A Tabletop Orrery: Connecting Learners with the Night Sky*

Larry Lebofsky, Michelle Higgins, Don McCarthy, Nancy Lebofsky, and the NIRCam E/PO Team

Introduction

Visualizing planetary motions and their relationships to each other is difficult for many learners. In many of our outreach programs over the years, we modeled the motion of the Earth around the Sun and the seasonal constellations, but this did not involve a lot of audience participation. Based on a series of articles and presentations, we finally came up with the idea of a portable human orrery and a small tabletop orrery that allowed for greater audience participation.

An orrery is a mechanical device that shows the relative positions of the planets in our Solar System. The first orrery was probably built in the first century BCE. One of the first modern orreries was constructed by John Rowley for Charles Boyle, the 4th Earl of Orrery hence the name we use today. While most orreries are mechanical (Fig. 1), modern orreries can also be computer-generated. Orreries can be fairly simple, they can be works of craftsmanship, or they can be made with Lego® pieces! Unfortunately, while illustrating the relative positions of the planets, orreries also create many misconceptions: the relative sizes of the planets, the relative distances of the planets from the Sun, the causes of the phases of the Moon, etc. They are not intended to be accurate scale models of the Solar System.

Figure 1: Four examples of mechanical orreries Far left, orrery for sale (credit: www.1worldglobes.com); left, replica of James Furguson's orrery for sale (credit: www.curiousminds.co.uk); right, an orrery showing the inner planets (credit: wikimedia commons); far right, an orrery made with Lego® pieces, built by George Moody (credit: ecg.mit.edu/George//lego/orrery.html/)

Background on Human Orreries

Figure 2: Armagh Observatory orrery (Credit: Armagh Observatory)

There are several "human orreries" that show the correct relative scale distances between the planets and give participants the opportunity to become the planets as they orbit the Sun. There are at least two permanent human orreries, one in Dynic Astropark in Japan and another at the Armagh Observatory, Northern Ireland (*Astronomy and Physics News* 2005, 46:3.31–3.35; *Sky and Telescope* May 2005; http://www.arm.ac.uk/orrery/). The Armagh Observatory model even has elliptical orbits and is able to show the correct relative positions of the planets (Fig. 2).

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There are also two published orreries that can be assembled and demonstrated: a GEMS activity (http://kepler .nasa.gov/files/mws/HumanOrrerySSSmsGEMS.pdf) designed for middle school, linked from the Kepler website, and one designed for a college-level class in Vancouver, Canada (Peter Newbury, *BAAS* 41:660; *The Physics Teacher* 48:473). A YouTube video of this activity can be found at: http://www.youtube.com/watch?v=ju4cfEp2BgU

The last two models are limited to showing the relative distances and motions of the planets and, perhaps, the relative sizes of the planets. More recently, we have created a version of the Human Powered Orrery that allows participants to view the actual positions of the planets on any given night while standing on the orrery (Fig 3). This was published by the Astronomical Society of the Pacific several years ago and is used in our *Girl Scout Leaders' Workshop in Hands-on Astronomy*:
https://astrosociety.org/wp-content/uploads/2013/02/uitc82.pdf
http://www.astronomycamp.org/

Figure 3: Positions of the planets during a teacher workshop in July 2011

These pictures were taken at one of our workshops. In the left image, a teacher (white blouse representing the Earth) is positioned at sunset and can see Mercury; but Venus, Mars, and Jupiter (hidden behind "Earth" and the author) are morning objects, so she would have to rotate 180 degrees counterclockwise (12 hours) in order to see all of these planets. In the right image, Saturn is also visible from the Earth at sunset. Note the scale of this model is 1 m = 1 AU. An Astronomical Unit, 1 AU, is the mean distance from the Sun to the Earth, 150,000,000 km. Jupiter and Saturn are 5.2 and 9.6 meters away, respectively (5.2 and 9.6 AU, respectively).

For the activities presented below, we have designed a Tabletop Orrery that can be either printed out on a large-format printer or printed in four segments and taped together. While it does not provide the visual power of being "in the model," it does provide the girls with the opportunity to visualize the positions of the planets prior to actually observing them in the sky.

