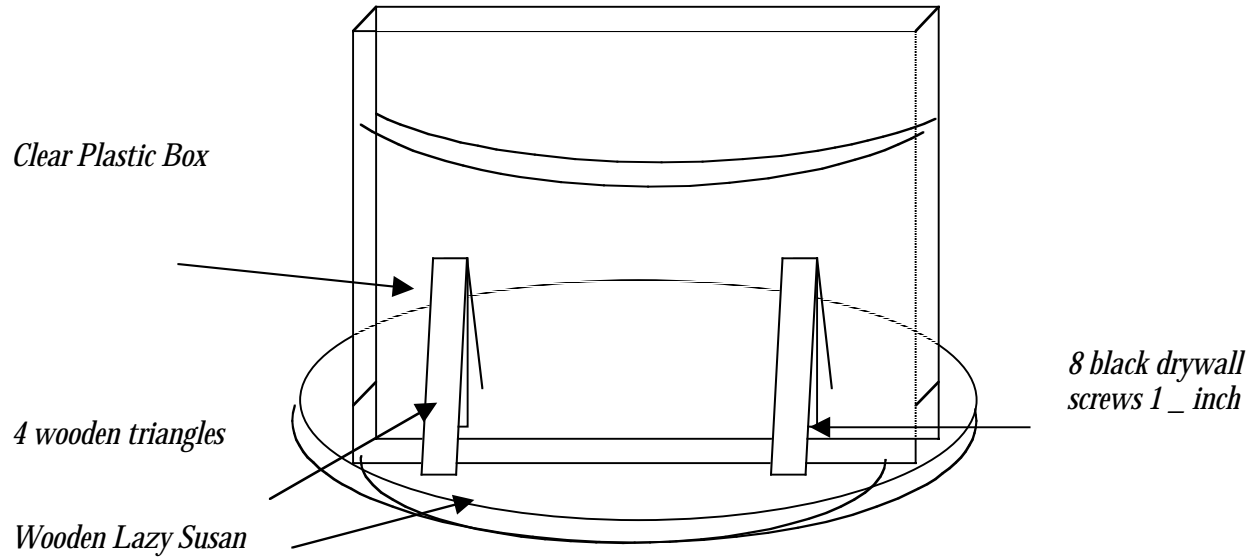


Whirling Water
How does circular motion affect water and wave patterns?
 By Maggie Robinson and Laura Zinszer

Diagram:



Construction Directions

1. Have the plastic pre-cut at Home Depot. Use silicon glue to build the plastic box. Test seals.
2. Cut the 1x6" board into 4 triangles which are 8 cm at the base and 13 cm high.
3. Remove the base from the Lazy Susan and save screws and base to reattach.
4. Mark the center of the Lazy Susan and draw the outline of the box through the center.
5. Place the triangles along the line and trace them.
6. Pre-drill two holes through the Lazy Susan into the traced areas for the triangles and through the base of the wooden triangles.
7. Apply wood glue to the base of the triangles and screw to the Lazy Susan through the bottom.
8. Reattach the base to the bottom of the Lazy Susan.
9. Place the box between the wooden triangles and fill partially with water.

List of Materials

1. One 30" x 12" acrylic sheet
 1/2 inch thick cut into 3-1x12 "
 and 2-12x12" pieces.
 Home Depot \$4.00
2. One wooden Lazy Susan
 RW 2087
 Wal-Mart \$8.97
3. Eight black drywall screws
 .06 each
 Home Depot \$.48
4. One 1x6 pine board about
 6 inches long for the wooden
 triangles.
 Home Depot \$.50
5. One tube clear silicon
 Home Depot \$1.50
6. Elmer's Wood Glue \$.50
7. Tiny boat with Mast (optional)

The Concepts:

When an object is being spun on a merry-go round, there are four primary concepts involved, inertia, centripetal acceleration, centripetal force, and velocity of spinning objects. Newton's First Law of Motion (inertia) states that an object moving in a straight line continues in a straight line unless a force acts on the object to change its direction. When an object is placed on a merry-go-round and spun, the object will fly off the merry-go-round in a direction that is tangent to the radius, unless a force acts on the object to keep it on the merry-go-round and going in a circle.

