

Model the Movements of the Planets

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Subject: Science, math

Audience: Teachers, teacher
educators

Grade Level: 5–10 (10–15)

Technology: Internet/Web

Standards: *NETS-S* 3, 5. *NETS-T* II,
III. (Read more about NETS at www.iste.org—select Standards Projects.)

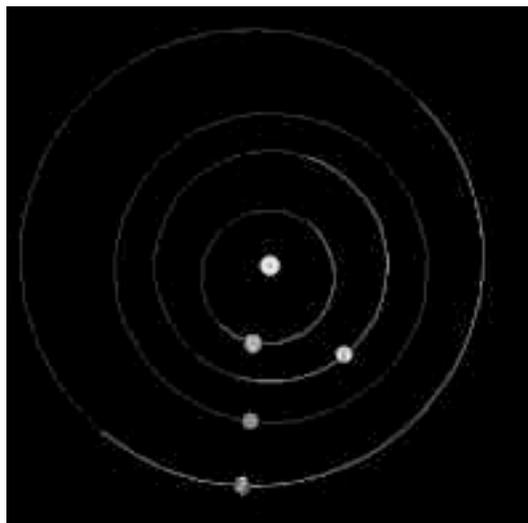


Figure 1. Inner planets at 2001-06-13 UTC 14:00:00.

Table 1. Distances and orbital periods of inner planets from Sun.

Data source: National Space Sciences Data Center Planetary Fact Sheets (<http://nssdc.gsfc.nasa.gov/planetary/planetfact.html>).

Object	Symbol	Distance Kilometers	Distance AU	Period Earth days
Sun	☉	0	0.000	
Mercury	♿	57,910,000	0.387	88
Venus	♀	108,210,000	0.723	225
Earth	♁	149,600,000	1.000	365
Mars	♂	227,920,000	1.524	687

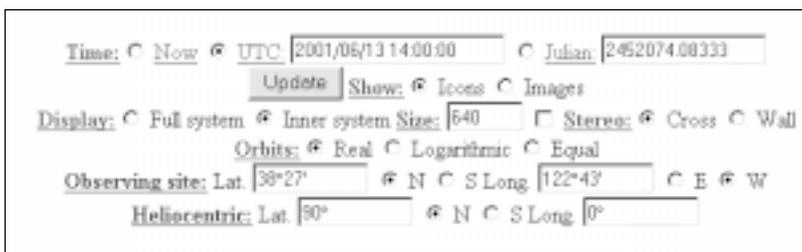


Figure 2. Solar System Live settings (www.fourmilab.to/solar).

During our measurement and modeling adventures, we have modeled the relative sizes of the planets in the solar system and the distances of the planets from the Sun (Albrecht & Davis, 2000–01, 2001). These models have been static models. As time passes, our scale model planets do not move the way real planets move. This time, we'll model the motion of the planets as they go around and around the Sun. To keep it simple, we'll model only the inner planets: Mercury, Venus, Earth, and Mars.

The planets travel around the Sun in elliptical orbits. However, in the spirit of keeping things simple, we'll use circular orbits. The radius of each circular orbit is equal to the average distance of the planet from the Sun. Table 1 shows the average distances from the Sun of the inner planets in kilometers and astronomical units (AUs). One AU is equal to 149.60 million kilometers, the average distance of Earth from the Sun. We'll use AUs in our models of planetary motion. Table 1 also shows the or-

bitual period of each planet, the number of Earth solar days (1 solar day = 24 hours) for the planet to make one complete orbit around the Sun.

To see where the planets are now or at any date and time you choose, go to Solar System Live (www.fourmilab.to/solar). In the first line of the first paragraph, click *inner planets* to go to a diagram showing the orbits and current locations of the inner planets as seen by an observer far above the North Pole of the sun. Below the diagram is an area in which you can enter the date, time, and other settings.

Farther down the page is an ephemeris showing such things as the coordinates of the Sun, Moon, and planets relative to the observing site on Earth. The observing site is at 47° North latitude, 7° East longitude. You can locate this site on Earth by using a world atlas. Changing the location (latitude and longitude) of the observing site changes the data in the ephemeris but does not change the

appearance of the diagram of the orbits and positions of the planets.