The Tabletop Orrery:

This model exists as a PDF file that is available from the authors. It is 16 inches wide and can be printed out on a large format printer or at a copy store as a small poster. We have also divided it into four sections so that it can be printed out on a standard printer and taped together. We use small wooden figures (Meeples; www.meeplesource.com), but Lego® or other small figures can also be used (See Fig. 4 and 5). We also put a face on the Earth Meeple, "Mt. Nose," to represent the direction we are looking from our perspective on the Earth (Fig. 5a.)

The circles are numbered 1, 2, 3, etc. in a counterclockwise direction to denote the various positions of the planets Mercury, Venus, Earth, etc. The separations of the circles are related to the counterclockwise motions of each of the planets around the Sun. For Venus, Earth, and Mars, each circle represents 16 days of orbital motion. Because Mercury moves much faster in its orbit (Kepler's Law; the farther a planet is from the Sun, the slower it moves in its orbit), the circles are separated by 8-day intervals. We have also included partial orbits for Jupiter and Saturn, along with their relative distances from the Sun on this scale. Because they are farther from the Sun, the circles are 80 days apart for Jupiter and 160 days apart for Saturn. Table 1 below can be used to find where a planet is located on any given date (Fig. 4 and 7).

Table 1: Orrery Planet Positions for 2017 to 2019

Date	Mercury	Venus	Earth	Mars	Jupiter	Saturn
Mar. 30, 2017	4	8	13	7		
Apr 15, 2017	6	9	14	8	3	
May 1, 2017	8	10	15	9		
May 17, 2017	10	11	16	10		
June 2, 2017	1	12	17	11		
June 18, 2017	3	13	18	12		
July 4, 2017	5	14	19	13	4	3
July 20, 2017	7	1	20	14		
Aug. 5, 2017	19	2	21	15		
Aug. 21, 2017	11	3	22	16		
Sept. 6, 2017	2	4	23	17		
Sept. 22, 2017	4	5	1	18	5	
Oct. 8, 2017	6	6	2	19		
Oct. 24, 2017	8	7	3	20		
Nov. 9, 2017	10	8	4	21		
Nov. 25, 2017	1	9	5	22		
Dec. 11, 2017	3	10	6	23	6	4
Dec. 27, 2017	5	11	7	24		
Jan. 12, 2018	7	12	8	25		
Jan. 28, 2018	19	13	9	26		
Feb. 13, 2018	11	14	10	27		
Mar. 1, 2018	2	1	11	28	7	
Mar. 17, 2018	4	2	12	29		
Apr. 2, 2018	6	3	13	30		
Apr. 18, 2018	8	4	14	31		
May 4, 2018	10	5	15	32		
May 20, 2018	1	6	16	33	8	5
June 5, 2018	3	7	17	34		
June 21, 2018	5	8	18	35		
July 7, 2018	7	9	19	36		
July 23, 2018	19	10	20	37		
Aug. 8, 2018	11	11	21	38	9	
Aug. 24, 2018	2	12	22	39		
Sept. 9, 2018	4	13	23	40		
Sept. 25, 2018	6	14	1	41		
Oct. 11, 2018	8	1	2	42		
Oct. 27, 2018	10	2	3	43	10	6
Nov. 12, 2018	1	3	4	1		
Nov. 28, 2018	3	4	5	2		
Dec. 14, 2018	5	5	6	3		
Dec. 30, 2018	7	6	7	4		
Jan. 15, 2019	9	7	8	5	11	

Table 1 (Continued): Orrery Planet Positions for 2019 to 2020

Date	Mercury	Venus	Earth	Mars	Jupiter	Saturn
Jan. 15, 2019	9	7	8	5	11	
Jan 31, 2019	11	8	9	6		
Feb. 16, 2019	2	9	10	7		
Mar. 4, 2019	4	10	11	8		
Mar. 20, 2019	6	11	12	9		
Apr. 5, 2019	8	12	13	10	12	7
Apr. 21, 2019	10	13	14	11		
May 7, 2019	1	14	15	12		
May. 23, 2019	3	1	16	13		
June 8, 2019	5	2	17	14		
June 24, 2019	7	3	18	15	13	
July 10, 2019	9	4	19	16		
July 26, 2019	11	5	20	17		
Aug. 11, 2019	2	6	21	18		
Aug. 27, 2019	4	7	22	19		
Sept. 12, 2019	6	8	23	20	14	8
Sept. 28, 2019	8	9	1	21		
Oct. 14, 2019	10	10	2	22		
Oct. 30, 2019	1	11	3	23		
Nov. 15, 2019	3	12	4	24		
Dec. 1, 2019	5	13	5	25	15	
Dec. 17, 2019	7	14	6	26		
Jan. 2, 2019	9	1	7	27		
Jan. 18, 2019	11	2	8	28		
Feb. 3, 2019	2	3	9	29		
Feb. 19, 2020	4	4	10	30	16	9

