CENTER OF GRAVITY

PROBLEM PRESENTATION / EXPLORATION

A. Balancing a meter stick
   1. Tie two objects with identical weight to opposite ends of a meter stick, at the 5 cm mark and the 95 cm mark.
   2. Balance the system on your forefinger, horizontally, by sliding it along the meter stick until one side or the other doesn't dip down.
   3. Now, substitute for the object at the 95 cm mark something that doesn't have the same weight as the one at the 5 cm mark. Can you find a place where this system can be made to balance?

B. Balancing a broom
   1. Find the place where you would have to move your finger on a broom handle so that it will balance when held horizontally. Is it closer to the heavier or lighter end?
   2. Now hold it vertically and balance it on the tip of your finger.
   3. If the top end tends to fall to the left, what do you do to keep it balanced? If the top end tends to fall to the right, what do you do to keep it balanced?

C. Balancing the state of Tennessee
   1. Cut out a map of Tennessee and paste it to corrugated cardboard. Now cut the cardboard around the boundary of the map. This will give you a flat map of Tennessee about 1 cm thick.
   2. Holding the map horizontal to the floor, where would you place your finger underneath it to make it balance on the tip of your finger?

CLASS RESPONSE / CONCEPT INVENTION

A. The point at where all the mass seems to be concentrated (right where your finger can balance the whole system) is called the CENTER OF GRAVITY.
   1. For a symmetrical object the center of gravity is located exactly at the heart of the object.
   2. For a nonuniformly weighted object, like the broom, the center of gravity is located more toward the heavier end.
   3. For an irregular object, like the map of Tennessee, the place where all of the mass seems to be concentrated (in other words where could we put our finger to support the whole state) must be found experimentally.

B. Finding the center of gravity of Tennessee
   1. Stick a long straight pin through Chattanooga on the map and push it through so that the pin will stick to a cork bulletin board on the wall (or large cardboard box sitting on the table). The map must be able to freely swing around the pin.
   2. Attach a heavy object such as a lead fishing sinker to a piece of thread and tie the thread to the straight pin so that it hangs down vertically. About 20 cm down the thread put a second straight pin right next to where the thread crosses the map.
   3. Remove the thread and heavy object and connect the two pins by stretching a thin rubber band from the first to the second pin. This will indicate where the thread hung down.
   4. Proceed to Memphis and repeat steps 1, 2, and 3.
   5. Because the map was hanging freely, the center of gravity must be somewhere on the line made up of the first two pins. Likewise, it must be on the line joining the second two pins. Where is the only point common to both of those lines? This must be the center of gravity. Place your finger under this point and attempt to balance the state of Tennessee. [The center of gravity is somewhere around Murfreesboro.]
   6. If you put another pin through Martin or Knoxville and repeated steps 1, 2, and 3, would this line cross at the same place as the other two? Try it!

C. Balancing a broom
   1. If the broom is held out **horizontally**, the pivot point [this is where your finger

can support the broom] and the center of gravity are at the same point.

2. Where must the pivot point be in relation to the center of gravity for the broom to balance **vertically**?
2. As long as the pivot point and center of gravity lie along the same vertical line the object will balance at the pivot point. But when the center of gravity starts to move right or left so that the pivot point and center of gravity are not on the same vertical line, the broom will tip. If we move the pivot point back under the center of gravity the broom can once again be brought into equilibrium.

C. Balancing a book

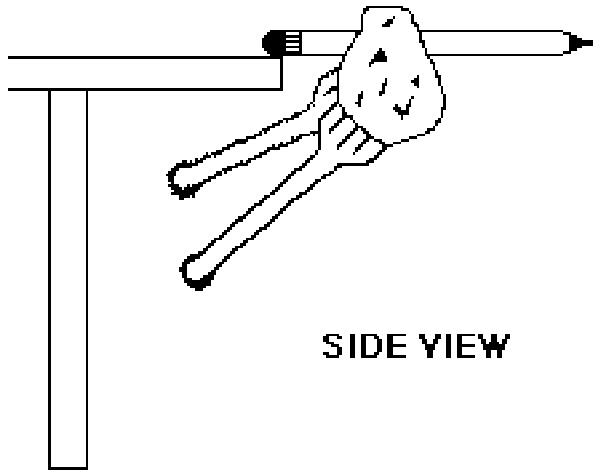
1. Place a book face down on a table. Now set it on its side. Finally, set it on its end. Which of these positions is the most stable for the book? In other words, which would be least likely to tip over if a small force were applied to it?
2. Where is the center of gravity with respect to the table for each position of the book? Are you more stable standing up in a row boat or sitting down in the row boat? Where is the center of gravity in with respect to the floor of the boat in each of these situations? Does the position of the center of gravity have anything to do with the stability of a system?
3. Try and stand a raw egg on its fat end. After a few tries, shake the egg vigorously and immediately set it down on its fat end. The yolk will become more mobile within the egg while shaking and will move down lower in the fat part of the egg. This lowers the center of gravity and the egg is much more stable.
4. In each of the three cases above t**he lower the center of gravity the more stable the system.** This is why powerful race cars are build low to the ground so that they are stable when cornering.
5. Arrange the angle of an inclined plane so that a book may be motionless while lying flat, but will fall over when placed on end.
6. In addition to raising the center of gravity when the book was stood on end, what other observation about the position of the center of gravity can you make that contributes to the book falling? [Setting the book on end not only raises the center of gravity (making it more unstable) but also moves the center of gravity so that it lies outside of the base of the book in contact with the plane and will result in the book toppling.]
7. What is the tallest stair step that can be made, before toppling, with 25 Lego® or Tyco® blocks. Each step may be no more that 1 cm steep. What key adjustment did you have to make to allow the stair step to get higher than 4 or 5 blocks? [The base had to be enlarged so that the center of gravity would not hang out over the base.]

