Pendulums and Planets

Let's Learn About Astronomy Lab

Elementary and upper grades versions included!

S.T.E.M. ON A SHOE STRING

By Brad Fulton

Educator of the Year, 2005

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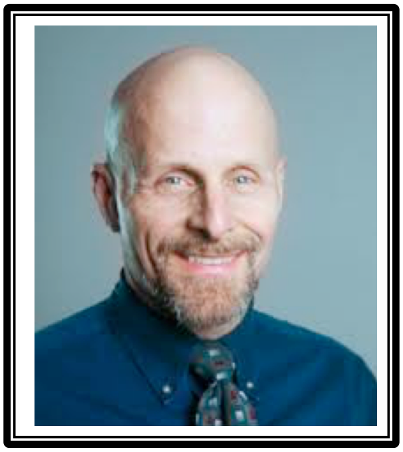

Brad Fulton

Educator of the Year

- ♦ **Consultant**
- ♦ **Educator**
- ♦ **Author**
- ♦ **Keynote presenter**
- ♦ **Teacher trainer**
- ♦ **Conference speaker**

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Known throughout the country for motivating and engaging teachers and students, Brad has co-authored over a dozen books that provide easy-to-teach yet mathematically rich activities for busy teachers while teaching full time for over 30 years. In addition, he has co-authored over 40 teacher training manuals full of activities and ideas that help teachers who believe mathematics must be both meaningful and powerful.

Seminar leader and trainer of mathematics teachers

- ♦ 2005 California League of Middle Schools Educator of the Year
- ♦ California Math Council and NCTM national featured presenter
- ♦ Lead trainer for summer teacher training institutes
- ♦ Trainer/consultant for district, county, regional, and national workshops

Author and co-author of mathematics curriculum

- ♦ Simply Great Math Activities series: six books covering all major strands
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Pendulums and Planets

A Let's Learn About Astronomy Lab

Overview:

In this hands-on activity, students will learn why planets orbit at different speeds. They will also understand the principles that govern the behavior of pendulums. Beginning students can collect and display data as they gain experience working with tables and coordinate graphs. Older students can use the data they collect to study a linear function integrating math and the sciences of physics and astronomy. Extensions allow students to take the lesson into a deeper study of the mathematics of planetary astronomy.

Required Materials:

- ☒ String
- ☒ Heavy washers
- ☒ Meter sticks
- ☒ Stopwatch or phone for timing

Optional Materials:

- ☐ Access to research material or internet connectivity

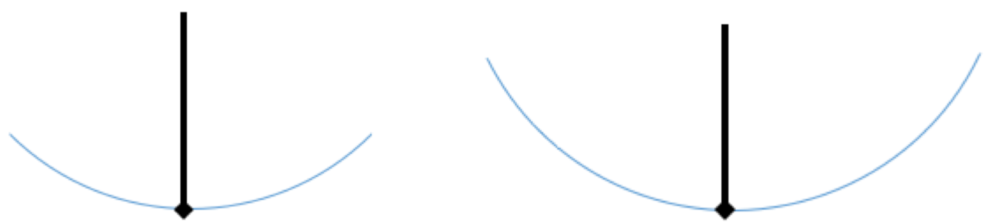
Procedure:

1. Each group of students will need a heavy washer and slightly less than a meter of string. I used ¾” washers. These have a ¾” hole in the center and are about 1½” in total diameter. The washer should be tied to the string as shown.
2. My students do this activity after learning about the orbital speeds of the planets and finding that Mercury takes only about 3 months to orbit the sun, while Pluto takes over 200 years. They suspect that this is due solely to the fact that Mercury, being the innermost planet, has a much smaller orbital path (circumference) than Pluto; it simply has less distance to travel. That is partly the case, but there is another factor. If they have ever observed or played the game of tetherball, they noticed that in the beginning it is fairly easy to hit the ball. However, once it has completed a few laps of the pole and the rope is shorter, it seems to speed up and become much more difficult to hit. In fact, this is true, and the students will see why later. If you prefer, this lab can be done prior to studying the planets or can be used independently of a study of astronomy. Here are some questions you can ask:
    a. How long does it take the earth to complete a revolution of the sun? (1 year)
    b. What have you noticed about how long it takes the other planets to orbit the sun? (The further the planet is from the sun, the longer it takes to complete a revolution.)

c. What do you think causes this? (Answers will vary.)

