Focused Learning Lessons
Science
Grades 9-12
ESS-H-D6

Overview:
This lesson enables learners to demonstrate the relationship between orbital velocity and orbital diameter.

Approximate Duration: This lesson takes about 40-45 minutes

Benchmark:
ESS-H-D6 demonstrating the laws of motion for orbiting bodies
ES GLE: 28. Identify the relationship between orbital velocity and orbital diameter.
Benchmark:
SI-H-A2 designing and conducting scientific investigations
SI GLE: 4. Conduct an investigation that includes multiple trials and record, organize, and display data appropriately.

Objectives:
1. The learner will measure changes in orbital velocity caused by changing the orbital diameter (radius) of a model orbiting body.
2. The learner will develop a general statement that describes the relationship between the size of a planet's orbit and its orbital velocity.

Teacher Preparation:
This lesson addresses the aspect of planetary motion that is related to a planet's distance from its star and how that distance influences planetary velocity. "The time it takes for a planet to orbit the sun is related to the average distance of that planet from the Sun. The outer planets take longer to orbit the sun for two reasons: They have longer orbits through which to travel, and they also move slower in their orbits." (McGuire, 1991, p. 37).

This lesson is most effective if used as a small group activity. It can be done as a teacher demonstration if necessary. Appropriate safety measures must be taken, and the security of knots in the string should be checked before <u>every</u> use of the model.

Materials/Equipment/Resources:
1 each of the following for each model to be constructed:
1-120 cm length of sturdy string
1 large metal washer
1 cardboard paper-toweling roller
A meter stick
A stopwatch or watch with second hand
Calculator (optional)
One student handout with data chart for each learner

Lesson Procedures:

Set or Opener:
This lesson is appropriate for use within the context of an astronomy unit that includes the solar system and the planets that orbit the Sun. It can be introduced to learners through display of a picture of the solar system or with a solar system model. After learners have had a few minutes to look at the picture or examine the model, introduce the idea of different planets traveling around the Sun at increasing distances from the Sun. Ask several introductory questions, sequenced to take learners from facts they probably know to questions they will need to investigate in the lesson. As each question is asked, let several seconds pass before allowing someone to offer an answer. Then allow a few more seconds to elapse before acknowledging the answer. Do not immediately agree or disagree with an answer. This gives many learners time to think about both the questions and the tentative answers.

Opening questions:

1. What period of time is measured by one complete orbit of a planet around the Sun? (*one year*)
2. Is a year the same length of time on all planets? (*no*)
3. Why not? (O*ne reason is that the planets are not all the same distance from the Sun*)
4. If some planets have a longer distance to travel, like the outer planets, do they travel faster to make the trip, or does the trip just take longer? *(Actually, they travel more slowly, and that, combined with the increased diameter of the orbit, makes the journey take much longer. DO NOT tell this to the learners at this time. This is what they will discover in the experiment they will conduct.)*
5. Does everyone think that the planets farther from the Sun travel faster in their orbits? (*probably, no*) So, how can we find out? (*by investigating*)

This is the point in the lesson where the orbital model consisting of a planet (the washer) tied with string (the gravitational pull of the Sun), orbiting the Sun (the focal point where the string leaves the paper-towel roller), is introduced and can be demonstrated with the safety instructions emphasized. The model should be set into motion only below waist level and always spinning parallel to the floor. (These precautions are written into the instructions for the learner.) When demonstrating the model for the first time, do not move the roller up and down on the string to change the radius of the circle. Hold the model in the same place so no hint about the outcome of the experiment is given ahead of time. Further, it is best when introducing the model to have the learners suggest what each part of the model represents rather than tell them up front. Once they have seen the structure of the completed model, they are ready for the next part of the lesson.

Body of Lesson:

1. Distribute a student handout, Attachment 1, to each learner. Review safety precautions and steps in the construction of the model.
2. Divide learners into groups of three or four, depending upon class size and available materials. A suggested division of labor can be found in Attachment 3. Once job assignments are determined the next step is to distribute materials to each group.

3. Allow time for the learners in each group to consider the question of how orbital velocity is affected by the size of the orbit and then develop a hypothesis that states the relationship between the two variables. Individual learners may choose a personal hypothesis or the group may come to consensus. Learners will write their hypothesis on their own lab data sheet (Attachment 1).
4. Learners in each group will use the instructions in Attachment 1 to construct the orbiting body model.
5. Learners in each group will conduct three trials of each of four orbital (radius) sizes. It is important for learners to review the relationship between the measurement of radius and diameter (Attachment 3, Vocabulary). The learners each record their own data for the three trials of each orbital radius on data sheets.
6. The learners examine the collected data to determine if it supports or refutes their original hypothesis. Learners will each write an analysis and a concluding statement that explains how the data supported their hypothesis or why the data refuted their hypothesis and how they would revise their original hypothesis.
7. Upon completion of the concluding statements, learners will turn in their lab data sheets, Student Handout 1, to the instructor.

