

ScienceNews

IN HIGH SCHOOLS | EDUCATOR GUIDE



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June 24, 2017

Flamingos' Bones Favor One-Leg Stance



SOCIETY FOR
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About this Issue

The article "[Flamingos' bones favor one-leg stance](#)" (10.8 readability score) discusses recent experiments that measured how difficult it is for flamingos to balance on one leg and explores flamingo anatomy to determine how it might account for the unusual pose. Students can focus on details reported in the article, follow connections to earlier articles about birds and balance, explore cross-curricular connections to other major science topics, and test the balance of structures that they build.

Science News for Students provides another version of this article written at a lower Lexile level (7.4 readability score): "[Flamingos' bones favor one-leg stance](#)." [Power words](#) are defined at the end of the *Science News for Students* article.

Want to introduce your students to an interesting STEM career related to this article? Check out [Cool Jobs: Motion by the numbers](#) (7.9 readability score) by *Science News for Students*.

Read more about the flamingo and its place in the bird family tree by reading "[Bird DNA leads to strange family tree](#)" (7.6 readability score) in *Science News for Students*. Or, find out more about technology that flies like a bird by reading "[These drones are for the birds](#)" (6.4 readability score) in *Science News for Students*.

Connections to Curricula:

Bird Anatomy
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Evolution
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Muscles
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Feedback control
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Stability
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Center of mass
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Center of gravity
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Force
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Balance
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Buoyancy

What's in this Guide?

- [Article-Based Observation](#): These questions focus on reading and content comprehension by drawing on information found in the article "[Flamingos' bones favor one-leg stance](#)." Questions focus on flamingo anatomy and center of gravity and recent research measuring how well flamingos balance on one leg.
- [Quest Through the Archives](#): With Internet access and your school's digital access to *Science News*, your students can use this short section to explore other articles about the history of research on birds as well as about balance problems in humans as reported by *Science News* since 1924.
- [Cross-Curricular Discussion](#): These questions and extension prompts connect to the article "[Flamingos' bones favor one-leg stance](#)" and encourage students to think in more detail about scientific areas related to the article. The section is subdivided roughly by science discipline for educators who would like to focus on one particular topic area. The extension prompts are either

more topic specific or more conceptually advanced. **Physical Sciences** questions focus on stability and center of mass. **Engineering and Experimental Design** questions discuss the stability of a wide variety of structures and vehicles.

- **Activity:** Like flamingos, students can perform their own balancing act. They can create their own structures, note where the center of gravity is and test how well the structures balance.

Standards Alignment

Next Generation Science	Common Core
Motion and Stability: Forces and Interactions: HS-PS-2-1 , HS-PS-2-2 , HS-PS-2-3 , HS-PS2-6	ELA Standards: Reading Informational Text (RI): 1, 2, 4, 5, 7
From Molecules to Organisms: Structures and Processes: HS-LS1-1 , HS-LS1-2 , HS-LS1-3 , HS-LS1-6	ELA Standards: Writing (W): 1, 2, 3, 4, 6, 7, 9
Biological Evolution: Unity and Diversity: HS-LS-4-2 , HS-LS-4-3 , HS-LS-4-4	ELA Standards: Speaking and Listening (SL): 1, 2, 4, 6
Engineering Design: HS-ETS1-1 , HS-ETS1-2	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 4, 7, 8, 9
	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 6, 7, 9

Article-Based Observation

Directions: Read the article "[Flamingos' bones favor one-leg stance](#)," and then answer these questions:

1. What were scientists trying to determine about flamingos, according to the article? Summarize what they studied.
2. What does neuromechanist Lena Ting study, in general? How would you describe the field of neuromechanics?
3. How did Lena Ting and Young-Hui Chang test flamingo balance? Specifically, what data was measured in their study?

4. The graphic “Wobbly Ways” (also below) shows the researchers’ data on shifts in pressure from flamingo feet. Summarize the findings and state their importance.

