

Teacher Guide: Balancing Act

Class time: Approximately 50 minutes

Purpose: To learn the concepts of balance and stability, students can create various shapes, find their centers of gravity and test how well they balance.

Materials:

- Printed Student Guide ([Blackline Master 3](#))
- Identical meter sticks
- Identical rulers
- Large binder clips or small spring clamps
- Poster boards
- Scissors
- Single-hole punch
- Thumb tacks
- Cork board on wall
- String
- Fishing weight or other small mass for end of string
- Pencils
- Rubber mallets
- Inexpensive metal silverware of all sorts
- Modeling clay or corks
- Toothpicks
- Drinking glass or beaker
- Metal coat hangers that can be bent
- Blue painting tape

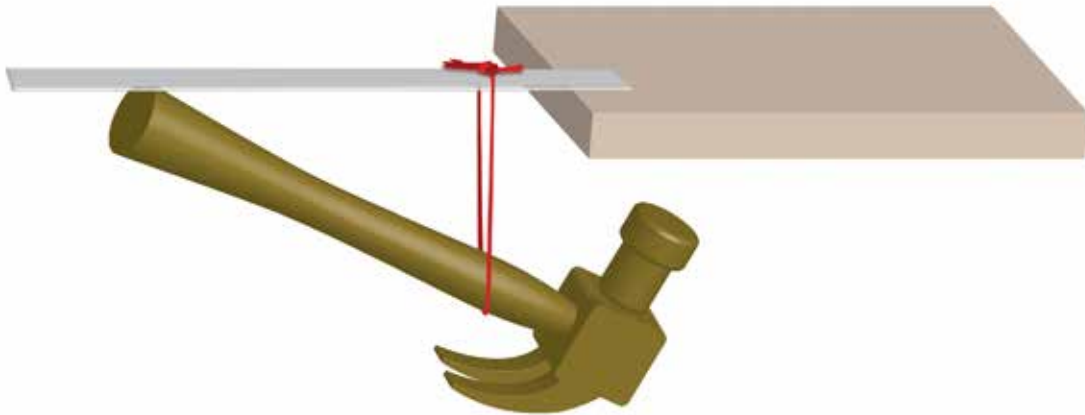
Notes to the teacher: When stood on end and released, a shorter stick will fall over faster than a longer stick. If two sticks are identical but have masses clipped on to them at different points, the stick with a lower center of mass will fall over faster. The simplest explanation you can give the students is that the lower the center mass is, the shorter distance it has to go to reach the ground. A more thorough explanation is that if the stick is pivoting about its lower end, a stick that is longer and/or has more mass higher up has a larger moment of inertia or rotational inertia; it is harder to start moving, and it must acquire more angular momentum to fall over, so it takes longer.

Thus it is advantageous for flamingos to be as tall as possible, and to have most of their mass as high up

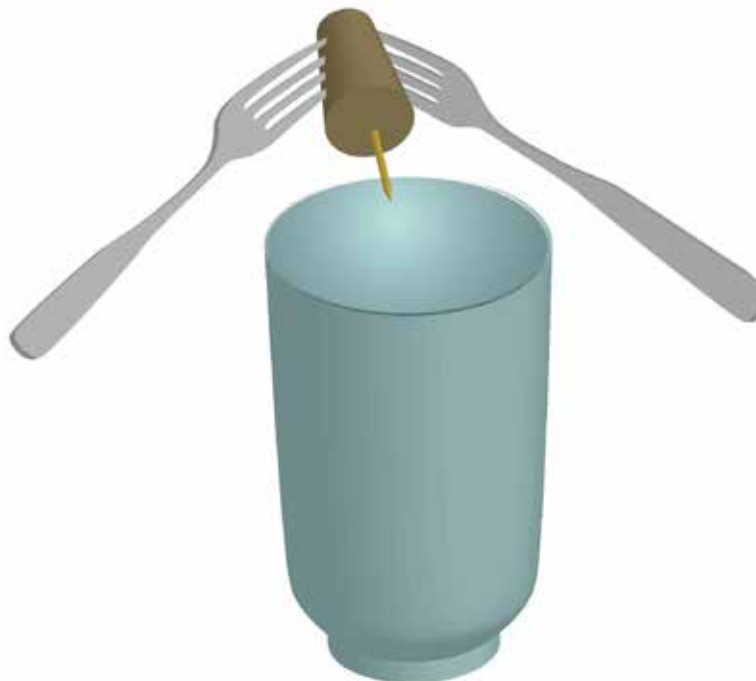
as possible. That makes them fall over more slowly, and gives them more time to react and apply muscles in the opposite direction if they do start to lean over.

Using the supplies provided, students can build creative shapes that do not look as if they should balance, but do anyway. If students need examples of such shapes to get started, here are some popular ones that you can create in your classroom:

- Object composed of a ruler, string, and hammer hanging on the edge of a table:
Note: It looks as if it should fall off, but it does not, since the center of mass for the combined object is directly below the point of suspension (the table), not beyond the edge of the table.