In this activity, when the Lazy Susan spins, the water wants to move in a straight-line tangent to the circle. However, the outside wall of the box in this activity restrains the water and changes the direction of the water, forcing it to move in a circle instead of a straight line.

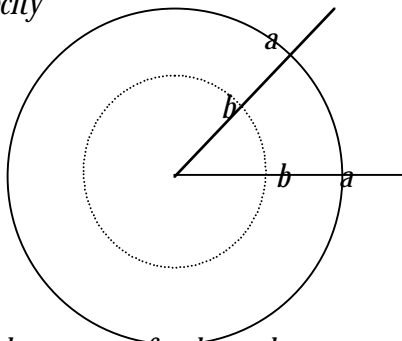
When an object travels at a constant speed in a circular path, this uniform circular motion requires constant acceleration because the path is constantly changing. Centripetal acceleration is the inward acceleration that forces an object to move in a curved path instead of a straight line. $a_c = v^2 / r$

Because the centripetal acceleration is directed radially, there is no acceleration in the tangential direction. This is why the magnitude of the tangential velocity does not change.

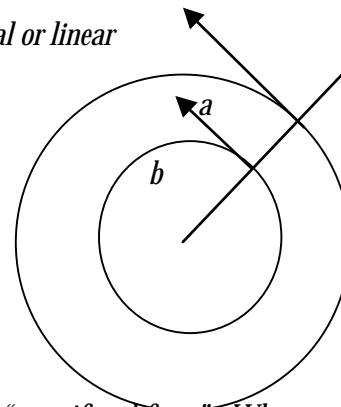
The third concept this activity addresses is velocity of spinning objects. Many people believe that the linear speed of an object traveling in a circular pathway is the same, no matter where the object is placed on a merry-go round. In our example, the water near the edge of the box travels in one large circle at the same time the water near the center goes around in a small circle. This means that the water near the edge travels faster than the water near the center. (Think about kids ice skating and playing Crack the Whip. the skater on the outside travels much faster than the kid in the center.) The angular velocity stays constant for both objects because the angle that both objects travel through remains constant. is the same. On the other hand, the tangential velocity for objects at different locations are not the same because the distance from the center of the circle (r) is different for each object.

$$\text{Orbital Velocity} = 2\pi r/t$$

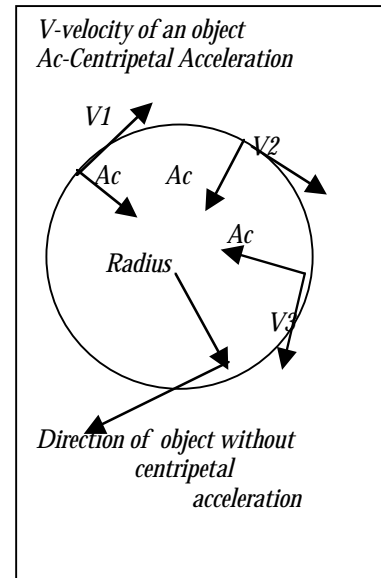
Angular velocity



tangential or linear velocity



The last concept for the students to consider is centripetal force vs "centrifugal force". When a student is riding in a car that is traveling around a corner, the student perceives that a "force" is pushing them into the wall of the car. In actuality, there is NO centrifugal force acting at all! Newton's First Law stated that an object in motion would keep traveling in a straight line unless another force acts upon it. The student who is riding in the car is actually obeying Newton's First Law and trying to move in a straight line. The wall of the car moves into



the student and forces the student to change direction. The force of the wall of the car pushing back on the student is centripetal force. The centripetal force (an inward force) like centripetal acceleration is directed toward the center of the circular path. When a force is continuously applied at 90° to the direction of motion only the velocity changes, there is no change in the magnitude.