Key Concepts

With the Tabletop Orrery, our primary goal is to connect the activity with actual observations of the night sky. Learners, Girl Scouts, other children, as well as educators, are able to use the positions of the planets as modeled by the orrery to predict what they will see that evening in the night sky.

- Orbits of the planets: prior knowledge (Activity 1)
- Scale of the Solar System (Activity 1)
- Rotation and day and night (Activity 1)
- Relative positions of the planets in the night sky (Activity 1)
- Predicting the night sky (Activity 1)
- Revolution of the Earth and seasonal constellations (Activity 2)
- Revolution and motion of the planets in the sky and relative motions of the planets in their orbits (Activity 3)

Note: When doing these activities, we suggest that you start by "rounding down" the date, e.g., if you do the activity on, say May 5, 2017, you should have the girls first stand on circles for May 1, 2017, and then move to the next date, May 17, 2017, to see how the positions have changed. For the following activities, we have chosen May 5, 2017 as an example of when a presentation might be held. It is also important that all girls participate. If you are doing only one or two activities, have all of the girls take turns being the Earth and seeing what the "sky" looks like from the Earth. Planets Uranus and Neptune and the dwarf planet Pluto move more slowly through the sky and are in Pisces, Aquarius, and Sagittarius, respectively, for the entire time. On page 14 (Fig. 8), there is a 1/2 scale version of the Tabletop Orrery. It includes the positions of the constellations as well as partial orbits for Jupiter and Saturn at 80-day and 160-day intervals, respectively.

Activity 1

Orbits of the planets: prior knowledge

Ask the girls what is at the center of our Solar System. Pick one of the girls who gives the correct answer (the Sun) and have them put the large yellow Meeple (or other figure to represent the Sun) at the center of the orrery. Then ask the girls which planet is closest to the Sun. Pick one of the girls who gives the correct answer (Mercury) and have them put the small black Meeple (or other figure) on the appropriate circle (in our example, since we are doing this on May 5, 2017, they should stand on circle 8 for Mercury, "rounding down" to May 1). Do the same for Venus (circle 10), Earth (circle 15), and Mars (circle 9); see Figure 4a. At this point, you can also do the two brightest "outer" planets, Jupiter (0.52 meters) and Saturn (0.96 meters). Because they are too far away from the Sun, we have only given the directions towards these planets. Their relative positions and distances can be seen in Figure 4b.

Ask the girls what is modeled correctly and what is not. The relative distances from the Sun are correct as are the relative positions of the planets. However, in this model the Sun would be represented by a 1 mm bead. The planets would be too small to be represented to scale in this model. Also, because of the way the model is set up, Jupiter and Saturn may be "beyond" the constellations depending how far you put the constellations from the four inner planets. In reality, the nearest stars (other than the Sun) are hundreds of thousands of times farther away from the Earth than the Sun is! At this point, you can also discuss the actual distances of the planets from the Sun and introduce the term Astronomical Unit.

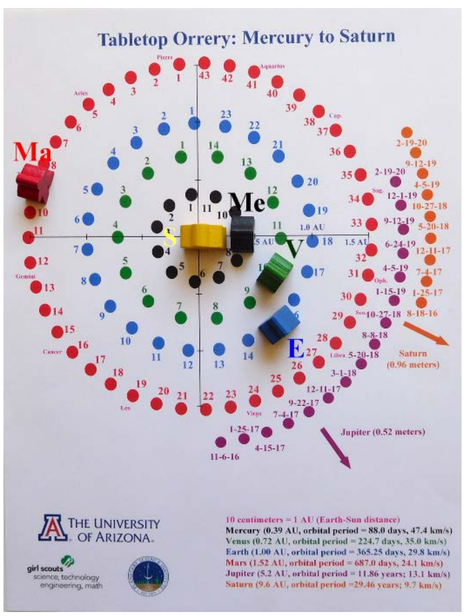


Fig. 4a. Planet positions on May 1, 2017
S = Sun, Me = Mercury, V= Venus, E= Earth, Ma = Mars