Closure:
A "wrap-up" discussion should include:

- how the model demonstrates the relationship between orbital velocity and orbital size,
- why repeated trials of each orbital size were needed,
- how this experiment demonstrates the effect a change in distance from the Sun would have on a planet such as Earth, and
- discussion of how environmental conditions on Earth would be affected by a change in orbital size is also appropriate.

Attachments:

Attachment 1: Student Handout, lab directions and data sheet
Attachment 2: Key
Attachment 3: Teacher Background

Sample Assessment Items:

1. If the following were actual orbital velocities of planets in our solar system, which would most likely be the orbital velocity of the planet closest to the Sun?
   A. Planet A, traveling at 24.2 kilometers per second
   B. Planet B, traveling at 29.8 kilometers per second
   C. Planet C, traveling at 6.8 kilometers per second
   D. Planet D, traveling at 13.1 kilometers per second

2. If the orbit of planet Earth were suddenly moved closer to the Sun, which of the following would change?
    A. a day on Earth would be shorter
    B. a day on Earth would be longer
    C. a year on Earth would be longer
    D. a year on Earth would be shorter

Key:

1. *B is the correct answer because planet B is traveling at the greatest velocity.*
2. *D is the correct answer because if planet Earth were closer to the Sun the time it took for one complete revolution (one year) would be shorter.*

Reference Links and Technology Connections:

McGuire, Thomas. (1991). *Reviewing Earth Science* (p 37). Amsco School Publications.

http://solarsystem.nasa.gov/planets/charchart.cfm
This chart provides important data on each planet in our solar system in a one page form that is suitable for teacher and learner use.

http://solarsystem.nasa.gov/planets/profile.cfm?Object=SolarSys
This links learners to information about each planet in our solar system and beyond; suitable for teacher and learner use.

http://home.cvc.org/science/kepler.htm
This site contains a web page designed by a high school instructor to aid in teaching Kepler's Laws of Planetary Motion complete with animations.

Attachment 1: Student Handout

Question: How does orbital size (radius) affect orbital velocity?

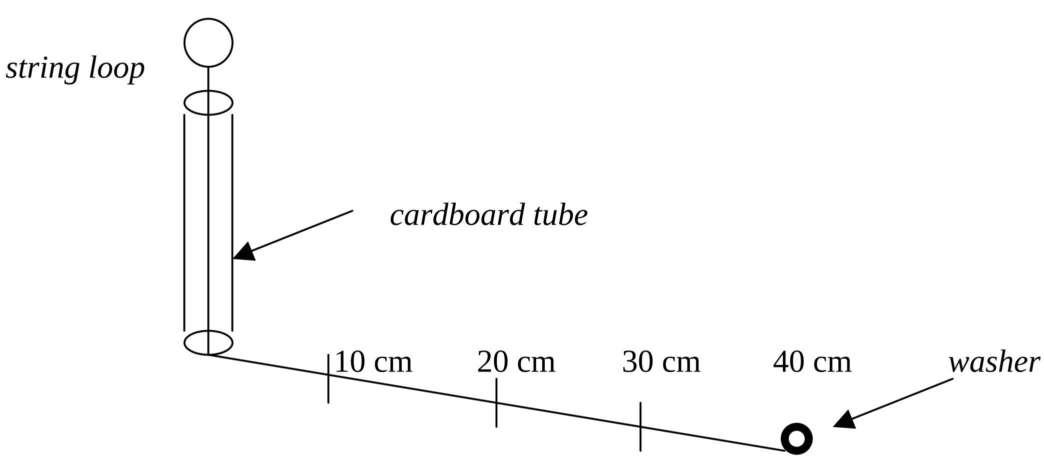
Hypothesis: ____

Materials/Equipment:

120 cm. length of sturdy string
1 large metal washer
1 cardboard paper-toweling roller
meter stick
stopwatch or watch with second hand
data chart
calculator (optional)

Instructions:

1. Cut a length of string 120 cm. Tie one end to the washer firmly using several tight knots.
2. Use the meter stick to measure 100 cm from the knot on the washer end of the string. Mark the string at that length. Make a finger-sized loop at the mark and tie a knot to secure the loop.
3. Using the knot at the washer end of the string as zero, mark the string at intervals of 10, 20, 30, and 40 centimeters.
4. Pass the loop end of the string through the paper-towel roller. Check the security of the knots at the washer end of the model.
5. The model is now ready to test each hypothesis.
6. Pass the loop over both knuckles of the index finger. Check the knot to be sure it is secure. Hold the cardboard tube with the other hand and allow the washer to hang down. Note that the cardboard tube can move freely up and down the string.
7. Move the cardboard tube up the string until the bottom edge is even with the highest (40cm.) mark on the string so the radius of the first trial is set at 40 cm.
8. Move the hand with the looped end of the string to waist level so the whole model is below the waist of the learner. **Note:** This model should only be put into motion close to the floor as a safety precaution.
9. Use the cardboard tube to set the washer into a circular orbit parallel to the floor, making sure that the washer DOES NOT AT ANY TIME swing upward.



