611-0370 (40-105) Center of Gravity Paradox

Warranty and Parts:
We replace all defective or missing parts free of charge. Additional replacement parts may be ordered toll-free. We accept MasterCard, Visa, checks and School P.O.s. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse or normal wear and tear. Intended for children 13 years of age and up. This item is not a toy. It may contain small parts that can be choking hazards. Adult supervision is required.

How to Teach with Center of Gravity Paradox:

Concepts Taught: Center of gravity; angular acceleration; moment of inertia.

Curriculum Fit: Newton's Second Law; gravity.
Additional Materials Needed:

- Protractor

Theory:

What is the center of gravity? It can be defined as: *the point where the mass of an object is equally balanced.*
What is angular acceleration? It can be defined as: *the rate of change of angular velocity over time.*
What is angular velocity? It can be defined as: *the rate of change of angular displacement with respect to time*
What is mass? It can be defined as: *the amount of matter in a particular object.*
What is the moment of Inertia? It can be defined as: *the tendency of a body to resist angular acceleration.*
What is Newton's Second Law? It can be defined as: *the acceleration of a particle is directly proportional to the resultant external force acting on the particle and is inversely proportional to the mass of the particle.*

Where is the center of gravity in an object? An easy experiment is done using a standard ruler. Place the ruler horizontally on your index finger and slide your finger along until you find the location where the ruler is perfectly balance. You will need to support the ruler with your other hand until the "perfectly balanced" spot is located. The Earth's gravity acts on all objects by pulling on them as if the weight were concentrated at one point, the center of gravity. When an object, such as the ruler, is unbalanced the object is not stable and will fall. The balancing point must be exactly over the center of gravity, so that the gravitational force and the supporting force exactly cancel out (i.e., the object is stable). What happens when you raise or lower the perfectly balanced ruler on your fingertip? If done correctly, the object should remain on your fingertip and not fall.

Experiment 1: Rod and Mass

The four-foot aluminum rod with self-gripping brass mass is an inherently unstable system. Our intuition tells us that the rod is most stable when the heavier end (end with brass mass) is balanced on one fingertip. However, this is not the case as will be demonstrated below.

Kit Components Needed: Center of Gravity Paradox

Procedure:

1. Have one student be responsible for holding the rod and mass system.
2. According to the table on page three slide the mass to each position indicated.

Height (cm)	Tippage Angle (Θ)
30.00	
60.00	
120.00	
121.92	

3. As the system is unstable, it is imperative that a second student is waiting with a protractor. Just as the rod begins to tip at the designated heights in the table, this second student should use the protractor to measure the tippage angle and record the data in the table above.
4. Students will observe that the speed at which the rod with mass begins to tip is substantially greater in the lower mass system than in the high system.
5. Newton's Second Law of Motion states:

   $\alpha = T/I$

   α = angular acceleration
   T = torque applied to the system about a rotation pivot
   I = system's moment of inertia
6. Angular acceleration can be determined by the following equation:

   $$\alpha = \frac{g * \sin(\theta)}{h}$$

   g = acceleration due to gravity (9.8 N/kg)
   h = height (cm)

   Calculate values for each height and record them in the table below.

Height (cm)	**Angular Acceleration (α)**
30.00	
60.00	
120.00	
121.92	

Discussion:
The angular acceleration is greatest in the scenario with the lowest height (cm) and thus requires a much quicker response time when attempting to balance the rode with mass. How do we minimize the speed with which the tipping occurs? We can increase the moment of inertia of the system by raising the mass.

Optional Experiment: Coins on a Ruler
Materials Needed: Standard 12 inch ruler and six pennies

Procedure:
1. Place a ruler on your fingertip so that it is perfectly balanced (cm marks should be readable by the person holding the ruler).
2. Have another student place one penny exactly on the one cm mark of the ruler. This is your "balance" penny. This penny will remain stationary on the ruler. It should not be moved for the rest of the experiment. This student should place another penny at the opposite side of the ruler from the "balance" penny. Move the coin until the ruler is perfectly balanced.
3. Record the position of the penny that moved below.

   Position of penny (cm) = ____

4. Continue adding pennies to the penny that moved (i.e., two pennies on top of each other, etc.). Move the pennies until the ruler is balanced and record the position below.

   Position of penny (cm) = ____

Discussion
1. What is the greatest number of pennies that can be balanced on one side of the ruler with only one penny at the 1 cm position?

   ____