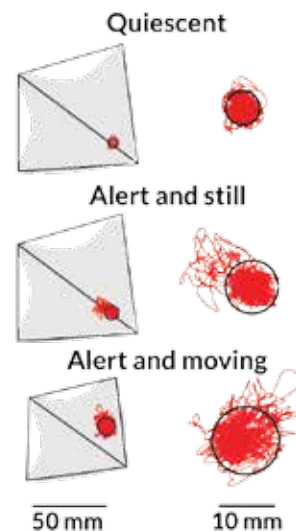


5. Does a flamingo expend less energy when it stands on one leg than when it stands on two? Explain.

6. Describe the flamingo's leg anatomy. How does it compare to human anatomy?
7. The new study examines how a flamingo stands on one leg, but not why. What did comparative psychologist Matthew Anderson give as a possible explanation for why flamingos do this? What other factors can you think of that might affect how a flamingo stands?
8. Try to stand on one leg like a flamingo. Taking leg anatomical differences between flamingos and humans into account, what would this position look like? What do you observe about your own balance?

Responses to Article-Based Observation

1. **What were scientists trying to determine about flamingos, according to the article? Summarize what they studied.** Possible student response: Scientists were trying to determine how flamingos stand on one leg by studying their unique anatomical structure and its function. The research provided insight into how a flamingo stands on one leg.
2. **What does neuromechanist Lena Ting study, in general? How would you describe the field of neuromechanics?** Possible student response: The article mentions that Lena Ting does research to measure the postural sway in standing humans and other animals. Neuromechanics studies the interaction of the nervous system with mechanical activity by living organisms. Neuromechanics is an interdisciplinary field of neurology and biomechanics.
3. **How did Lena Ting and Young-Hui Chang test flamingo balance? Specifically, what data was measured in their study?** Possible student response: Ting and Chang tested balance in young Chilean flamingos using an instrument that measured their sway. As a flamingo wobbled, its pressure center varied and was recorded by the instrument. The approximate area of pressure variance was measured while the scientists observed and recorded certain flamingo behaviors (quiescent, alert and still, and alert and active).
4. **The graphic “Wobbly Ways” (also below) shows the researchers’ data on shifts in pressure from flamingo feet. Summarize the findings and state their importance.**



Possible student response: When a bird was at rest, its center of pressure wobbled within a radius of about 3.2 mm. When the bird was alert and moving, its center of pressure wobbled within a radius of 5.1 mm. When the bird was alert and still, its center of pressure wobbled within a radius roughly 4.6 mm (using the diagram to estimate). Scientists found that the least wobbling occurred when the birds had tucked their heads in for a nap. This data shows that flamingos are very stable on one leg and use the least amount of muscle effort to balance while resting or sleeping.

5. Does a flamingo expend less energy when it stands on one leg than when it stands on two? Explain.

Possible student response: The study showed that a dead flamingo specimen's body was more stable on one leg than on two, but it does not prove that flamingos' one-legged stance allows them to expend less energy overall. As scientist Reinhold Necker points out, for example, the recent study does not measure the energy required to retract the second leg up to the body.

6. Describe the flamingo's leg anatomy. How does it compare to human anatomy? Possible student response: The hip and knee are inside the flamingo's body. A flamingo's ankle bends backward in the center of the exposed leg, about where the human knee would be. According to scientists, the bones don't seem to have a locking mechanism but do have features that would facilitate standing. The flamingo's center of gravity is close to the knee, which is inside its body and at the top of the column that extends to the ground to support the bird. A human's center of gravity while standing is not directly above one leg, whether the other leg is tucked up or not.

7. The new study examines how a flamingo stands on one leg, but not why. What did comparative psychologist Matthew Anderson give as a possible explanation for why flamingos do this? What other factors can you think of that might affect how a flamingo stands? Possible student response: Anderson found that more flamingos rest on one leg when temperatures drop, so it may also be a way of keeping warm. Other environmental factors could affect a flamingo's stance, such as whether the flamingo is standing in water or not. Flamingos' age, sex and health might also affect its preferred stance.