We went to Solar System Live and entered settings to obtain the diagram in Figure 1. It shows the inner planets relative to our observing site (38° 27' North latitude, 122° 43' West longitude) for the date 2001-06-13 and time UTC 14:00:00 (Coordinated Universal Time—2:00 P.M. in Greenwich, England). This time is 07:00:00 (7 A.M. Pacific Daylight Time). In this view of the inner planets, the planets are moving counterclockwise. To change the date and time to the ones you want, click the UTC button and enter the date and time. We also set the Size to 640 and the Orbits to Real. Our settings are shown in Figure 2.

On June 13, 2001, at UTC 14:00:00 hours (2:00 P.M. in Greenwich, England), Mars will be in *opposition* to Earth. Mars will be on the opposite side of Earth from the Sun and you can draw a straight line through the centers of the Sun, Earth, and Mars. Mercury is catching up with

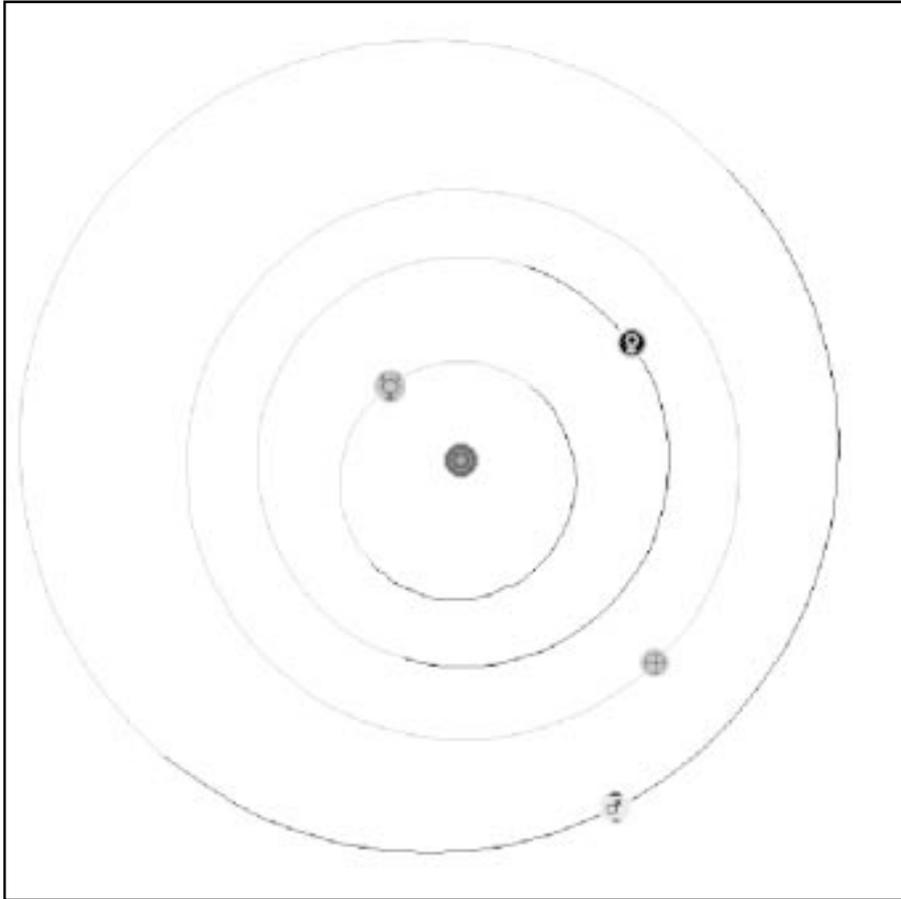


Figure 3. Inner planets at 2001-08-05 UTC 22:00:00.

Earth and approaching *inferior conjunction*. Inferior conjunction of Mercury occurs when Mercury is between Earth and the Sun, and you can draw a straight line through the centers of the Sun, Mercury, and Earth. Mercury will be at inferior conjunction 2001-06-16 UTC 13:00:00. You can enter this date and time into Solar System Live and see a diagram with Mercury at inferior conjunction.

