side.

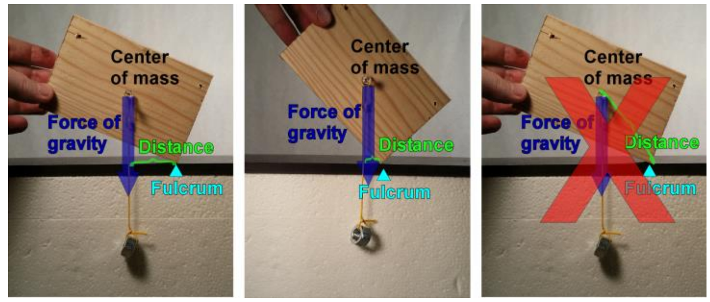
6. The center of mass is a shortcut (shown by the hanging string), though. Since it is possible to think of the mass of the block being concentrated at the center of mass, it automatically shows which side of the fulcrum has the greater desire to turn.

What's Going On?
Unbalanced torques cause objects to change their rotation. What causes a torque? A torque is a force applied to an object some distance away from the object's fulcrum. The bigger the force, the bigger the torque; the bigger the *perpendicular* distance away, the bigger the torque.



Since the weight of a block can be imagined to be at the block's center of mass, the center of mass can create a torque on the block by applying a force a perpendicular distance away from the edge.

The hard thing to remember is that it isn't the overall distance from the center of mass to the edge that counts. Rather, only the part of the distance that is the perpendicular distance



between the center of mass and the edge that contributes to the torque.

If the torque from the block runs into a surface, the surface can apply a torque back. This balanced torque won't start the object rotating. That's why if an object's center of mass is over its base, the object won't start to rotate.

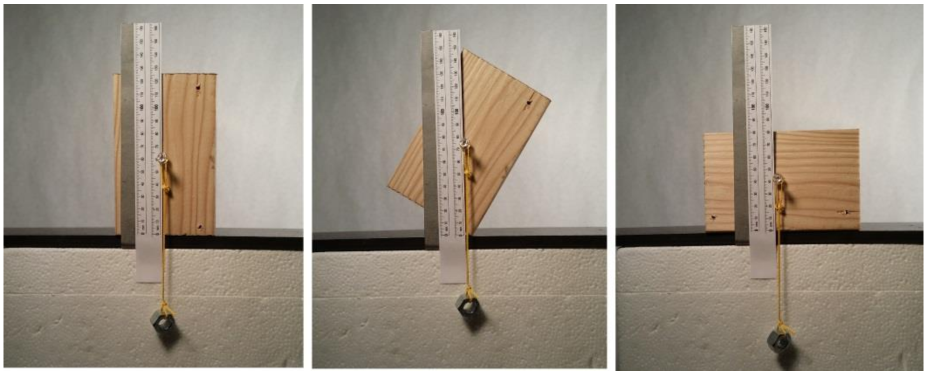
If the torque, however, doesn't run into the surface, then there is an unbalanced torque on it, and the block will start rotating.

The direction of the rotation will be the same as the direction of the unbalanced torque.

If dancers pictured here want to hold still without rotating, they need to put their centers of mass over their bases. If they don't do that, they will change their rotation.

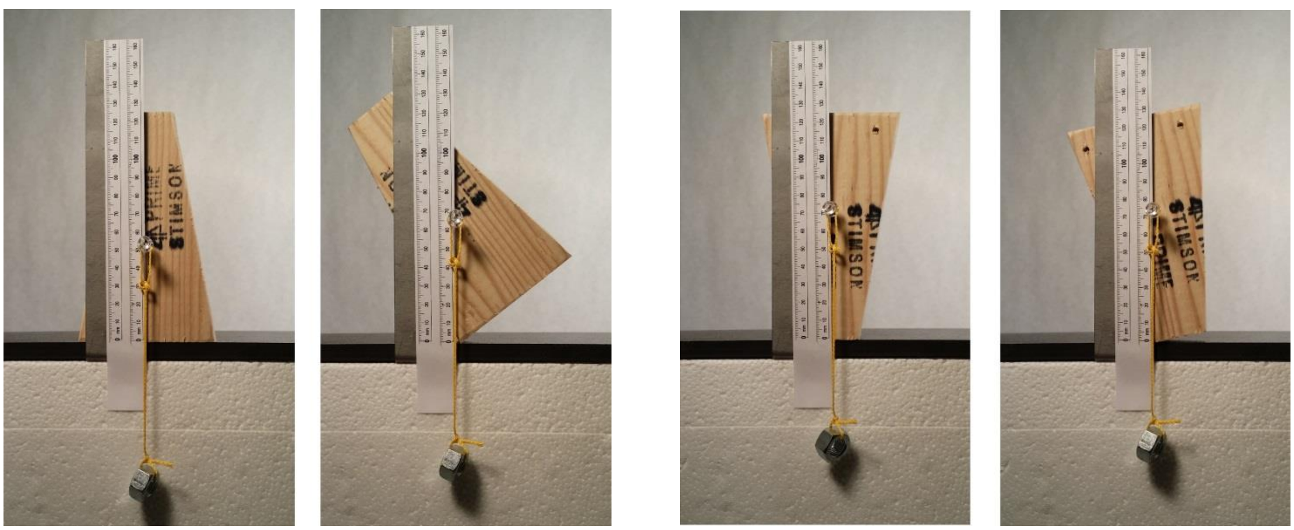
Going Further:

To make an object flip over, the object has to rotate enough so that its center of mass passes from one side of the fulcrum to the other. If the center of mass has to move upwards, that requires energy. The energy needed is proportional to the weight of the object and the amount it moves upwards. Thus, objects where the center of mass has to move more tend to be more stable.



In this example, the center of mass of the rectangular block starts at 61 mm moves up to 75 mm to flip over.

You can also determine how important the size of the base is.



With the wide side down, the trapezoid has to move from 53 mm to 65 mm. With the narrow side down, the trapezoid can flip with the center of mass—only moving from 73 mm to 75 mm.

This is important for dancers, too. When they need their greatest stability, for example in a lift, they often spread their legs to make a wide base.

References

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