Lesson Title	Kepler's Third Law and Celestia
Length of Lesson	1.5 hours
Created By	Dr. Donna Pierce, William Funderburk, and Justin Warren
Subject	Physics
Grade Level	11-12
State Standards	Physics: 2d
DOK Level	DOK 2
DOK Application	Make observations and interpret
National Standards	Physics B
Graduate Research Element	The researcher uses Microsoft Excel to manipulate and plot data from which inferences are made.

Student Learning Goal:
The students will the freely available software Celestia and Microsoft Excel to verify Kepler's third law.

State Standards
Physics 2: Develop an understanding of concepts related to forces and motion. d) Apply the effects of the universal gravitation law to graph and interpret the force between two masses, acceleration due to gravity, and planetary motion. (DOK 2)
- Kepler's third law.

National Science Education Standards of Content 9-12
B (Physical): Motions and Forces: Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on an object. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

Materials Needed (supplies, hand-outs, resources):
Computer with the programs Celestia (which can be downloaded at the following URL: http://www.shatters.net/celestia) and Microsoft Excel

Lesson Performance Task/Assessment:
The students will need to collect three pieces of data for each of the eight planets: the distance of each planet from the sun, the beginning date of an orbit, the ending date of the orbit. They can either write these down or enter them directly into Excel to save a step. Figure 1 shows the screen when Celestia is first opened.
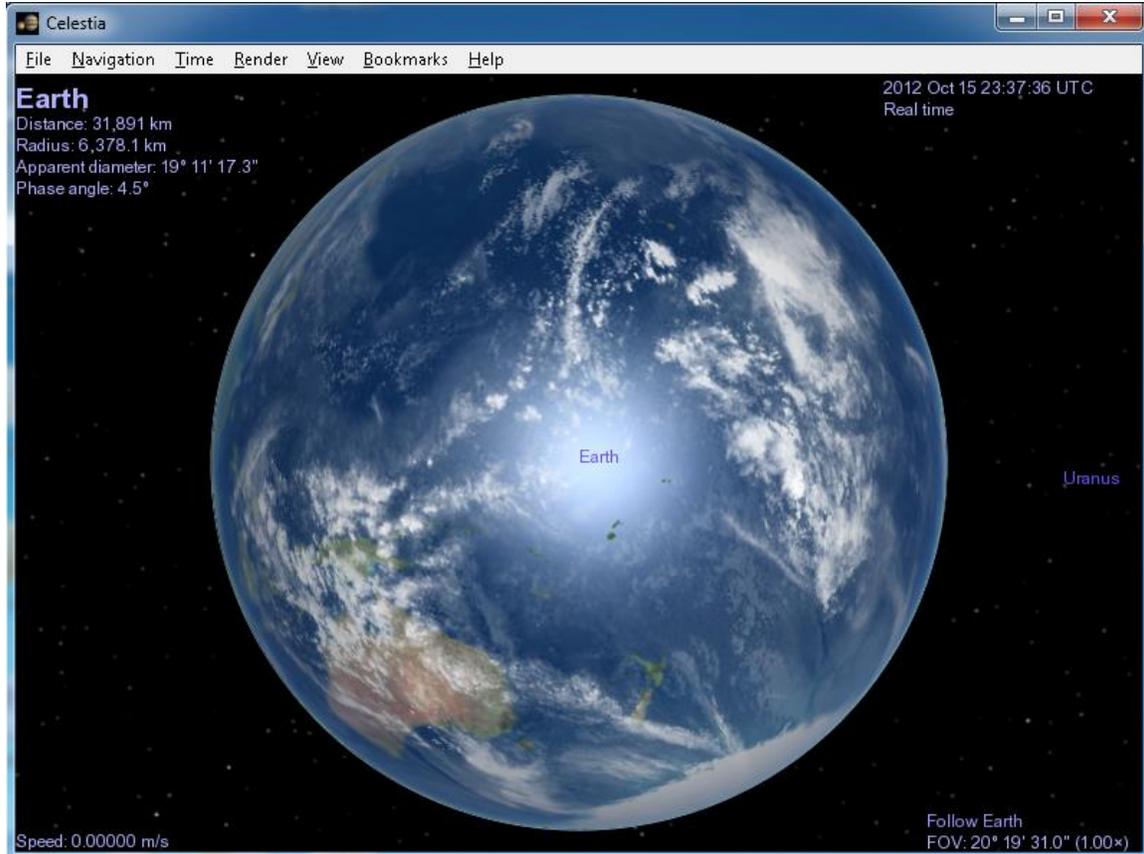

Figure 1. Celestia opening screen

Notice that some basic information on the planet can be seen in the upper left of the screen, and information regarding the date can be seen in the upper right. The lower left will indicate various commands which are being followed which can be helpful if the program is not performing as intended. Usually the command in the lower left can be a clue that you have a command turned on which you didn't intend.