3. I then show the students a swinging pendulum. I explain that a *period* means one full swing out and back to the starting position. I ask them to time the period. Typically, this is difficult and students do not have matching times. This is because it happens so quickly that it is difficult to start and stop their timers accurately. I then suggest that we time ten full periods and divide by ten to get an average for one period.

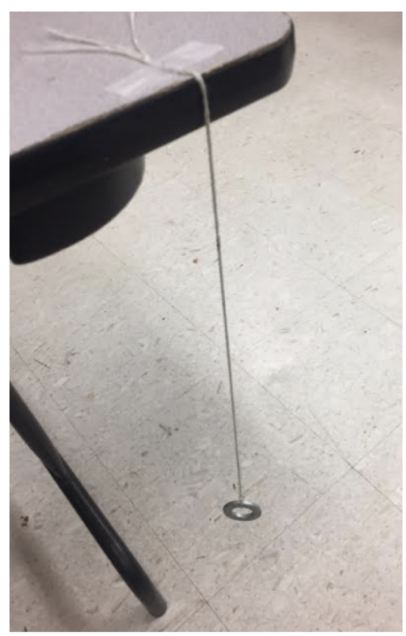
4. Some students might suggest that this strategy isn't a good idea. They notice that as the pendulum continues to swing, it seems to be moving more slowly. This is true, but it is also swinging through a smaller arc each time. *Its period time stays constant*. This is critical. I demonstrate this by timing ten periods of a smaller arc and ten with the pendulum dropped from a much greater height as shown.



Interestingly, the students see that the two periods have the same time. *Thus arc length does not determine the length of the period*. This property is called *isochronism*. Because of this property, pendulums are useful in keeping time.

This is an important point to consider during the lab. Students do not need to pull the washer back a long distance to time ten cycles. A much shorter drop will give the same results and is easier to manage.

5. Here are some questions you can ask to help students to connect this lab to astronomy:



   a. What does the washer represent in this lab? (A planet or orbital body.)

   b. What does the string represent? (Gravitational force.)

   c. What would be at the top of the string? (The sun.)

6. Give students one of the two worksheets to gather their data.

7. Have the students hang the pendulum over the edge of their desk or table so that the pendulum is 30 cm long. I have students measure to the center of the washer. You could also suspend them from a ring stand if you have them.

8. Have them time ten periods and record it in the middle column of their table. Then they can divide by ten (or simply move the decimal point) to calculate the time of one cycle. This is recorded in the right column of the table.

9. Have them repeat this with a 40 cm pendulum. Once they understand the process, they should continue recording in 10 cm increments.

10. Soon their pendulums will reach the floor, and they will not be able to gather data. Have them graph the data points that they have collected. (On the upper grades version, they will have to find appropriate scales for the axes.) They will notice that the data points appear to form a straight line. If our measurements and equipment were perfect, they would indeed form a perfectly linear relationship.

11. Students can use a ruler to draw a straight line that as closely as possible aligns with the points. They can then use this *line of best fit* to predict the times for the periods of greater lengths of string.

12. Students may also be able to do this using the table. They may notice that the lengths of the periods increase in a fairly consistent way. Any time we *measure* our results are never perfect. When we *count* in math, we can be exact, but measurement is always approximate. This is because we always round off to some significant increment. Two students who are 5 feet tall may not in fact be exactly the same height.