10. Practice setting the washer into orbit and maintaining the orbit with as little movement of the cardboard tube as necessary to continue motion.
11. When ready, set the model into motion, establish a steady orbit and use the stopwatch or watch with second hand to count the number of complete orbits in one minute. Record the number on the data chart. Repeat the procedure two more times. Average the three trials and record the average. Round to two decimal places.
12. Follow steps 7-11 again, using the 30 cm radius, then the 20 cm radius, and finally the 10 cm radius.

Data:

Orbital Data Chart				
Trials	Orbital Radius			
	40 cm	30 cm	20 cm	10 cm
1				
2				
3				
Average (revolutions/min.)				

Question prompts for examination of data:

1. At which orbital radius did the model complete the greatest number of orbital revolutions in one minute? The fewest?
2. To what factor was the number of orbital revolutions directly related?
3. How does orbital size (radius) affect orbital velocity?
4. Compare your findings to your original hypothesis. Was your hypothesis supported? If not, how can you explain the discrepancy?
5. If you were asked to write a hypothesis now, using what you learned from your investigation, what would it say?
6. What would change if the radius of orbit for planet Earth were increased? What would not change? Explain your reasoning on the back of this page or a separate page.

Concluding statement: ____

Attachment 2: Key
Suggested Answers to Prompt Questions

1. *The greatest number of orbital revolutions should be a the shortest radius (10.cm). The fewest revolutions should be with the longest radius. Actual numbers of revolutions may vary slightly.*

2. *Orbital revolutions are directly related to the size (radius) of the orbit.*

3. *The larger the orbit, the slower the planetary velocity.*

4. *Answers will vary depending upon original hypothesis, but learners should be able to explain how the data collected differed from what they originally thought would happen.*

5. *Based on the results of the experiment, a revised hypothesis should accurately reflect the relationship between orbital radius and orbital velocity (the smaller the radius the greater the velocity).*

6. *Answers will vary. Some possible answers include:*
    a. *Climates would be colder (Earth farther from the Sun).*
    b. *Sunlight would be dimmer (Earth receiving less direct sunlight).*
    c. *The year would be longer (larger orbit would mean more time required to make one complete trip around the Sun).*
    d. *One answer that might be offered is that the length of a day on Earth would change. Unless the rotation on its axis changed, the length of a day would remain the same. Since a change in rotational speed was not specified as a variable in the experiment, that would be an incorrect answer choice.*

Attachment 3
Teacher Background

Group Work and Suggested Lab Jobs

During the activity phase of this lesson, it will be useful if each member of the activity group has a specified task to perform. A suggested division of labor is listed below for both three-member groups, with a modification for a fourth member.

Three-member group:

Job 1-Materials Manager
This member is accountable for picking up and returning materials and supplies, and making sure that everyone has the materials they need to perform their task. This group member is also responsible for the appropriate use and handling of materials and equipment in the care of the group.*

Job 2-Principal Investigator
This member of the group has the primary duty of constructing the model and using the model in the experiment. It is important to point out that trials of the experiment can be shared among group members, but it is the role of the Principal Investigator to oversee safe and correct use of the model at all times.

Job 3-Recorder/Reporter
This group member will speak for the group in post activity discussions and will record and maintain the "official data" report for the group (although each member is responsible for completing an individual lab report). Having only Recorder/Reporters ask questions for the group during the activity will also keep the activity manageable for the instructor.

*If a four-member group is desirable, the fourth person can be the "Quality Control Expert" who makes sure data are being collected accurately, time is being used wisely, and learners are consistently on task. If there is no fourth person, the Activity Manager and perform these tasks.

It is strongly recommended that the lab jobs be rotated on a regular basis.

Vocabulary

1. Revolution-the movement of an object around another object, as a planet revolves around the sun

2. Rotation-turning in place around a central axis, as the Earth rotates on its axis

3. Orbital velocity- the speed and direction of an object in orbit around another object

4. Orbital diameter-the distance across an orbital path and passing through the focal point of the orbit

5. Radius-the distance from the center of a circle to the outside bounding line (2 x radius = diameter)

6. Day-the measurement of time required for a body to complete one rotation on its axis (Earth completes one rotation on its axis in one day)

7. Year-the measurement of time required for a body to complete on revolution around another body (Earth completes one revolution around the Sun in 365.25 days)