Click on the Render button and View Options to display the box seen in Figure 2. Note the setting chosen, specifically orbits, markers, and verbose. The verbose option gives you a bit more interesting information in the upper left hand corner.
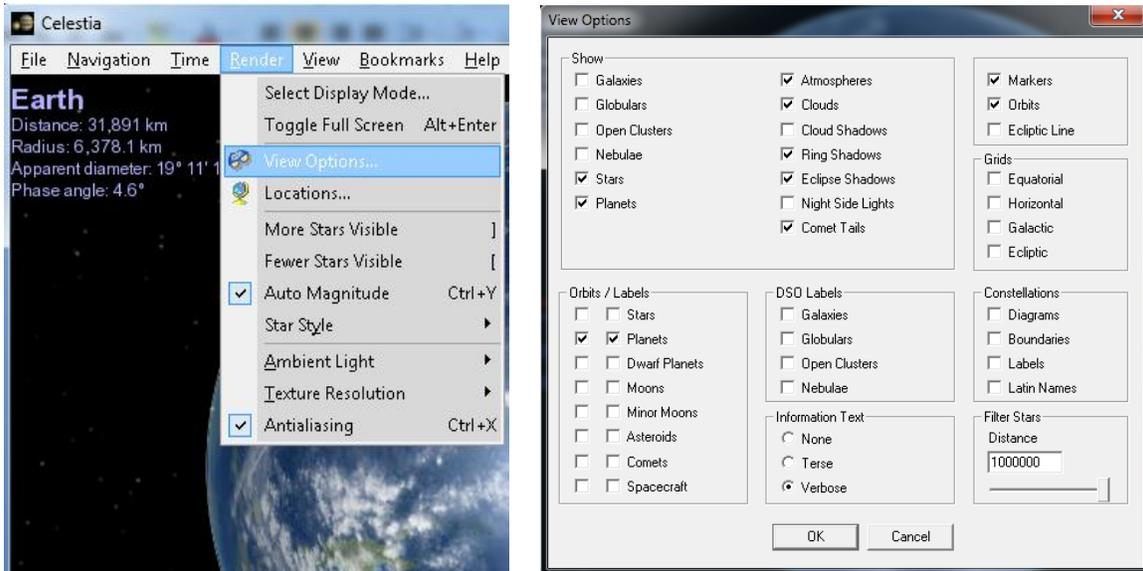
Figure 2. View Options window

To collect the data for the distance from a planet to the sun, punch the number key associated with each planet (for example, punch the 3 key for Earth) and then punch the letter G to go to the planet. Celestia will take you to the selected planet and will display new information in the upper left hand corner of the screen. The number 5 key has been punched in Figure 3. Note that Jupiter is listed in the upper left corner and that a small red arrow has appeared on the far left amongst the orbit lines indicating that at this particular time Jupiter is located to the left.
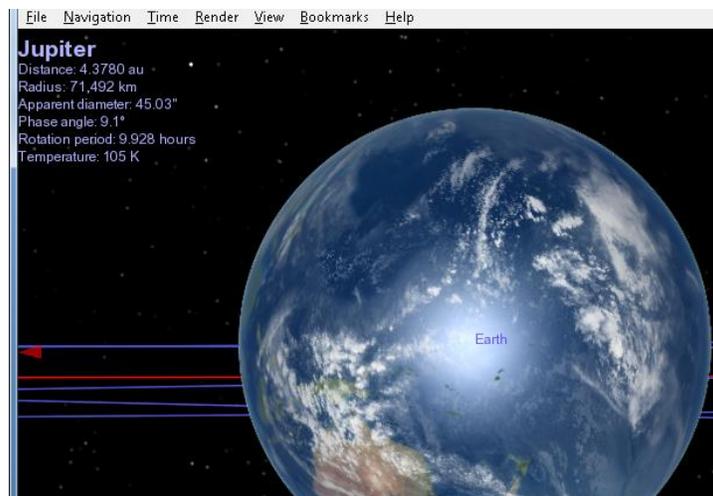