Venus was at inferior conjunction 2001-03-30 UTC 04:00:00. Enter this date and time into Solar System Live and see a diagram with Venus at inferior conjunction. Venus travels faster than Earth, so by June 13, it has moved well past Earth. Remember, the planets are moving counter-clockwise in this view.

Mercury travels even faster than Venus, so it will catch up with Venus, momentarily be at inferior conjunction to Venus, and then pass Venus and hurry

around the Sun. How can you use Solar System Live to find the next date when Mercury will be at inferior conjunction to Venus?

Figure 3 shows the inner planets on 2001-08-05 UTC 22:00:00. Mercury is at *superior conjunction* to Earth. It is on the opposite side of the Sun from Earth, and you can draw a straight line through the centers of Earth, the Sun, and Mercury. Compare this diagram with the diagram in Figure 1, in which Mars was at opposition. Earth travels faster than Mars, so in Figure 3 it has passed Mars. On 2002-08-10 UTC 22:00:00, Mars will be at *conjunction* relative to Earth. It will be on the opposite side of the Sun from Earth, and you can draw a straight line through the centers of Earth, the Sun, and Mars. Enter this date and time into Solar System Live and see a diagram with Mars at conjunction with Earth.

In astronomical lingo, a planet whose orbit is outside Earth's orbit is a superior planet, and a planet whose orbit is inside Earth's orbit is an inferior planet. We would prefer outside planet and inside planet, but we'll go with the standard jargon.

An inferior planet can be at inferior conjunction or superior conjunction. It is at inferior conjunction when it is between Earth and the Sun, and Earth, the planet, and the Sun are lined up in a straight line. An inferior planet is at superior conjunction when it is on the opposite side of the Sun from Earth, and the Earth, the Sun, and the planet are lined up in a straight line.

At inferior conjunction, the Sun, Venus, and Earth are lined up like this:



At superior conjunction, Venus, the Sun, and Earth are lined up like this:



A superior planet can be at conjunction or opposition. It is at conjunction when it is on the opposite side of the Sun from Earth, and the Earth, Sun, and the planet are lined up in a straight line. A superior planet is at opposition when it is on the opposite side of Earth from the Sun, and the Sun, Earth, and the planet are lined up in a straight line.

At conjunction of Mars with Earth, Mars, the Sun, and Earth are lined up like this:



At opposition of Mars with Earth, the Sun, Earth, and Mars are lined up like this:



Of course, if you live on Mercury, all of the other planets are superior planets, and they can be at conjunction or opposition relative to Mercury. If Venus is your domicile, Mercury is an inferior

planet, and Earth and Mars are superior planets. If you reside on Mars, Mercury, Venus, and Earth are inferior planets.

Planet Movement Models

At Solar System Live, you can see where the inner planets are every day, once a week, or as often as you want, so make a big poster of the orbits and attach small pictures or symbols of the planets in their orbital positions. Every few days, move the symbols or pictures of the planets to their current orbital positions. To do this accurately, copy the Solar System Live diagram into a graphics editor, enlarge it, and print it. Before printing it, reverse the colors to get rid of that toner-gobbling black background.

We first made a small model on 21.6 cm by 27.9 cm (8.5 in. by 11 in.) paper, the right size to put in our Starship Gaia D-ring binder. The radius of Mar's orbit is about 1.5 AU, so the diameter is about 3.0 AU. Our paper is 21.6 centimeters wide, so we chose a scale of 20 centimeters to 3 AU. A few algebraic alakazams provided the following scales (for more about scale in the solar system, visit <http://lyra.Colorado.EDU/sbo/mary/Scale>):

- 20 cm : 3 AU.
- 6.67 cm : 1 AU.
- 1 cm : 0.15 AU.

Using the data in Table 1, we calculated the scale radii of the orbits of the inner planets and rounded the answers to a tenth of a centimeter.