Fig. 4b. Planet positions including Jupiter and Saturn with distances to scale

Day and night—rotation and revolution

Have the girl who has the Earth Meeple turn the Meeple so that its face, Mt. Nose, faces directly toward the Sun Meeple (Fig. 5b). Caution the girls never to look directly at the real Sun! Explain to them that their nose represents a mountain on the Earth pointing directly up at the sky. Ask the first girl what the time of day is for Mt. Nose, it is noon. Have them rotate the Meeple counterclockwise (you should explain or ask what this motion is) and stop them when they have made a 1/4 rotation, 90 degrees (Fig. 5c). Again, ask them what time it is (around sunset). Have them continue their rotation through midnight (Fig. 5d), sunrise, and back to noon. You should then note that one rotation of the Earth on its axis is equal to one day (day/night cycle) of the Earth. At this point, you can either mention that all of the planets rotate and have day/night cycles or ask the girls what they think. You may also mention that you will be talking about orbiting (revolving) in a few minutes. **Note:** At this point or prior to Activity 1, you may want to demonstrate the rotation and revolution of the Moon. **Note:** the actual rotations of some of the planets, including the Earth, and how this relates to their actual day/night cycles is somewhat more complicated and can be discussed with older girls.

Fig. 5a. Mt. Nose (drawn) on Meeple

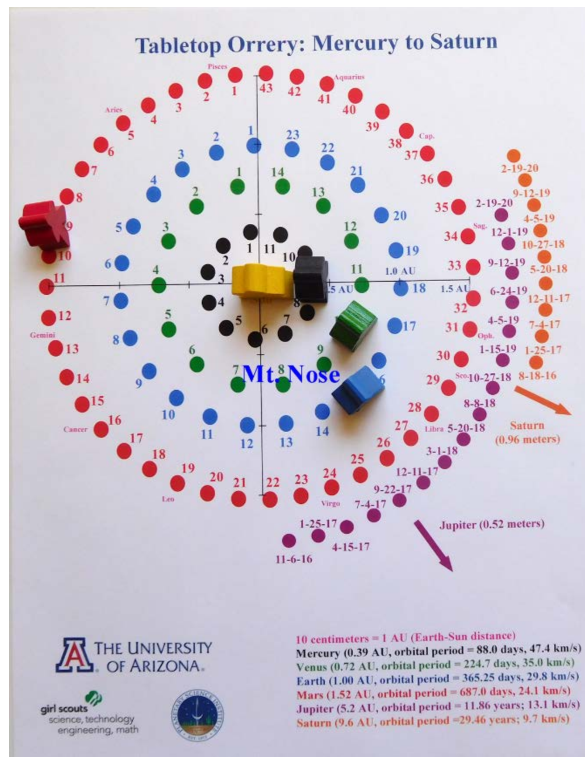


Fig 5b. Noon on Earth: Mt. Nose toward Sun

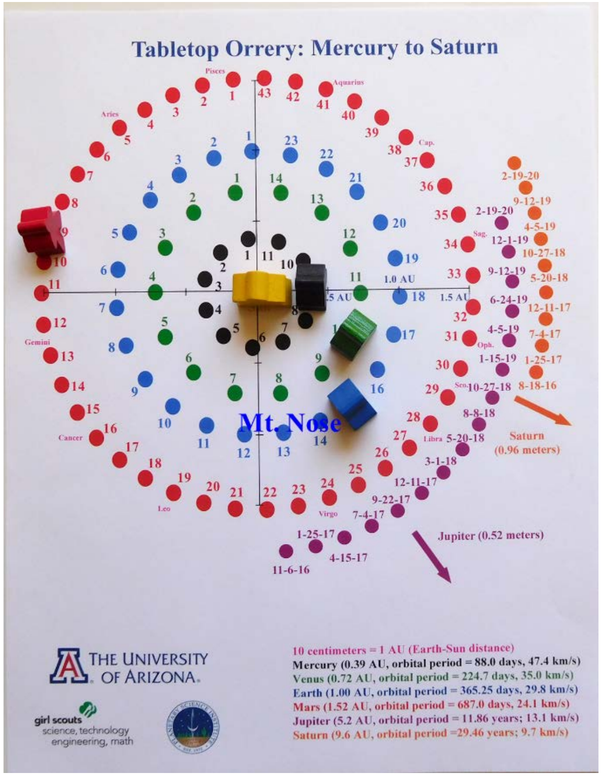


Fig 5c. Sunset on Earth: Mt. Nose turned 90 deg. from Sun

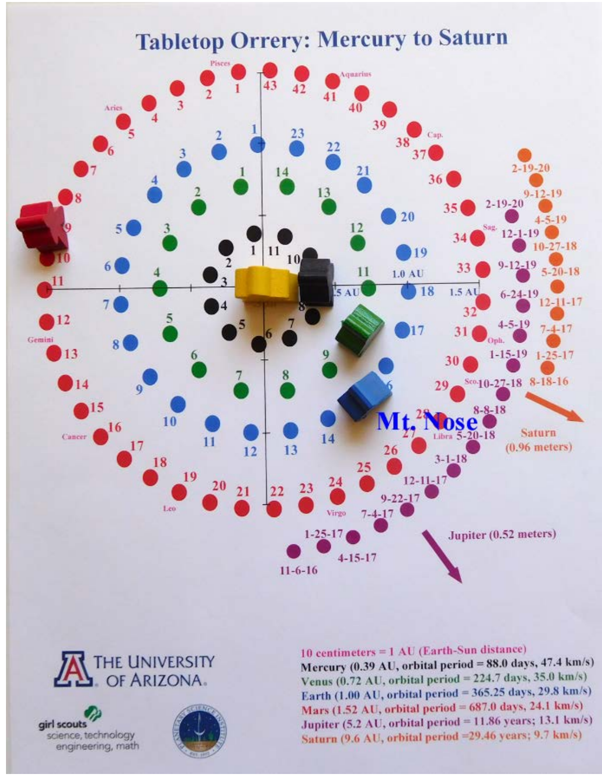


Fig 5d. Midnight on Earth: Mt. Nose away from Sun

The positions of the planets in the night sky