Figure 3. Screen after a planet number has punched

Figure 4 shows the screen after the letter G has been punched. Note that the view can be zoomed in or out using the scroll wheel for convenience or by pressing the home or end keys for zooming in and out respectively.
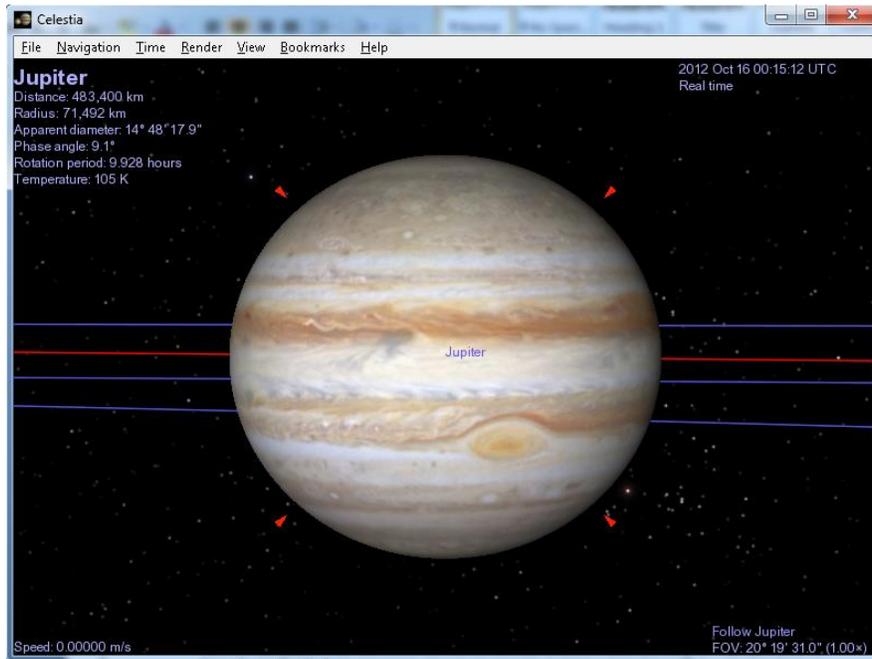

Figure 4.

Once at the planet, hit the letter H, but do not hit G afterwards (hitting G will take you to the selected entity). Note in Figure 5 that the upper left information has changed after hitting H. Now the student can record the distance from Jupiter to the sun in astronomical units (1AU = 92,955,807 miles). Repeat this process for each planet.
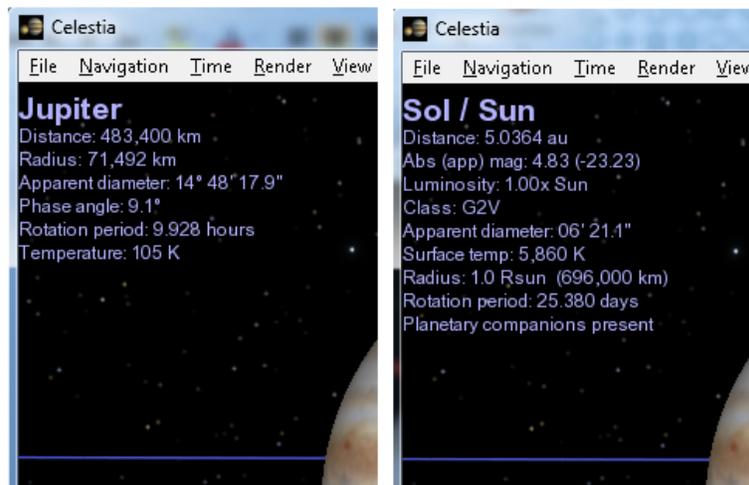

