Angular Momentum

Educator Notes

Learning Objectives

Students will:

- Use mathematical representations to prove angular momentum is a conserved quantity in a closed system.
- Recognize the relationship between angular and linear momentum.

Challenge Overview

Understanding angular momentum is important because it affects everything from driving cars around corners to the orbit of objects in space. In this lesson, students will expand their understanding of Newton's first law of motion by exploring angular momentum in a hands-on experiment. To do this, students will begin by reviewing the concept of linear momentum, which is the product of the object's mass and linear velocity. Angular momentum describes the momentum of an object moving in a circular path and incorporates a third component, its radius, or the distance the object is from its axis of rotation.

Review of Linear Motion: For an object in linear motion, its momentum can be defined as $p=mv$, or the momentum of an object (p) is equal to its mass (m) multiplied by its velocity (v). Momentum is a conserved quantity in a closed system, meaning if no outside forces act on the system, its total momentum will always stay the same. If two objects collide in a secure system, their total momentum after the collision will be the same as before the crash.

Angular Momentum: An object traveling in a circular motion also has conserved momentum. This is called angular momentum and, in addition to dependance on the object's mass (m) and velocity (v), it is also influenced by the distance of the object from its axis of rotation or radius (r). Angular momentum (L) is defined as $L=mvr$, or an object's angular momentum (L) is equal to its mass (m) multiplied by its velocity (v) and multiplied by its radius (r). You can also think of angular momentum as an object's linear momentum multiplied by its radius, or $L=pr$.

⚠ Safety

- Practice safe cutting techniques when using scissors. Be sure to support the piece being cut carefully.
- Avoid using scissors, cutting tools, or other sharp objects while walking around the room.
- Ensure there's plenty of space between the student teams to avoid collisions with the spinning objects.
- Consider safety goggles in case an object becomes loose.

Grades 6 to 12

Suggested Pacing

45 minutes

Materials

- Student Activity Sheet
- Pencils
- Straws
- Scissors
- String
- Washer or small fishing weight that can be tied to a string
- Metric Ruler
- Timer or Stopwatch
- Safety Goggles

National STEM Standards

- MS-PS2-4
- HS-PS2-2

Expedition 61 Flight Engineers, Christina Koch and Jessica Meir, perform equipment lock configuration operations in the Quest Airlock in preparation for a spacewalk. **Credits: NASA**

Challenge Preparation

The educator should:

- Read the Challenge Overview section and become familiar with the activity.
- Prepare the materials listed.

Introduce the Challenge

To activate prior knowledge, ask students the following questions:

- Have you ever spun something around your hand, such as a lanyard with keys, and then allowed it to wind up around your hand or fingers? As it turned around and around, and its length became shorter and shorter, what did you notice about the object's motion?
- Have you ever watched a figure skater spin around in place and notice the rate of their spin suddenly increase? What did the skater do to suddenly speed up? How did they slow back down? (You may want to consider showing a brief video clip of this concept).

Facilitate the Challenge

Engage

- Show the STEMonstration Angular Momentum available at https://www.nasa.gov/stemonstrations.
- Ask students to think about the following questions:
  - How does changing the distance between an object moving in circular motion and its axis of rotation or its radius affect its velocity? Why does it affect its velocity?
  - Then, share ideas in a whole class discussion.

Explore

- Divide the students into pairs and pass out the supplies.
- While in pairs, students will tie one end of the string to their weight and thread the other end through the straw.
- With the string threaded through the straw, hold the straw with one hand and the free end of the string with the other. Allow the weight to hang freely about 30 cm from the end of the straw. Begin to gently spin the weight around while holding tightly to the free end of the string. Make sure students spin the weight fast enough so the string stays tight. Then, slowly pull the string through a straw, shortening the distance between the weight and the straw. Observe what happens to the velocity of the weight. What causes this change in velocity?
- Allow the weight to hang freely again, about 15 cm from the end of the straw this time. Begin to spin the weight, but slowly release the string through the straw to allow the weight to get farther away as it spins. Observe what happens to the velocity of the weight this time.
  - Have students form groups and discuss what happened in the experiment and how it is an example of angular momentum.

Explain

- Show the video about Angular Momentum: Angular Momentum - YouTube.
- Discuss how is the experiment the teams just performed is an example of angular momentum.
  - Angular momentum is an object's moment of inertia multiplied by its angular velocity. If one variable increases, the other variable decreases, and vice versa. When the string is pulled through the straw, bringing the weight closer, the moment of inertia is reduced as its mass gets closer to the rotation point. The weight's angular velocity must increase to compensate and keep the angular momentum constant. The reverse happens when the string is loosened and the weight moves farther away from the center, its moment of inertia increases, so the rotational speed must decrease for angular momentum to remain constant.