Now have the girl who represents the Earth start rotating their Meeple again. As they do, have them look at the locations of the five other planets and call them out as the Earth Meeple rotates. Have them stop when they are facing each planet and ask them whether or not they think that they would be able to see the planet in the real sky. What you want to get across is that, if the Sun is up, they will not be able to see the planet. They will be able to see any given planet only if the Sun has set and it is dark! This is a good point at which to get other girls to take the role of the Earth and to look at the other planets in the sky.

Predicting the night sky
Have girls who are not one of the planets or the Sun stand around the orrery, near the constellation illustrations (Fig. 6) and have them call out the names of the constellations one at a time starting from the direction of the lowest numbered circles (Pisces). Note that when they go outside and if it is dark enough to see the stars, they should be able to see this planet “in” (within the boundaries of) this constellation. Now ask all of the girls to predict what they would expect to see if they went out after sunset: what planets would be in the night sky, where would one be or at what time would one have to go out to observe them, and what constellations would one see. If this activity is followed up by an evening event, they will be able to follow up their predictions with actual observations!

Activity 2
Revolution of the Earth and the seasonal constellations
For this activity, you should just have the Earth orbit (revolve) around the Sun. To engage the most girls, have a girl stand on each of the constellation positions Have the girl who has the Earth Meeple turn the Meeple so that its face, Mt. Nose, faces directly toward the Sun Meeple. Again, caution the girls never to