Figure 5. Distance to the sun listed after hitting H

Next select Goto Object under the Navigation button and fill in the data seen in Figure 6. After hitting okay, you'll be taken to the sun as seen in Figure 7.
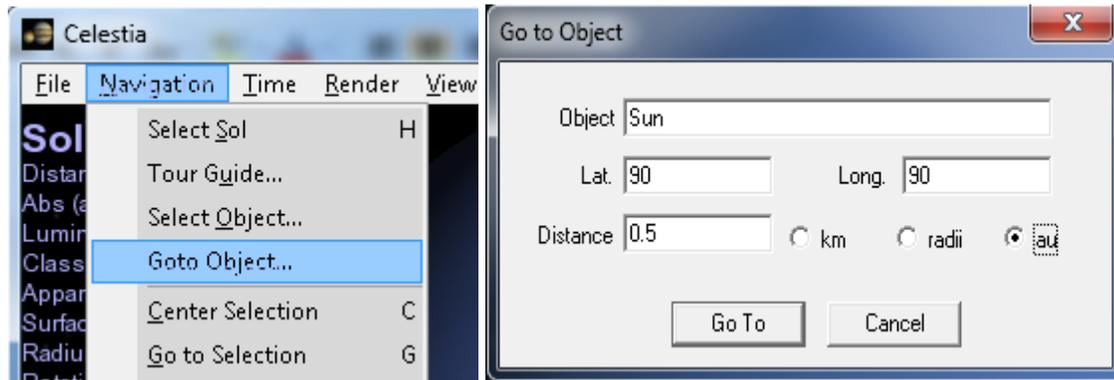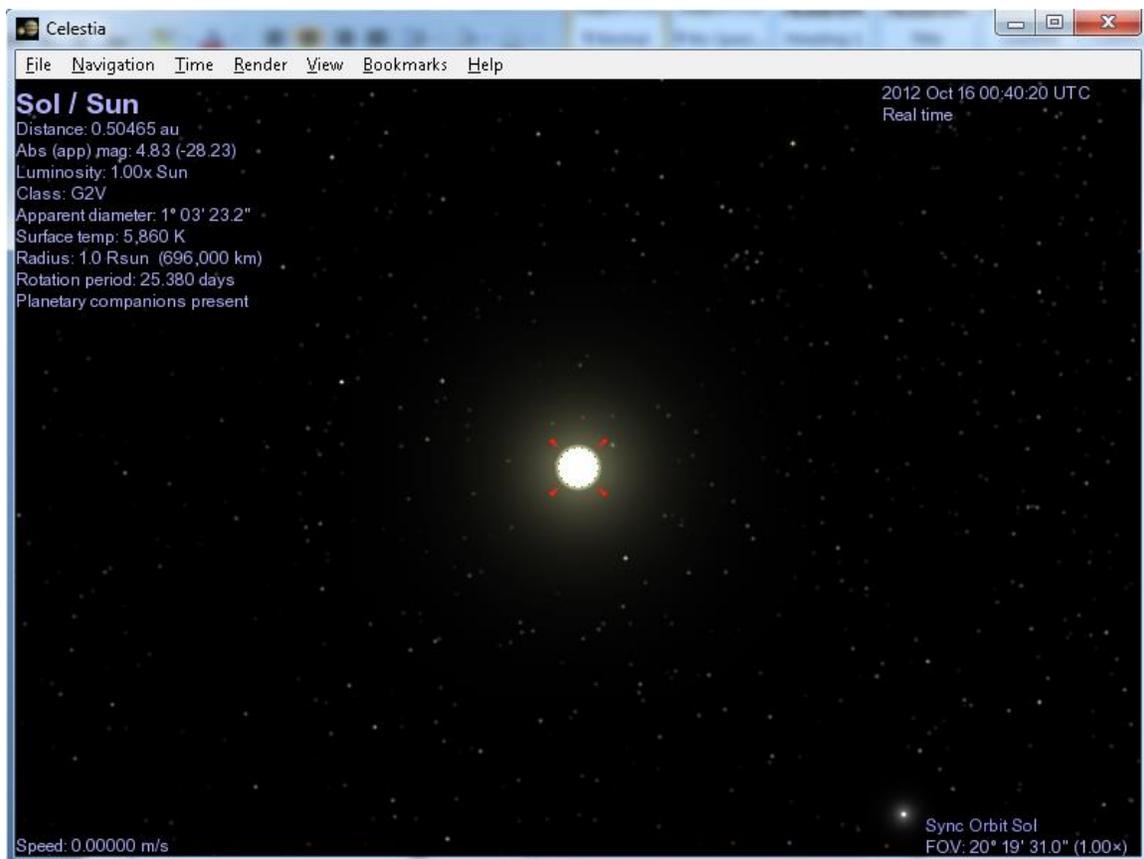

Figure 6. Go to the sun

Figure 7.