- Mercury:
(0.387 AU)(6.67 cm/AU) = 2.6 cm.
- Venus:
(0.723 AU)(6.67 cm/AU) = 4.8 cm.
- Earth:
(1.000 AU)(6.67 cm/AU) = 6.7 cm.
- Mars:
(1.524 AU)(6.67 cm/AU) = 10.2 cm.

We put the Sun at the center of the paper and drew circles corresponding to the scale orbits. We also drew horizontal and vertical axes passing through the

Sun in the center of the page. We put the paper with the orbits into a sheet protector and drew the planet symbols on small dots that we can stick to the orbits. We got the diagram of the inner planets at Solar System Live, put it into a graphics processor, made a negative image to get rid of the black background, and printed it.

On the printed copy, we drew horizontal and vertical axes passing through the Sun and measured the angle that each planet made with the horizontal axis. Using this data, we stuck our planets onto their orbits and then rested. Every week or so we'll get the new positions and move our tiny planets to their new orbital positions.

Wouldn't it be lovely to have an inner planet poster on the classroom wall that is updated every week or so? We went to our neighborhood art supply store, bought a 55.9 cm by 71.1 cm (22" by 28") poster board, and made a larger scale model of the inner planets. After making a few mistakes, we homed in on a scale factor of 50 centimeters to 3 AU. The usual algebraic alakazams produced:

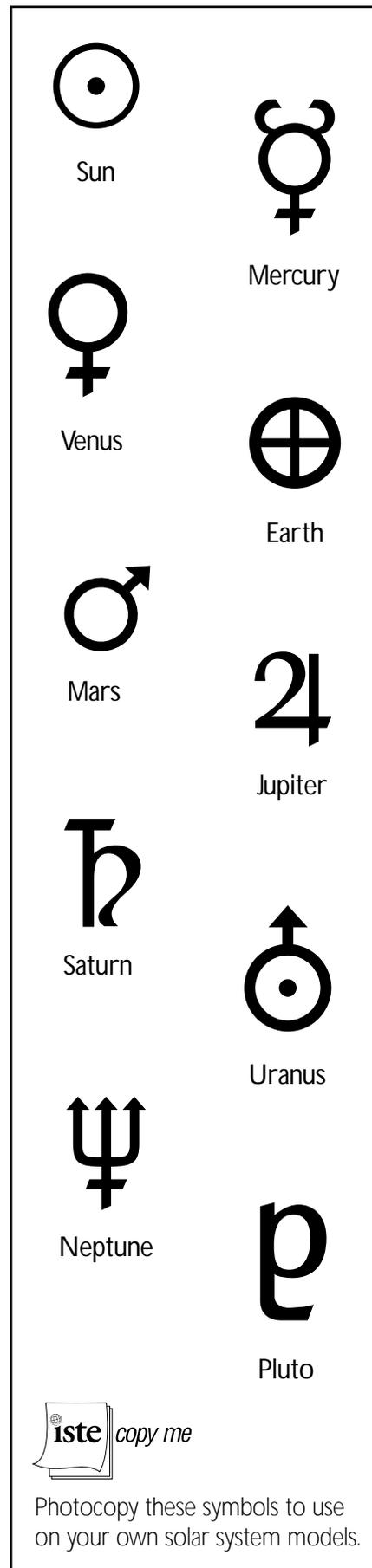
- 50 cm : 3 AU.
- 16.7 cm : 1 AU.
- 1 cm : 0.06 AU.

Using the data in Table 1, we calculated the scale radii of the orbits of the inner planets and rounded the answers to a tenth of a centimeter.

- Mercury:
(0.387 AU)(16.7 cm/AU) = 6.5 cm.
- Venus:
(0.723 AU)(16.7 cm/AU) = 12.1 cm.
- Earth:
(1.000 AU)(16.7 cm/AU) = 16.7 cm.
- Mars:
(1.524 AU)(16.7 cm/AU) = 25.5 cm.

Hmmm ... our protractor doesn't draw circles with radii of 16.7 cm or 25.5 cm. Never mind. We cut a piece of cardboard 30 cm long and 2.5 cm wide; poked a hole near one end for the

Model continued on page 61.