look directly at the real Sun. Ask them what constellations are behind the Sun and if they would expect to see these constellations in the real sky (no, they are "up" during the day and "behind" the bright Sun). Have the girl rotate the Meeple 1/4 turn counterclockwise (6:00 pm, around sunset) and ask them what constellations they see and then have them turn the Meeple an additional 1/4 turn (midnight) and ask them what constellations they see. This can be repeated for sunrise. Have the girl move the Earth Meeple from one circle to the next circle (circle 16, May 17), one step in a counterclockwise direction. Explain to the girls (or ask them) that this represents the motion of the Earth in its orbit around the Sun (orbiting, or revolving). Ask the girls what the Earth is doing as it moves from one circle to the next (it rotates) and mention that, since each step represents 16 days, the Earth rotates 16 times (they can try to rotate the Meeple 16 times). As time allows, have the Earth step 5 additional steps (1/4 of the way around the Sun, circle 21, August 5), 6 more steps (1/2 of the way around the Sun, circle 4, November 9), and 6 more steps (3/4 of the way around the Sun, circle 10, February 13, 2018. Ask the girls how much time has passed (about three, six months, and nine months for 5, 11, and 17 steps, respectively). Ask the Earth to again rotate and describe what constellations they see (the constellations that were "up" at night cannot be seen because they are "behind" the Sun). This describes why we see different constellations at different times of the year.