13. Students will see that the length of the string is a factor that determines the length of the period. The length of the arc is not a factor. Though the worksheet for the younger students ends at this point, you may wish to offer some extensions.

    a. What happens to the time of the period if the weight is changed? (It turns out that weight is not a factor in period length.)

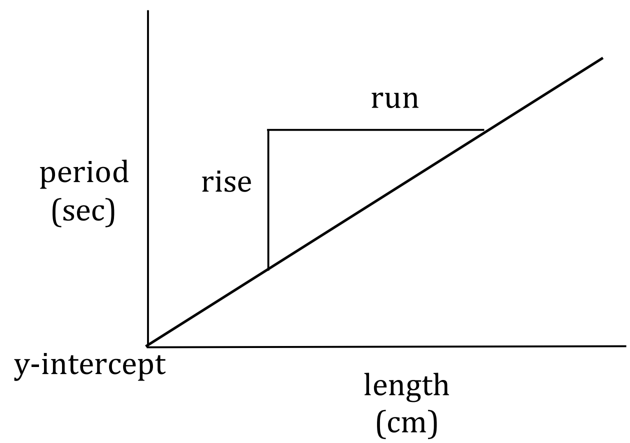
    b. Is there a pattern when a 50 cm pendulum has one, two, three, or four washers on it? (All the times appear to be the same when the length of the string is held constant and weight varies.)

    c. Can you predict the period length if there were eight washers? (It would be the same as when one washer was used.)

    d. What would this represent astronomically? (The mass of the planet is not a factor. It turns out that length of the pendulum and gravitational force are the factors affecting period.)

14. Younger students can end the lesson here. Older students on the other had, can extend this to find the formula for the pendulum. Once they have constructed the line of best fit, they can see the y-intercept and the slope of the line. The y-intercept should be zero, and the line will appear to intersect there. Even if it doesn't the formula will be fairly accurate. They can find the slope of the line also by comparing the rise and run. Alternately they can determine the slope and y-intercept from the table. They will need to find the value for a length of zero by extending the table backwards. This is shown in the graph and table below. The data and resulting formula may not match the results you get in your class with your materials.

	length (cm)	period (sec)	
	0	0	← y-intercept
	10	.06	
	20	.09	
	30	.11	
run	40	.13	rise
	50	.14	
	60	.16	



Slope: rise/run = .07/40 = .00175
Formula: y = .00175x

15. Students may want to research the orbital periods of the planets. You can suggest they research the following topics:
    a. Orbital periods and distances from the sun
        i. What is an orbital period?
        ii. How do orbital periods vary with distance from the sun?
    b. Astronomical unit (AU)
        i. What is an astronomical unit?
        ii. Why do we measure in astronomical units instead of miles?
        iii. When do we measure in light years?
    c. Johannes Kepler
        i. When did Kepler live?
        ii. What contribution did he make to astronomy?
    d. Kepler's 3rd Law
        i. What did Kepler's laws help to explain?
        ii. What does his third law explain?
    e. $P^2 = a^3$
        i. What does this formula mean?
        ii. What do the variables represent?
        iii. What measurement units are used in this formula?

A follow-up worksheet, “Planets and Their Orbits”, is provided for this.

Answer Key:

Pendulums and Planets:

Answers will vary somewhat due to measurement approximation. The formula for the period is $T \approx 2\pi\sqrt{\frac{L}{g}}$ where L is the length of the pendulum and g is the acceleration due to gravitational force. If L is measured in meters, then the gravitational acceleration is 9.8 m/s^2. Here is a table showing the times when this formula is used.

L *(cm)*	*T* *(sec)*
0	0.000
10	0.063
20	0.090
30	0.110
40	0.127
50	0.142
60	0.155
70	0.168
80	0.179
90	0.190
100	0.201
110	0.210
120	0.220
130	0.229
140	0.237
150	0.246
160	0.254
170	0.262
180	0.269
190	0.277
200	0.284

Planets and their Orbits: (You may wish to have students check their answers by researching the data in a text or on the internet. Answers are rounded to the nearest tenth of a year or tenth of an AU. Actual data regarding the planets will vary slightly because the values in the worksheet have also been rounded.)