Zoom out to see the inner and outer planets as seen in Figures 8 and 9 respectively. This is a great way to see the relative size of the orbits. Note how small the inner planets' orbits are compared to the outer planets.
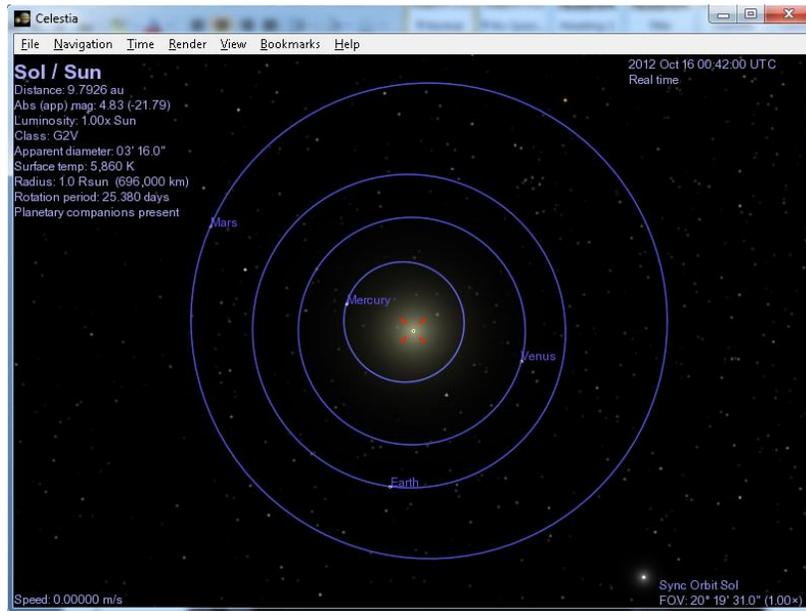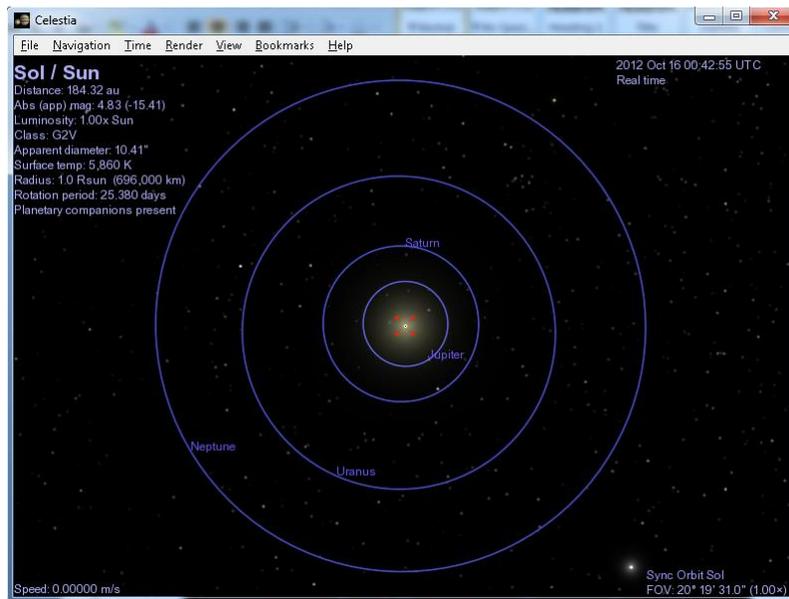