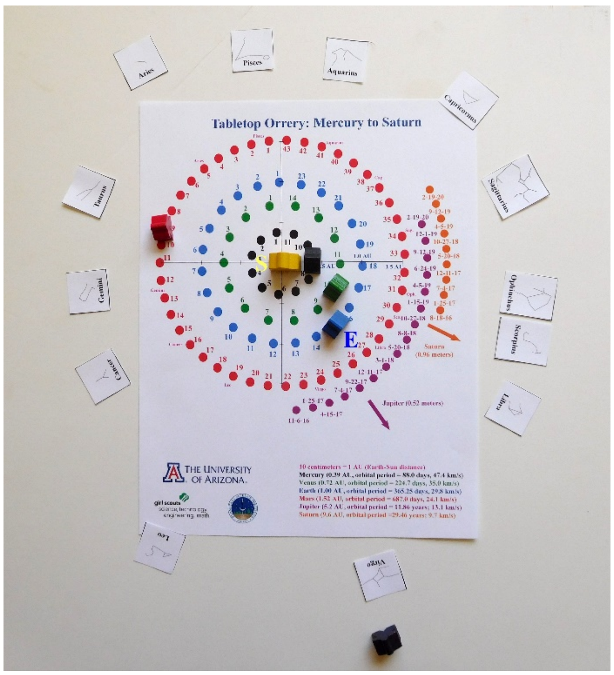


Fig. 6a. May 1, 2017

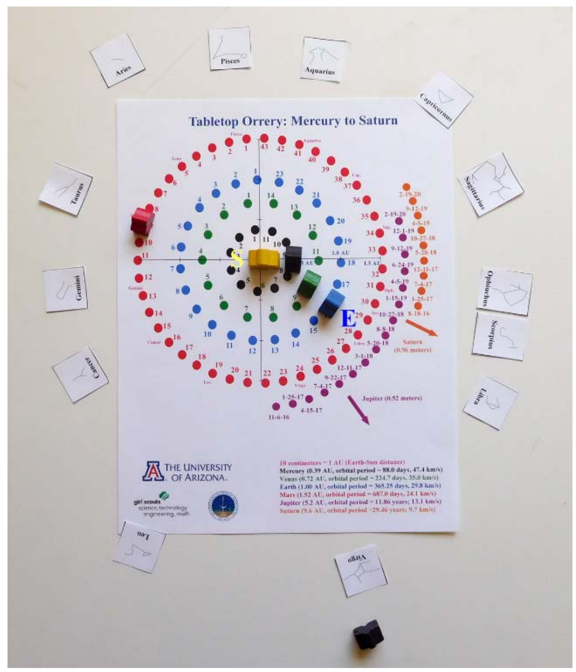


Fig. 6b. May 17, 2017

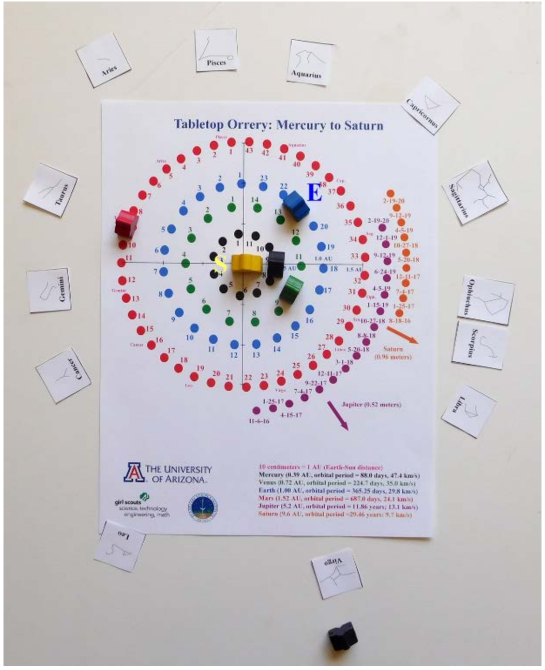


Fig. 6c. August 5, 2017

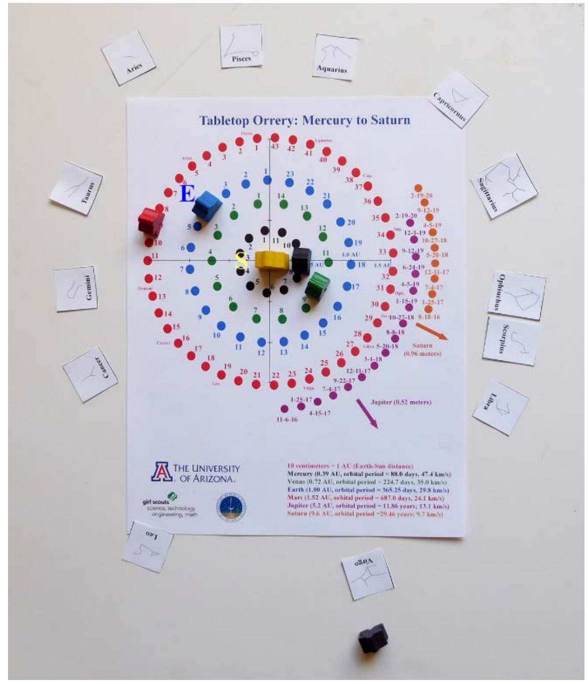


Fig. 6d. November 9, 2017

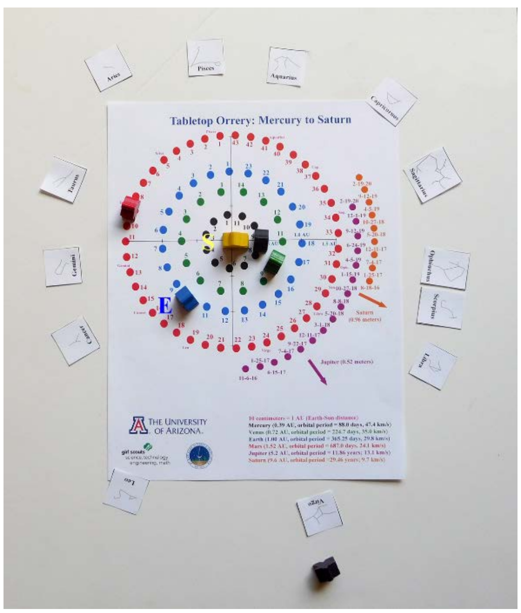


Fig 6e. February 13, 2018

Activity 3

Revolution—motion of the planets in the night sky

As time permits, you can now talk about the revolution (orbit) of all of the planets around the Sun. This is a more advanced activity and best done with upper elementary or middle school girls. Have “Earth” move back to its original position (circle 15, see Fig. 7a). Explain to the girls that you will now have all the planets orbit (revolve around) the Sun. Have the girls who represent each of the planets move their Meeples from one circle to the next (see Fig 7b). In the case of Mercury, this should be two steps, noting that Mercury moves faster in its orbit. This represents the positions of the planets on May 17, 2017 At this point, there are two concepts that are being addressed: the motion of the planets in the night sky and the orbital motion of the planets. **Note:** At some point, the girls may ask about the rotation of the other planets. On page 11, Table 2, we have provided you with additional information about the planets, including their periods of rotation.