Elaborate

- Have students cut a longer string, tie the weight to one end, and go outside to twirl the weight over their heads. Observe if the results changed. What caused the results to change?
- Instruct students to add more weight to the string. Observe if it affected the results. Explain.

Evaluate

- Ask students to consider examples of angular momentum in everyday life?
- The demo in the video is done in a microgravity environment. The activity the students will conduct is on Earth. Ask students why do we see the same relationship between radius and velocity (assuming constant mass) in both scenarios (both closed systems, angular momentum is always conserved, etc.)? What would happen if the mass of the object in each scenario was adjusted but the radius remained the same (speed would be influenced, but how)?
- Instruct students to create a slide showing the everyday example and how increasing or decreasing the velocity would keep the angular momentum constant.

Extensions

Try the STEMonstration: Moment of Inertia: STEMonstrations: Moment of Inertia - NASA

Share

Engage students with the following discussion questions:

- What are some other examples you have observed that show the change in velocity of an object as its radius changed? (Possible Examples: tetherball, an object circling a drain, etc.)
- Think back to the yo-yo example performed by the astronaut. When the radius increased, the circular motion of the yo-yo slowed to a prolonged rotation. Is that experiment easily performed here on Earth? Why? How was the astronaut able to complete it?

Reference

- STEM Content - NASA
- STEMonstrations Classroom Connection: Orbits
- Angular Momentum Teaching Resource

Angular Momentum

Student Activity Sheet:Your Challenge

Engage

Watch the Angular Momentum STEMonstration video. [Angular Momentum - YouTube]

- Answer the following question in your journal, then share your answers with a partner:
  - How does changing the distance between an object in circular motion and changing the object's axis of rotation, or its radius, affect its velocity? Why does it affect its velocity?

Explore

Work in pairs to conduct an experiment on angular momentum.

- Tie one end of the string to the weight and thread the other end through the straw.
- With the string threaded through the straw, hold the straw with one hand and the free end of the string with the other. Allow the weight to hang freely about 30 cm from the end of the straw. Begin to gently spin the weight around while holding tightly to the string. Make sure you spin the weight fast enough so the string stays tight. Then, slowly pull the string through a straw, shortening the distance between the weight and the straw. Observe what happens to the velocity of the straw. What causes this change in velocity?
- Allow the weight to hang freely again, about 15 cm from the end of the straw this time. Begin to spin the weight, but slowly release the string through the straw to allow the weight to get farther away from the straw as it spins. Observe what happens to the velocity of the weight this time.
- Discuss in groups what happened during the experiment and how it is an example of angular momentum.

Explain | Elaborate | Evaluate

Your educator will show you the video Angular Momentum:

- In your journal, answer the following question:
  - How was the experiment you conducted an example of angular momentum?
- Cut a longer string and go outside to twirl the weight over your head. Did your results change? Why do you think that is?
- If you add more weight to the string, does it affect the results? Try adding more weight and see what happens.
- What is an example of angular momentum in everyday life? Create a slide showing the example and how you could increase or decrease the velocity to keep the angular momentum constant.

Share

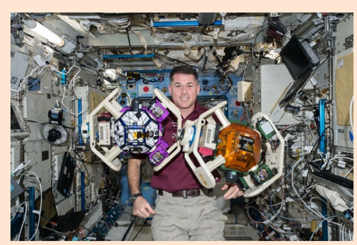
- What are some other examples you have observed that show the change in velocity of an object as its radius changes?
- Think back to the yo-yo example performed by the astronaut. When the radius increased, the circular motion of the yo-yo slowed to a prolonged rotation. Is that experiment easily performed here on Earth? Why? How was the astronaut able to complete it?

NASA astronaut Shane Kimbrough poses for a portrait in the Space Exploration Vehicle (SEV), an engineering concept used to test new technologies for future surface and deep-space exploration vehicles. **Credit: (NASA/Bill Ingalls)**

Career Corner

Astronaut Shane Kimbrough joined NASA in 2000 and was selected as an astronaut candidate in 2004. During his astronaut career, he became only the fourth astronaut to fly on three different rockets and performed a total of nine spacewalks! Prior to joining NASA, he was an officer in the United States Army, flying helicopters and even taught math at the United States Military Academy!

Learn more: [kimbrough-rs.pdf (nasa.gov)]



NASA astronaut Shane Kimbrough is seen executing the SPHERES-RINGS experiment aboard the International Space Station. **Credits: NASA**