- Object composed of two forks, a cork (or modeling clay), and a toothpick hanging on the edge of a drinking glass or beaker:
Note: It looks as if it should fall off, but it does not, since the center of mass for the combined object is directly below the point of suspension, not beyond the edge of the glass.



Student Procedure (answers included):

Part 1: Center of mass in one dimension

1. Balance a meter stick (flat side down) on the edge of a ruler, like a seesaw. Why must the meter stick's center of mass be directly above the ruler edge for the meter stick to balance? [*The meter stick will balance if the center of mass is directly above the ruler edge on which it is suspended. If the center of mass is off to the side, the force of gravity pulling downward on the center of mass will rotate the meter stick.*]
2. Where is the center of mass of the meter stick? Be as specific as possible, using the measurements on the meter stick. [*The center of mass should be at the center of the meter stick, at approximately the 50cm mark.*]
3. Attach a large binder clip or small clamp to the meter stick. Record where you attached it: [*Students' answers will vary.*]
4. Find the new center of mass of the meter stick and record it. Why has it changed? [*The center of mass moves toward the binder clip or clamp.*]
5. Attach more binder clips or clamps to the meter stick and record their locations. [*Students' answers will vary.*]
6. Where is the center of mass of the meter stick now? Why? [*The center of mass will shift depending on the locations of the binder clips or clamps.*]
7. Place the meter stick flat on the table so that it hangs over the edge. In order for the meter stick not to fall off the table, where must the center of the mass of the meter stick be relative to the edge of the table? [*The center of mass must be within the boundary of the table, not over the edge of the table.*]
8. If a flamingo standing on one leg ceased to adjust its balance, it might fall over. Do you think a tall flamingo or a short flamingo would fall over faster and hit the ground sooner? Write down your prediction below. [*Students' answers will vary.*]
9. Test your theory. Stand a meter stick vertically on its end on a table, and a ruler vertically on its end on the table. Since we're not using flamingos, the meter stick and ruler will be our tall and short flamingos, respectively. Let go of the meter stick and the ruler at the same time. Which one hits the table first? Repeat the experiment several times. What are your results? [*The ruler should hit the table before the meter stick.*]
10. What determined which "flamingo" hit the table first? Why? What does this tell you about the balance of different flamingos? [*A shorter flamingo will fall over faster than a taller flamingo. The simplest explanation is that the lower the center mass is, the shorter distance it has to go to reach the ground. A more thorough explanation is that if the flamingo is pivoting about its foot, a flamingo that is*

taller has a larger moment of inertia or rotational inertia; it is harder to start moving, and it must acquire more angular momentum to fall over, so it takes longer. Thus it is advantageous for flamingos to be as tall as possible. That makes them fall over more slowly, and gives them more time to react and apply muscles in the opposite direction if they do start to lean over.]

11. Take two identical meter sticks and stand them vertically on end on a table, and let them fall over. Repeat the experiment several times. Does one tend to hit the table before the other, or both at the same time? Why? *[Two identical meter sticks should hit the table at approximately the same time.]*
12. Repeat the experiment with two identical meter sticks, but attach a large binder clip or small clamp to the top of one meter stick, and a large binder clip or small clamp to the lower part of the other meter stick. If you let the meter sticks fall over, which one hits the table first in repeated trials? Why? What does that tell you about the balance of different flamingos? *[When stood on end and released, a shorter stick will fall over faster than a longer stick. If two sticks are identical but have masses clipped on to them at different points, the stick with a lower center of mass will fall over faster. The simplest explanation is that the lower the center mass is, the shorter distance it has to go to reach the ground. A more thorough explanation is that if the stick is pivoting about its lower end, a stick that is longer and/or has more mass higher up has a larger moment of inertia or rotational inertia; it is harder to start moving, and it must acquire more angular momentum to fall over, so it takes longer. Thus, again, it is advantageous for flamingos to be as tall as possible, and to have most of their mass as high up as possible. That makes them fall over more slowly, and gives them more time to react and apply muscles in the opposite direction if they do start to lean over.]*

Part 2: Center of mass in two dimensions

13. Use scissors to cut a large shape out of poster board. Make the shape as weird as you want—it can even have tentacles, as long as it is all one piece. Punch several holes near the outer edge of the shape—say one at the top, one at the bottom, one on the left side, one on the right, or a couple more if you would like. Attach your shape to a corkboard on the wall using one thumbtack in one hole. Make sure the shape is free to rotate around the thumbtack. The shape should rotate until its center of mass is directly below the thumbtack. Why would that be true? *[The shape will not move if the center of mass is directly below the hole from which the shape is suspended. If the center of mass is off to the side, the force of gravity pulling downward on the center of mass will rotate the shape.]*
14. Cut about a meter of string and tie a weight to the end of the string. You can hold the other end of the string. Thanks to gravity, if the string isn't swinging, it should always be vertical. Hold the top of your string at the thumbtack that is holding up your poster board shape, and hook it around the thumbtack. Let the string and weight hang down past your shape. Use a pencil to draw a vertical line down the shape where the string falls. Why should the center of mass be somewhere along that line? *[The force of gravity is pulling directly downward on the center of mass. Therefore, if the object is balanced, the string, which indicates the direction of the force of gravity,*

should intersect the center of mass.]