CONCEPT EXTENSION

A. Locating the center of gravity when it falls outside the system

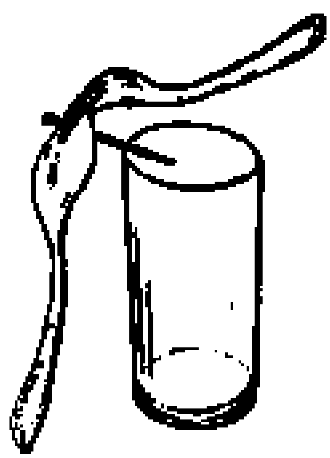
1. In every example above, except possibly the construction of the Lego® block stair step, the center of gravity has physically resided within the object under consideration.
2. At first, it might seem as though the center of gravity must remain within the object. To prove that this is not always the case do the following. Obtain a large fork and spoon, possibly those big wooden ones used for tossing salad, or two large barbecuing utensils. Interweave them so as to make a curved system. (The tines of the fork should fit around the spoon or spatula.) Another way would be to stick two large utensils into opposite end of a potato. Now, using the procedure for finding the center of gravity that we employed to find the heart of Tennessee, find the G.G. of this system. This will show that the center of gravity falls somewhere in between the utensils but not residing within either. It just hangs out there in the open air.
3. We have learned that as long as the center of gravity and pivot point are in the same vertical line that a system can be made to balance. Also we have seen that a system is more stable if the center of gravity can be lowered.

Therefore, we should be able to make the spoon/fork combination balance on the eraser end of a pencil by adjusting the position of the pencil so that the pivot point is directly below the center of gravity. This same feat is often illustrated by supporting a belt in a wooden holder and suspending the whole system on one's finger.



B. Challenges

1. It might be interesting for students to devise other seemingly impossible feats of balancing. Possibly a contest could be conducted for the most amazing system that can be constructed from common objects located around the home. Below are two that should get the ball rolling.
2. Take an ordinary spoon and fork. Attach the spoon to the fork by pushing it in between the tines. Place a toothpick between two of the fork's tines and let the system balance from the toothpick resting on the rim of a drinking glass. What do you think would happen if you lit the toothpick with a match? Light it from both ends. [Because it is perfectly balanced the toothpick will burn down to where it makes contact with the utensils and from the inside of the glass to the rim. During the whole process the system remains balanced.]



2. A hammer, a plastic ruler, and a short string can be made to hang over the edge of a table to seemingly defy gravity. But really all that is happening is that the center of gravity is directly below the pivot point and when adjusted place the system in equilibrium.

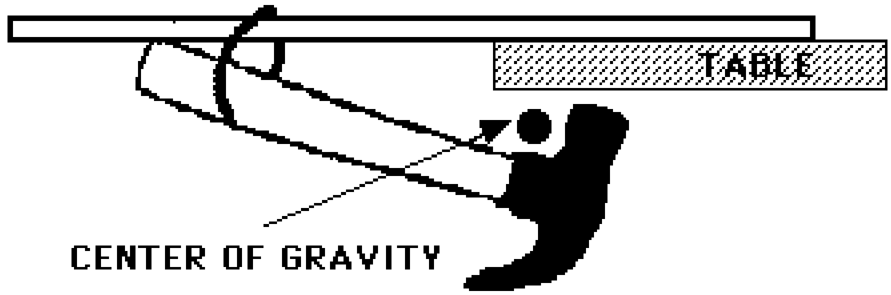


TABLE
CENTER OF GRAVITY