Figure 8. Inner planet orbits

Figure 9. Outer planet orbits

Now the students can begin recording period data for each planet. To do this, punch the number key associated with each planet. In Figure 10 Mars has been selected by pressing the number 4 key. Note that the red arrow markers will assist you in finding each planet on its orbit.
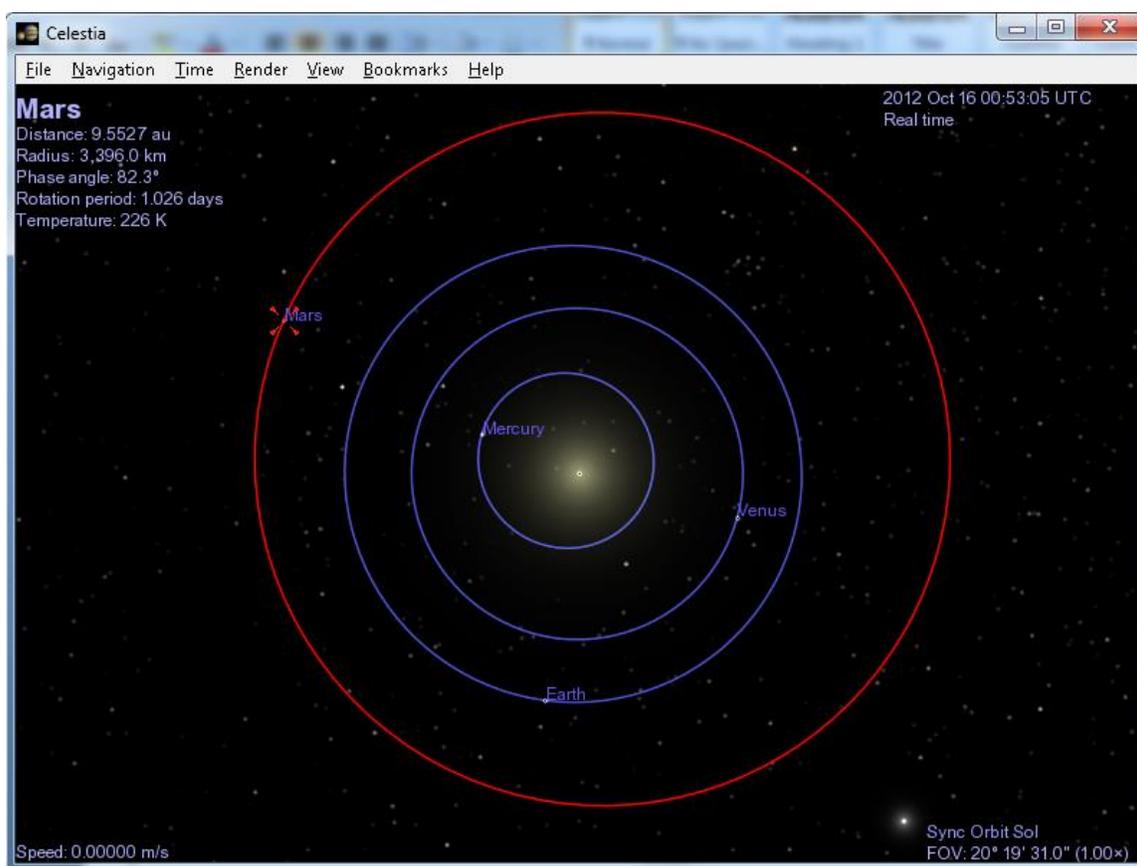

Figure 10. Selected Mars orbit by pressing 4

Hit the Esc key to cancel any motion commands which might be in place. Then place the cursor crosshairs directly over the planet and record the month, date, and year shown in the upper right hand corner of the screen. The goal here is to record the beginning and ending dates for a single orbit. The keys L and K speed up and slow down the passage of time respectively. Punch the L key several times to speed up the planets progression through its orbit and the K key to slow down time as the planet comes full circle and nears the crosshairs (which you haven't moved). Bring time back to real time just as the planet is under the cross hairs again and record the date in the upper right hand corner. Do this for each planet. Note that you want the orbit you're interested in to take up the entire screen so that it's easier to see when the planet has completed a full orbit and is under the crosshairs again. Also note that you can double click on the sun to re-center it. As a check, Earth's period is one year.