Model continued from page 35.

position of the Sun; poked more holes at the scale distances of Mercury, Venus, Earth, and Mars; and used this homemade tool with a pushpin and a pencil to draw the circular orbits. It worked well!

Our next project will be a larger poster, using thick cardboard. We'll choose an appropriate scale, draw the orbits on the cardboard, and use pushpins to attach the images representing the planets.

Your Turn

Make models of the inner planets like the ones we described. Each student can make a small model for his or her notebook. Teams of students can make larger models to hang on the wall. As described previously, move small pictures or symbols of the planets into their orbital locations every few days. Once a week is fine.

Add one or more of the outer planets: Jupiter, Saturn, Uranus, Neptune, and Pluto. At Solar System Live, you can click on *entire solar system* to get a diagram of the orbits and positions of all of the planets. Table 2 shows the average distances from the Sun and orbital periods of the outer planets. Distances are shown in kilometers and AUs.

Mercury, Venus, Mars, Jupiter, and Saturn are sometimes visible in the nighttime sky. You can see them if you know where and when to look. If you make a motion model of the planets from Mercury out to Saturn, you can learn a lot about where the planets are in Earth's sky and how they move in their journeys around the Sun.

- You can determine whether Mercury, Venus, Mars, Jupiter, and Saturn are visible in the nighttime sky.
- You can learn where and when to look for a planet that is visible in the nighttime sky.
- You can estimate the times when the planets rise in the east and set in the west.

Table 2. Distances and orbital periods of outer planets from Sun.

Data source: National Space Sciences Data Center Planetary Fact Sheets (http://nssdc.gsfc.nasa.gov/planetary/planetfact.html)					
Object	Symbol	Distance Kilometers	Distance AU	Period Earth days	Period Earth years
Sun	☉	0	0.000		
Jupiter	♃	778,570,000	5.204	4,331	11.9
Saturn	♄	1,433,530,000	9.582	10,747	29.5
Uranus	♅	2,872,460,000	19.201	30,589	83.7
Neptune	♆	4,495,060,000	30.047	59,800	164
Pluto	♇	5,869,660,000	39.236	90,588	248

- You'll see that a planet closer to the Sun moves faster than a planet farther from the Sun.

Do you know your latitude and longitude? If not, you can get it from these sites:

- How Far Is It?: www.indo.com/distance
- AstroDienst—Atlas Query: www.astro.com/cgi-bin/atlw3/aq.cgi?lang=e

To get dates and times of planetary phenomena such as oppositions and conjunctions, go to NASA RP 1349 (<http://sunearth.gsfc.nasa.gov/eclipse/TYPE/TYPE.html>). Scroll down to Planetary Phenomena: 1995–2010 and click a year to get a long list of interesting planetary events.

Extending the Fun

Thanks to personal computer pioneer Stanley Veit, founder of *Computer Shopper Magazine*, there is an Internet site under construction where we can display expanded versions of our instructional stuff. Go to DragonFun at www.dragonfun.net. Once there, you can view instructional stuff we are developing in several strands, including:

- Algebra Backpack
- Measurement & Modeling

- Play Together, Learn Together
- Starship Gaia

Have a great summer! We'll see you in October 2001.

References

Albrecht, B., & Davis, P. (2000–01). Make your own system: Measurement and modeling on a solar scale. *Learning & Leading with Technology*, 28(4), 32–35, 57.

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Bob Albrecht (SSGaia2000@aol.com) is a writer and developer of science, math, and technology curricula. George Firedrake is his alter ego and takes the form of a dragon.

Laran Stardrake, whose quotes sometimes lead off the column, is another of Bob's "accomplices." She's half dragon and half human. As Laran is fond of saying, "Reality expands to fill the available fantasies." The DragonFun image is from an original painting by Marcy Kier-Hawthorne.



Paul Davis (ctec1@mchs.srca.k12.ca.us) is a mathematics teacher at Maria Carrillo High School in Santa Rosa, California. He was a happy, normal teacher until he met Bob Albrecht and George Firedrake in 1992 and became another one of their accomplices. Since then, Paul has been intertwining math, science, and technology in his classroom with the help of Bob and George.