Magnitude of centripetal force: $F_c = ma_c = mv^2/r$

If we were swinging a ball overhead, the pull of the string back to the center is the centripetal force. This is the inward pulling force, which is continually changing the direction of the spinning ball. If the string is cut, the centripetal force is reduced to zero and the ball will fly out from the circle in a path that is tangent to the radius of the circular pathway.

Missouri Frameworks:

Science 5-8:

IV. Force, Motion, and Mechanical Energy

A. Relative Motion

3. Acceleration occurs when an object speeds up, slows down, or changes direction.
 - a. Explain how an object's acceleration is affected by outside forces and its mass.

B. Types and Properties of Forces and Motion

1. The overall effect of many forces acting on an object at the same time is called net force. The size and direction of this net force determines the change in motion of an object.
 - a. Use technologies to determine the direction of acceleration and the net force for an object moving in a circle.

Science 9-12:

IV. Force, Motion, and Mechanical Energy

A. Relative Motion

1. Motion can be described in terms of velocity and acceleration and be represented by equations and vectors.
 - a. Represent and analyze motion both quantitatively and graphically using velocity and acceleration.

B. Types and Properties of Force and Motion

1. Acceleration of an object is related to its mass and the forces acting on it.
 - b. Analyze information from inquiries to interpret the effect of velocity on force and motion.
2. The action of all forces can be explained by Newton's Laws of Motion that are used to predict change in linear or rotational motion.
 - a. Evaluate the information to describe how Newton's Laws of Motion are used to describe moving objects.

Misconceptions about spinning:

When you spin a device like a merry-go round with an object sitting on it, what are the forces that students believe are acting on the object? have many different misconceptions about circular motion. These may include:

1. Circular motion does not require a force.
2. An object moving in circle with constant speed has no acceleration.
3. An object moving in a circle will continue in circular motion when released.
4. When an object is moving, there is a force in the direction of its motion.
5. Motion is proportional to the force acting on an object, so a stronger force makes an object go faster.
6. An object in circular motion will fly out radially when released.
7. Centrifugal forces are real.

8. *The centrifugal force is the outward pushing force people feel when they are moving in circles.*
9. *The linear speed on an object is the same, no matter where the object is placed on a merry-go round.*

Demonstration:

1. Step-by-step description

The teacher walks into the classroom with a tennis ball swinging in a circle over her head on a string. Once the teacher has demonstrated the twirling tennis ball (but not released it), she has the students write predictions and explain what they think would happen. Then, the teacher actually swings the ball and releases it tangentially to the circular path.

Now, the teacher will bring out the Whirling Water demo. Place the boat in the center of the box, which is half full of water. Have the students use their prior knowledge from the swinging tennis ball to predict what happens to both the water and the boat in the demo. Spin the Whirling Water demo and have the students describe their observations.

2. Examples of Scientific Concepts

The teacher uses the tennis ball demo to elicit ideas about circular motion from the students.

This demonstration provides an excellent example of centripetal force, centripetal acceleration, velocity of spinning objects, and inertia. The teacher spins the Lazy Susan and the water surface forms a parabola in the box. If the boat is placed in the center of the box, it will maintain its original position. If the boat is placed on either side of the box, the mast will remain perpendicular to the surface of the water, even though the water is curved. The parabola shape of the water's surface provides evidence of inertia, centripetal force, centripetal acceleration, and uniform velocity of spinning objects.

3. Hallway Exhibit-with docent

Sheets of paper and pencils should be provided for the students to make predictions. Provide a box for 'used predictions' to tally later so that the students can consider changes in their original ideas. The docent needs to be available to provide supervision for care of the exhibit, provide thought provoking questions for the students, and explanations of the concepts included in the activity.