1. 164.3 years
2. 253.0 years
3. 1.8 years
4. 9.5 AU
5. .4 AU
6. 600 AU
7. 14,696.9 years

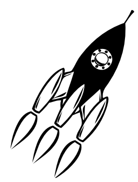
Pendulums and Planets

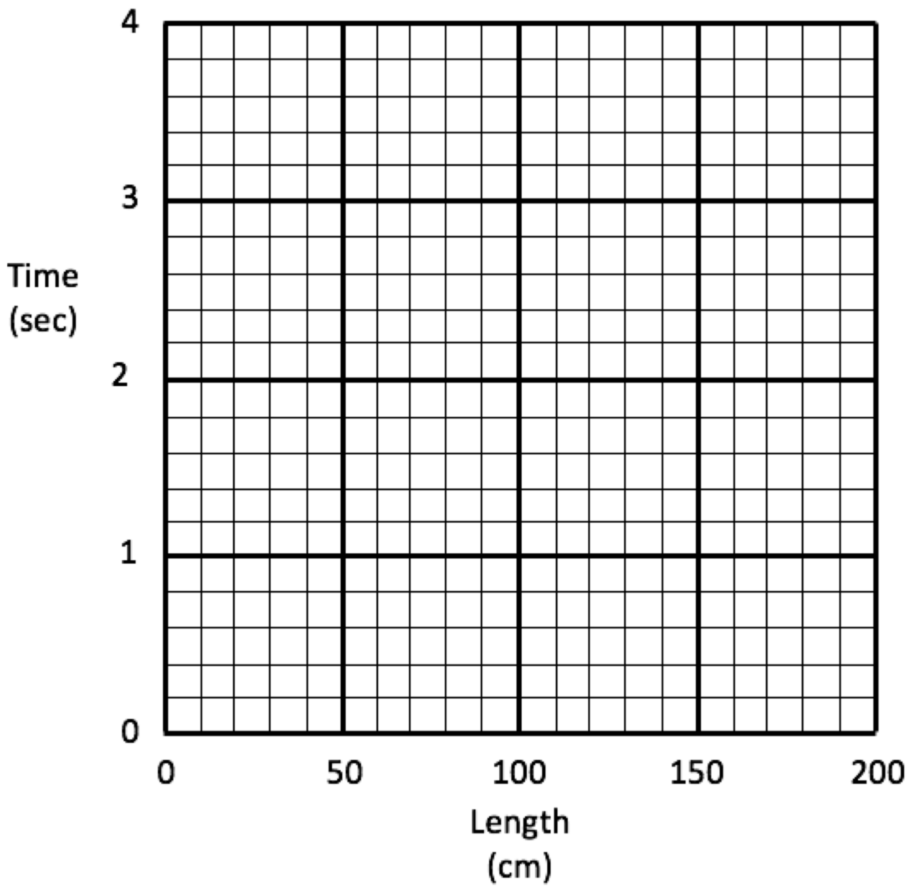
Name________________________________

Date______________________ Class_____

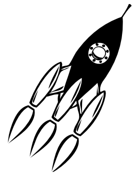
Record the times for ten periods of each pendulum length listed in the table. Then find the time for one period. Fill in the table and graph your points.