8. Try to stand on one leg like a flamingo. Taking leg anatomical differences between flamingos and humans into account, what would this position look like? What do you observe about your own balance? Possible student response: A human would have to bend his or her knee at a 90-degree angle standing on one leg to achieve a flamingo stance. In order to achieve this position (if you are even able to balance), the upper body needs to be bent forward over the knee. Technically, you would also need to be standing on only your toes while bent over. Balancing in this position requires a lot of upper leg strength and energy. It's more like a yoga pose for a human than a way to save energy.

Flamingos' Bones Favor One-Leg Stance

Quest Through the Archives

Directions: After reading the article "[Flamingos' bones favor one-leg stance](http://www.sciencenews.org)," use the archives at www.sciencenews.org to answer these questions:

1. Search for an article that describes how climate change has affected flamingos. What does the article discuss?
2. The researchers in this article were concentrating their studies on the flamingo's sway or wobble on one leg. Search for an article that examines another bird that wobbles. Explain what it is about.
3. The flamingo clearly has overcome balance issues. Search for an article about balance problems in human beings. What is the problem and what is being done to overcome this problem?

Responses to Quest Through the Archives

- 1. Search for an article that describes how climate change has affected flamingos. What does the article discuss?** Possible student response: In the article "[French flamingos froze to death without freezing](#)," published 10/16/2014, researchers discuss the idea that climate change events have led to the deaths of large numbers of flamingos, not because they froze in low temperatures, but because they didn't appropriately time migrations or meals because of the lack of food caused by low temperatures. Researchers found that flamingos did not have enough protein stores to abate the effects of the lack of available invertebrates to eat.
- 2. The researchers in this article were concentrating their studies on the flamingo's sway or wobble on one leg. Search for an article that examines another bird that wobbles. Explain what it is about.** Possible student response: The article "[Chubby king penguins wobble when they waddle](#)," published 2/17/2016, discusses the idea that when a king penguin carries extra weight on the front of his body, its center of gravity is shifted. The shift in its center of gravity makes it less stable while walking on land.
- 3. The flamingo clearly has overcome balance issues. Search for an article about balance problems in human beings. What is the problem and what is being done to overcome this problem?** Possible student response: The article "[New pelvic exoskeleton stops people from taking tumbles](#)," published 5/11/2017, discusses the use of a wearable motorized exoskeleton that can sense balance irregularities and correct them to help the wearer. Stroke victims and those with spinal cord injuries would benefit from these devices by preventing them from falling.

Cross-Curricular Discussion

After students have had a chance to review the article "[Flamingos' bones favor one-leg stance](#)," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students.

To get your students moving and thinking about related concepts before the discussion, have them try some of the "[Other Fun Center of Gravity Activities](#)" toward the end of the Center of Gravity Experiment from Mississippi's Department of Education.

Physical Sciences

Discussion Questions:

- 1. What is the center of mass, or center of gravity, of an object (these terms may be used interchangeably when the gravitational field is uniform)?** *[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—for example, if one side of the object is especially heavy, the object's center of mass will be closer to that side. The force of gravity pulls directly downward from an object's center of mass.]*
- 2. If gravitational force is pulling downward on the center of mass of an object but the object does not accelerate downward, what might be keeping the object from falling?** *[Some upward force must be supporting the object, pushing or pulling the object upward to oppose the downward pull of gravity. Examples of a supporting force include:*
 - An upward force from a table on which the object is resting
 - Upward forces of rockets or aircraft
 - The upward buoyant force of a less dense object floating in a denser fluid
 - Upward force from an overhead string, rope, or hook pulling up on the object.]
- 3. For an object to be stable against tipping or falling over, where must the upward supporting force be applied, relative to the object's center of mass?** *[The upward supporting force must be directly above the object's center of mass for the balance to be stable. If the supporting force is above the center of mass but off to the side, the object will want to swing until its center of mass is directly below the supporting force. An object in this position has unstable balance. If the supporting force is below the center of mass but is not lined up directly below it, the object will tend to tip or fall over so that the center of mass would move lower. An object in this position also has unstable balance.]*