Teacher's role:

The teacher's role is to conduct a safe demonstration that will help the students understand the concepts, become excited about the activity, feel comfortable about asking questions and predicting outcomes, and be able to relate the concepts they have learned back to their environment.

The teacher walks into the classroom with the swinging tennis ball on a string and proceeds to describe the following story. "A student with a smile walked into the classroom with a tennis ball swinging in a circle over her head on a string. Just as it was going really fast, she aimed it directly at one of the other students in the class. No one had a chance to move." (Freeze) Will the ball hit the student? Why or why not? Once the teacher has demonstrated the twirling tennis ball (but not released it), she has the students write predictions and explain what they think would happen. The teacher needs to help the students organize their predictions in different ways through the class discussion. Now, teacher actually swings the ball and releases it tangentially to the circular path of the tennis ball. What is the direction of motion? What do the students observe? Discuss these observations with the class, list ideas on a class chart or diagram, and compare the observations with the original class predictions.

After the discussion about circular motion, the teacher is not correcting misconceptions or affirming information. Now, the teacher will bring out the Whirling Water demo. Place the boat in the center of the box, which is half full of water. Have the students use their prior knowledge from the swinging tennis ball to predict what

happens to both the water and the boat in the demo. Spin the Whirling Water demo and have the students describe their observations.

Finally, the teacher needs to use the final observations from the Whirling Water demo, student predictions, and ideas from the whirling tennis ball activity to make an explanation about what is happening to objects moving in a circular path.

Student's Role:

The role of the student is to listen to the story about the tennis ball, write predictions about the circular movement, and explain their predictions. They will also observe the tennis ball in flight and describe observations about the movement. Students will write their predictions and observe the Whirling Water demonstration. Finally, the students will analyze the classroom predictions and observations for both activities to create an explanation about circular motion. Students will also answer several thought problems to assess their understanding of circular motion.

Student Predictions

Students will probably predict that the water in the box will make waves, spill out, or keep a straight line. They will not expect the water to form a neat parabola. Students will also predict that the boat will move toward the edge of the box or tip over. They will not see the water's surface. Students will identify centrifugal forces as the primary reason for any observable changes that push out on the water. Finally, the students will also state that the water toward the outside of the box is moving at the same speed as the water toward the center. Of course, they also may predict that the container might fly off the Lazy Susan altogether. Gee Whiz! ☺

Outcomes:

1. What should students gain from this demonstration?

When the Whirling Water demonstration is finished, the students should have observed the surface of the water forming a parabola, the boat maintaining its position in the water, and the boat's mast remaining perpendicular to the water's surface. The students should begin to have a clear understanding of centripetal force, inertia, and speed and acceleration of circular movement. The students should also begin to understand that there is no real "centrifugal force". Finally, we would like the students to be able to relate these ideas with things they are familiar with in their own environment.

2. Next Steps

The students may require more activities to aid in their understanding of the concepts. A role playing activity may include pretending that they are in a car—the car turns to the left but the top of their body sways to the right (discuss the outcome). In the gym or on the playground, form a line (radius) and instruct the center person to swing the line. Have each student answer the following questions. How fast they were going? What force was moving the students? If the students let go of the line, what would happen?

3. Assessments

Thought Problem-1

The assessment consists of a thought problem for the students. The first three planets from the sun are orbiting in an aligned pattern along the radius of the circle. Mercury is the planet closest to the sun, Venus is second and the Earth is third along this radius. Which planet would travel the greatest linear distance and why? Which planet would travel the fastest and which would travel the slowest? How can we relate what we have learned about circular motion to the motion of planets around the sun?

Thought problem-2

If you were on a merry-go-round sitting half-way out from the center, and became afraid because you were spinning too fast, where can you move to without getting off the ride to slow down your rotation and why?

Thought Problem –3

What rides have the students been on at Six Flags or World's of Fun which used circular motion as the main theme for the ride? How did the student move on this ride? Can they identify examples of centripetal force, inertia, centripetal acceleration, and uniform in velocity on the ride?

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