String length (cm)	Ten periods (sec)	Average period (sec)
30		
40		
50		
60		
70		
80		
90		
100		
:		
200		





Pendulums and Planets

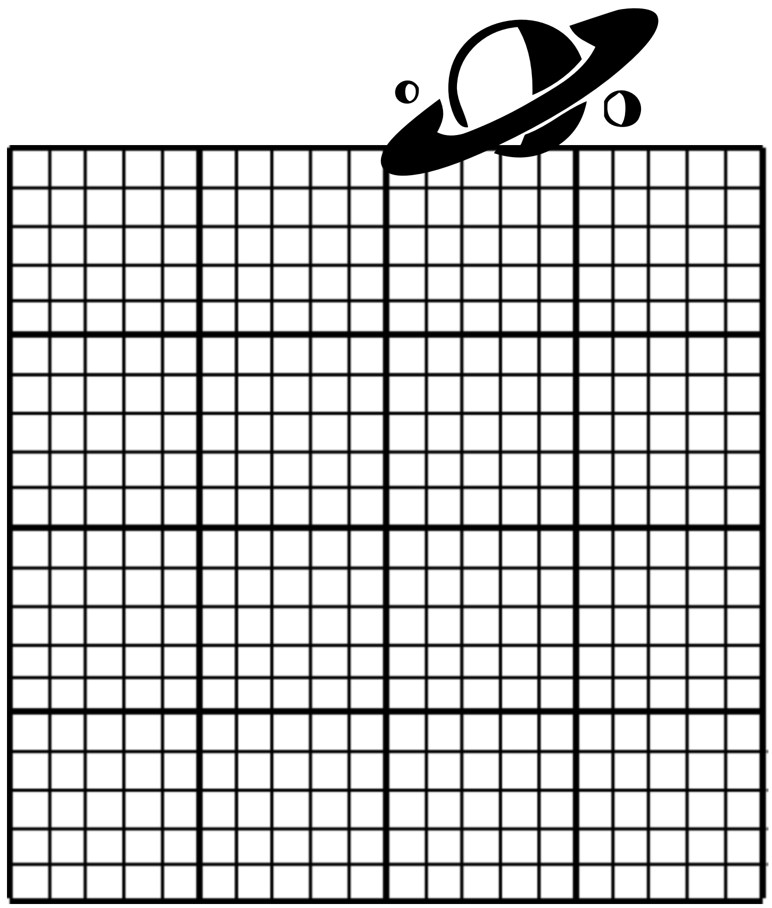


Name________________________________

Date______________________ Class_____

Record the times for ten periods of each pendulum length listed in the table. Then find the time for one period. Fill in the table and graph your points. Then use a line of best fit to find a formula. Use your formula to solve for the other data points.

String length (cm)	Ten periods (sec)	Average period (sec)
30		
40		
50		
60		
70		
80		
90		
100		
:		
200		



Formula: ______________________________

Planets and Their Orbits

Name________________________________

Date______________________ Class_____

Nearly 400 years ago, astronomer Johannes Kepler studied the orbits of our planets and derived a formula that predicts their distances from the sun. His formula, called Kepler's 3rd law is written

$$P^2 = a^3$$

The variable P represents the orbital period of the planet measured in years. For Earth, this has a value of 1. The second variable, a, is the distance from the sun in Astronomical Units. This also has a value of 1 for Earth.

The formula states that the square of the revolution around the sun, (orbital period: P), is equal to the cube of the distance from the sun (a). We can use either piece of information to find the other.

Here is how the formula is used. If a planet were *twice* as far from the sun as the Earth it would be 2 AU distant.

$$P^2 = 2^3$$

$$P^2 = 8$$

$$P = \sqrt{8} \approx 2.828$$

Thus this planet would take nearly 3 Earth-years to orbit the sun.

1. Neptune is 30 AU from the sun. What is its orbital period? ____________
2. Pluto is nearly 40 AU from the sun. What is its orbital period? ____________
3. Mars is 1.5 AU from the sun. What is its orbital period? ____________
4. Saturn has a revolution of 29.5 years. How far is it from the sun? ____________
5. Mercury has a revolution of 0.25 years. How far is it from the sun? ____________
6. In 2016, researchers at Caltech discovered evidence suggesting that a Planet X exists 20 times further from the Sun than Neptune. How many AU would that be?

   ____
7. Based on your answer to question 6, what is its orbital period? ____________

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Happy teaching,

Brad