Extension Prompts:

4. Which situation is more stably balanced, an apple being held by a supporting force pushing upward on the center of the bottom (like a finger), or an apple being held up by a supporting force pulling upward on the stem on top? **Why?** *[If the upward supporting force is applied to the stem at the top of the apple, the center of mass is directly below the upward force and the apple is stable. If the finger is supporting the apple, the upward supporting force is below the center of mass, so the apple is not stable. In general, if nothing prevents a stationary object from lowering its center of gravity, then it will move to do so.]*
5. What are the differences between objects that are stable (in stable equilibrium), neutrally stable (in neutrally stable equilibrium) and unstable (in unstable equilibrium)? *[If an object moves and experiences forces that push it back to its original position, it is in stable equilibrium; a simple example is a ball resting at the bottom of a spherical bowl. If an object moves and does not experience forces that push it back to its original position or that push it further from its original position, it is in neutrally stable equilibrium; a simple example is a ball on a flat surface that is pushed slightly to one side and then remains still. If an object moves and experiences forces that push it further away from its original position, it is in unstable equilibrium; a simple example is a ball sitting on top of a spherical hill. If it is pushed to one side, it will move further away and cannot return to its original position.]*

Physical Sciences Question Bank

What is the center of mass, or center of gravity, of an object (these terms may be used interchangeably when the gravitational field is uniform)?

If gravitational force is pulling downward on the center of mass of an object but the object does not accelerate downward, what might be keeping the object from falling?

For an object to be stable against tipping or falling over, where must the upward supporting force be applied, relative to the object's center of mass?

Which situation is more stably balanced, an apple being held by a supporting force pushing upward on the center of the bottom (like a finger), or an apple being held up by a supporting force pulling upward on the stem on top? **Why?**

What are the differences between objects that are stable (in stable equilibrium), neutrally stable (in neutrally stable equilibrium) and unstable (in unstable equilibrium)?

Engineering and Experimental Design

Discussion Questions:

1. Define the center of buoyancy of an object floating on a liquid. For a ship on the ocean to be stable, where should the center of mass be relative to the center of buoyancy? In practical terms, where should heavy supplies, equipment or pirate treasure be stored? *[The center of buoyancy of a floating object occurs at a point where the center of mass of the displaced liquid would lie. The center of mass should*

be directly below the center of buoyancy—generally the further below it is, the more stable the ship will be. A more in-depth explanation is that the metacenter, the point where the vertical buoyancy force and the centerline of the tilting object intersect, must be above the center of gravity for the object to be stable. If the object is unstable and its center of buoyancy shifts toward the higher side, the metacenter where the vertical line of buoyant force and the tipping centerline of the object intersect will be below the object's center of mass. This method of achieving stability does not apply to an object like a submarine that is completely immersed in a fluid, since the center of buoyancy would not shift its relative location within the tipping object.

Practically, this means that to make the center of mass as low as possible, heavy supplies, equipment or pirate treasure should be stored in the lowest compartments of the ship.]

2. **For an aircraft to be stable, where should the center of mass be relative to the center of aerodynamic lift (central point at which upward supporting aerodynamic forces on the wings act)?** *In practical terms, what does that mean for where the luggage should be stored? [The center of mass should be directly below the center of lift. Heavy luggage should be stored as low as possible, just as with ships.]*
3. **Which is more stable, a sports car low to the ground, or a tall SUV?** *[The sports car has a much lower center of gravity and is more stable. Tall SUVs with a higher center of gravity are more prone to turning over in road accidents.]*
4. **How well could a helicopter fly upside down, if the rotor were turning in the right direction to exert an upward force?** *[It would be unstable—the upward supporting force exerted on the rotor would be below the helicopter's center of mass, so the helicopter would want to flip over. If the helicopter flipped over in this case, the rotor (turning in the direction to exert an upward force when it was on the bottom of the helicopter) would then be rotating in such a direction to pull the helicopter downward.]*
5. **Are these stable, neutrally stable, or unstable? Why?**
 - Flamingo standing on one leg
 - A human standing up
 - A very curved banana balancing on a chair (concave side down)
 - Segway scooter
 - Rocket taking off (ignore the fins and aerodynamic forces)