The students can then use Excel to calculate the period of each planet in Earth years. Then a plot of the periods squared versus the distances to the sun cubed can be made. It should be noted that because the planet orbits are very near circular, the distance from the sun is a good approximation of the orbit's semi-major axis. A linear trendline should be added to this plot and its equation and r squared value (goodness of fit) displayed on the plot. Both the slope of the line and the r squared value should be very near one. See Figure 11 for a sample plot. Note that most of the data points are very near the beginning of the plot. With this finished, the students have verified Kepler's third law.
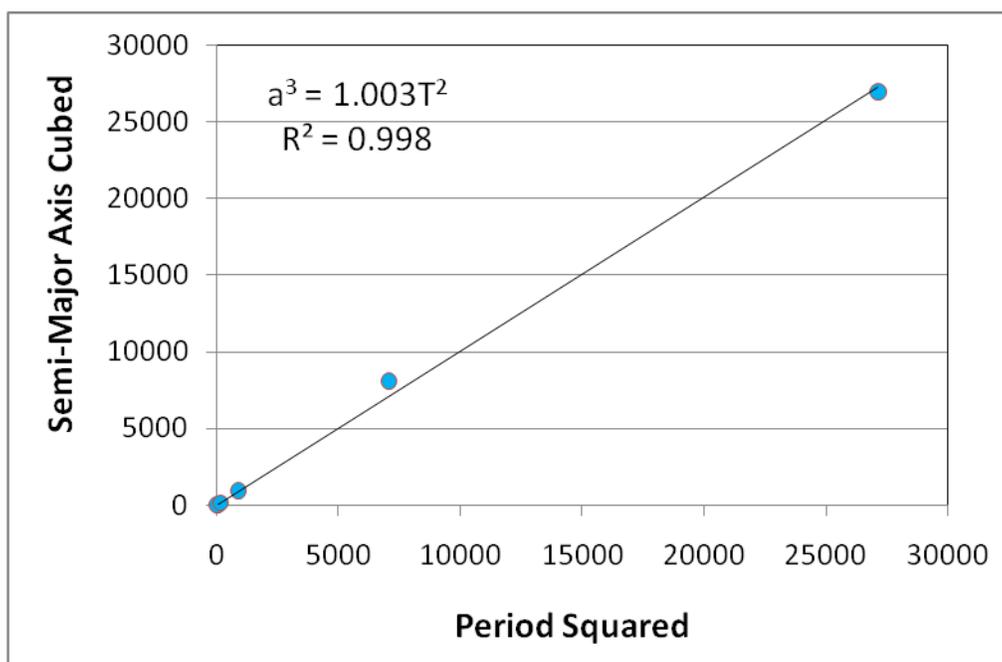

Figure 11. Period squared versus semi-major axis cubed

Lesson Relevance to Performance Task and Students:
The students will verify Kepler's third law which states that "the square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit" by using Celestia to manually determine the orbital period and semi-major axis of each of planet. They will input this data in Excel and plot the orbital period squared versus the semi-major axes cubed. Then a trendline will be fitted to the data from which a proportional relationship will be observed.

Anticipatory Set/Capture Interest:
The instructor will guide the students through a quick tour of the solar system using Celestia. This will not only be meant as an interesting activity, but it will also introduce the students to the basic operations of Celestia. A Celestia user's guide can be found at http://www.shatters.net/celestia/documentation.html.

Guided Practice:
The instructor will discuss the lesson procedures after the solar system tour before the students begin working on the lab.

Independent Practice:
It's preferable that the students work individually if there are available computers. The entirety of the lesson will be carried out on their own as the instructor moves about the room answering questions and offering advice if students are obviously performing the lesson incorrectly.

Remediation and/or Enrichment:
Remediation: Individual IEP

Enrichment: In Celestia there are many fun and interesting things to explore. Encourage students who finish the lab early to explore their favorite planets, moons, or galaxies.

Check(s) for Understanding:
The student should be able to demonstrate the validity of Kepler's third law by using the plots and trendlines they've developed in Excel.

Closure:
Following the lab, the instructor will lead a short discussion on how programs like Celestia and Excel are important tools for engineers and scientists.

Here are some provocative questions to ask the class:
- Celestia is a fun program, but how might it be of use to a scientist?
- Can you think of a way that Celestia could be used to verify Kepler's second law?
- How do trendlines help us to better understand data?

Possible Alternate Subject Integrations:
Introduction to data manipulation with Microsoft Excel

Teacher Notes:
Make sure to tell the students that Celestia is a free program that anyone can download from the aforementioned website.