15. Now mount the shape to the corkboard using a different hole, and see how the shape wants to hang. What makes the shape stop rotating? *[The shape will not move if the center of mass is directly below the hole from which the shape is suspended. If the center of mass is off to the side, the force of gravity pulling downward on the center of mass will rotate the shape.]*
16. Use your weighted string to draw a vertical line down the shape from the hole by which it is currently hanging. Why should the center of mass be somewhere along that line? *[The shape always rotates to put the center of mass directly below the hole from which the object is suspended.]*
17. Based on your two lines, where is the center of mass of the object? *[The center of mass is at the intersection of the two lines.]*
18. Try mounting the shape to the corkboard using other holes. Do you find the same location for the center of mass? Why? *[Yes. The shape always rotates to put the center of mass directly below the hole from which the object is suspended.]*

Part 3: Center of mass in three dimensions

19. From your part 1 and part 2 experiments, for an object not to fall off a table, where must the object's center of mass be relative to the edge of the table? *[The center of mass must be within the boundary of the table edge, not beyond the table edge.]*
20. From your experiments above, for an object to be stable (not wobbling or falling over), where must its center of mass be relative to the point that supports the object? *[The center of mass must be directly below the point of support.]*
21. Based on your answers to 19 and 20, construct an object that looks like it should fall over but does not (because of the location of the center of mass for the whole object). Your teacher can give you ideas if necessary. Describe or draw your object. Why does it stay balanced? *[Provide examples listed in the notes above.]*
22. How many other freaky balancing objects can you construct? Describe or draw them. *[Students' creations may vary.]*

Analysis:

23. Where is the center of mass of a flamingo standing on one leg? *[Approximately at the top of the leg, in the center of the body.]*
24. Where is the point of suspension for a flamingo standing on one leg? *[The ground provides an upward force of suspension to the bottom of the foot.]*
25. Based on your experimental results, would a flamingo be naturally stable (without using its brain and muscles)? Why or why not? *[No. Without active feedback control, any slight leaning would cause*

the flamingo to lean over further and further until it falls.]

26. Based on what you found, why is it evolutionarily advantageous for flamingos to be built the way they are? *[By being very tall and having most of their mass concentrated at the top, flamingos naturally fall over more slowly, so they have longer to make small muscle movements to counteract their motion if they start to lean over.]*

Student Guide: Balancing Act

Purpose: To demonstrate the concepts of balance and stability by creating various shapes of objects, finding their centers of gravity and testing how well they balance.

Background: The center of mass (or center of gravity in a uniform gravitational field), is the point within an object where half of the object's mass is to the left of that point and half to the right of it, half of the object's mass is above that point and half is below it, and half of the object's mass is in front of that point and half is behind it. Thus it is the averaged center of the object's mass. The center of mass may not be the actual center of the object or even on the object—for example, if one side of the object is especially heavy, the object's center of mass will be closer to that side. Or, a doughnut's center of mass would be located in the hole of the doughnut. The force of gravity pulls directly downward from an object's center of mass.

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- Inexpensive metal silverware of all sorts
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Procedure:

Part 1: Center of mass in one dimension

1. Balance a meter stick (flat side down) on the edge of a ruler, like a seesaw. Why must the meter stick's center of mass be directly above the ruler edge for the meter stick to balance?
2. Where is the center of mass of the meter stick? Be as specific as possible, using the measurements on the meter stick.
3. Attach a large binder clip or small clamp to the meter stick. Record where you attached it:
4. Find the new center of mass of the meter stick and record it. Why has it changed?

5. Attach more binder clips or clamps to the meter stick and record their locations.

6. Where is the center of mass of the meter stick now? Why?

7. Place the meter stick flat on the table so that it hangs over the edge. In order for the meter stick not to fall off the table, where must the center of the mass of the meter stick be relative to the edge of the table?

8. If a flamingo standing on one leg ceased to adjust its balance, it might fall over. Do you think a tall flamingo or a short flamingo would fall over faster and hit the ground sooner? Write down your prediction below.

9. Test your theory. Stand a meter stick vertically on its end on a table, and a ruler vertically on its end on the table. Since we're not using flamingos, the meter stick and ruler will be our tall and short flamingos, respectively. Let go of the meter stick and the ruler. Which one hits the table first? Repeat the experiment several times. What are your results?
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15. Now mount the shape to the corkboard using a different hole, and see how the shape wants to hang. How does the shape decide when to stop rotating?

16. Use your weighted string to draw a vertical line down the shape from the hole by which it is currently hanging. Why should the center of mass be somewhere along that line?

17. Based on your two lines, where is the center of mass of the object?

18. Try mounting the shape to the corkboard using other holes. Do you find the same location for the center of mass? Why?

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