[All are unstable, except the banana. For the unstable scenarios, the center of mass is above the point at which an upward supporting force is applied—the ground for the flamingo, human, and Segway, and the rocket engine for the rocket. The center of mass of a very curved banana is in empty space below the concaved side (not actually on the banana itself). When the banana is balancing on a chair, the supporting upward force, which is from the chair, would be above the center of mass.]

6. **How can fins on the back make a rocket stable when it is flying through the atmosphere?** *[If the rocket starts to tilt to the side, air hitting the fins applies a corrective force to push the rocket back toward flying straight, just as a weather vane points into the wind because of the large fins on the other end of the weather vane.]*
7. **How do unstable objects or animals, like humans or balancing flamingos, keep from falling over?** *[There must be a brain, computer, or other feedback control system. The control system senses when the object starts to tilt one way, and applies a corrective force in the opposite direction. Without even consciously thinking about it, flamingos and humans use their muscles to counteract any swaying and stay upright. (You don't usually notice that when you are standing on two feet, but try standing on one leg as long as possible, and you will notice your constant muscle movements to compensate in one direction or another.) The Segway has a computer that senses which way is up, and torques the wheels one way or the other as necessary to avoid falling over. The rocket has a guidance system that senses which way is up and tilts the engine back and forth as necessary to avoid tipping over. Model rockets and some real rockets use fins and hence do not require a guidance system for stability.]*
8. **Why might it be desirable to design fighter jets to be neutrally stable or unstable? Are passenger planes built to be stable?** *[Passenger planes are designed to be very stable so they won't flip over, even if the engines stop working. Fighter jets are designed to be able to make very fast maneuvers, including flipping over. If a fighter were very stable (center of lift well above the center of gravity), the pilot would have to apply extreme forces to overcome that stability, which would be difficult for maneuvering quickly. To compensate for the lack of inherent stability, the computer in a fighter constantly senses the fighter plane's tilt relative to the ground and applies forces to keep it from flipping over when the pilot does not want it to.]*

Engineering and Experimental Design Question Bank

Define the center of buoyancy of an object floating on a liquid. For a ship on the ocean to be stable, where should the center of mass be relative to the center of buoyancy? In practical terms, where should heavy supplies, equipment or pirate treasure be stored?

For an aircraft to be stable, where should the center of mass be relative to the center of aerodynamic lift (central point at which upward supporting aerodynamic forces on the wings act)? In practical terms, what does that mean for where the luggage should be stored?

Which is more stable, a sports car low to the ground, or a tall SUV?

How well could a helicopter fly upside down, if the rotor were turning in the right direction to exert an upward force?

Are these stable, neutrally stable, or unstable? Why?

- Flamingo standing on one leg
- A human standing up
- A very curved banana balancing on a chair (concave side down)
- Segway scooter
- Rocket taking off (ignore the fins and aerodynamic forces)

How can fins on the back make a rocket stable when it is flying through the atmosphere?

How do unstable objects or animals, like humans or balancing flamingos, keep from falling over?

Why might it be desirable to design fighter jets to be neutrally stable or unstable? Are passenger planes built to be stable?

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

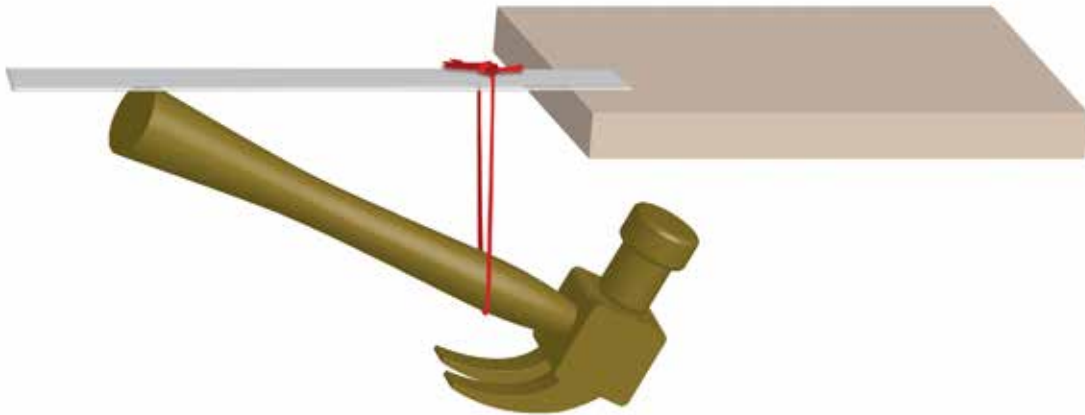
Notes to the teacher: When stood on end and released, a shorter stick will fall over faster than a longer stick. If two sticks are identical but have masses clipped on to them at different points, the stick with a lower center of mass will fall over faster. The simplest explanation you can give the students 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

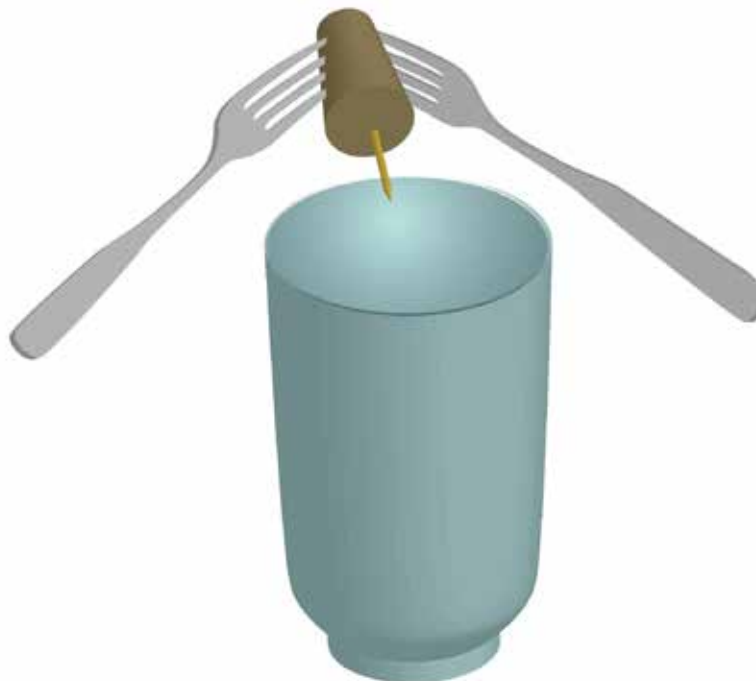
as possible. That makes them fall over more slowly, and gives them more time to react and apply muscles in the opposite direction if they do start to lean over.

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.

Materials:

- 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 or hammers
- 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

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?
10. What determined which "flamingo" hit the table first? Why? What does this tell you about the balance of different flamingos?
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?

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?

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?
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?

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?

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?

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?

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?

22. How many other freaky balancing objects can you construct? Describe or draw them.

Analysis:

23. Where is the center of mass of a flamingo standing on one leg?

24. Where is the point of suspension for a flamingo standing on one leg?

25. Based on your experimental results, would a flamingo be naturally stable (without using its brain and muscles)? Why or why not?

26. Based on what you found, why is it evolutionarily advantageous for flamingos to be built the way they are?