Now that the girls have taken one step (except for Jupiter and Saturn, who move one circle only after everyone else has moved, five circles for Jupiter and 10 circles for Saturn), have the girl who represents the Earth look at the other "planets" and "constellations." Have them rotate the Earth Meeple, saying the name of each planet as they see them and the constellations they are "in." Ask the girls if the planets are in the same positions relative to the Sun and constellations after 16 days. Have the "planets" take another step and repeat (Figure 7c, June 2, 2017). The girls should notice that, as time goes by, the planets are moving relative to each other, relative to the constellations, and relative to the Sun. Some planets may disappear in the glow of the evening Sun while others may appear in the morning sky. Doing this two more times will have the planets in the position illustrated in Figure 7d, July 4, 2017. Have the girls make predictions about the movement of the planets over the next month or two and write this down. Use it the next time you meet with the girls at night and see if their predictions were correct.

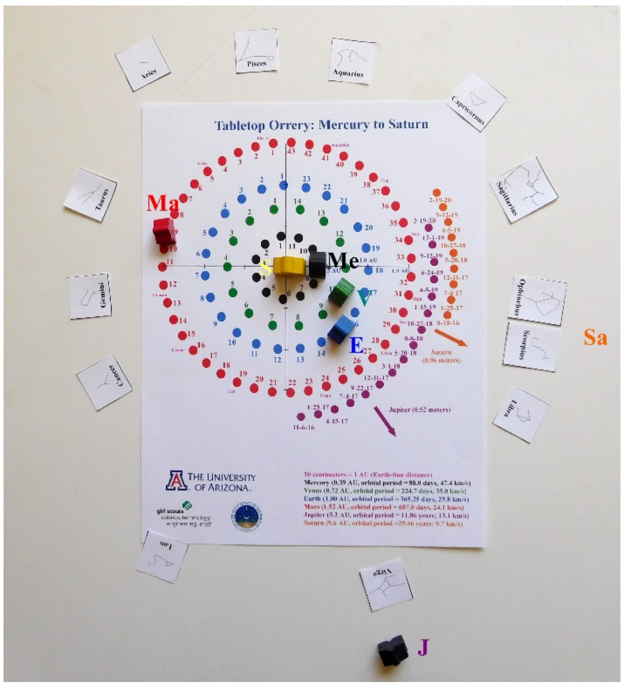


Fig. 7a. Planetary positions on May 1, 2017: Mars is visible just after sunset low in the west and Jupiter is visible most of the night. Saturn is not visible until after midnight, Venus rises a few hours before the Sun and Mercury is starting to be visible in the east just before sunrise.
S = Sun, Me = Mercury, V= Venus, E= Earth,
Ma = Mars, J = Jupiter, Sa = Saturn

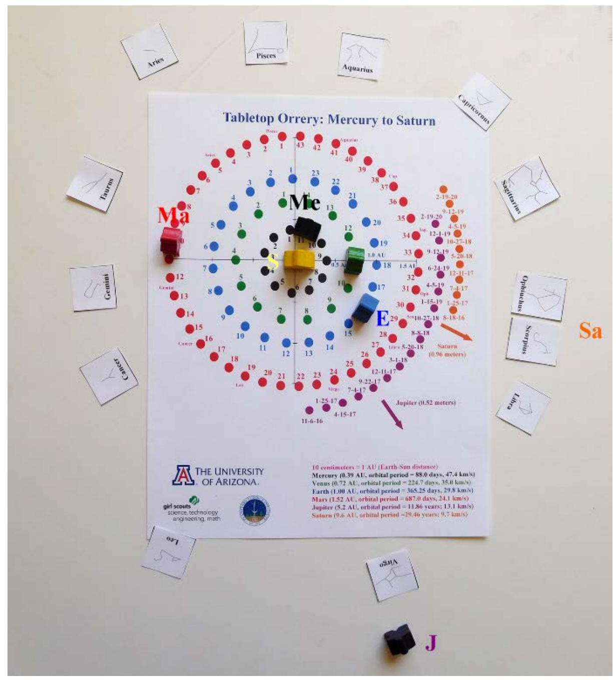


Fig. 7b. Planetary positions on May 17, 2017: There is not much change for most of the planets, though Mars is getting lower in the west just after sunset. Mercury is close to its greatest distance from the Sun as viewed from Earth in the morning sky.

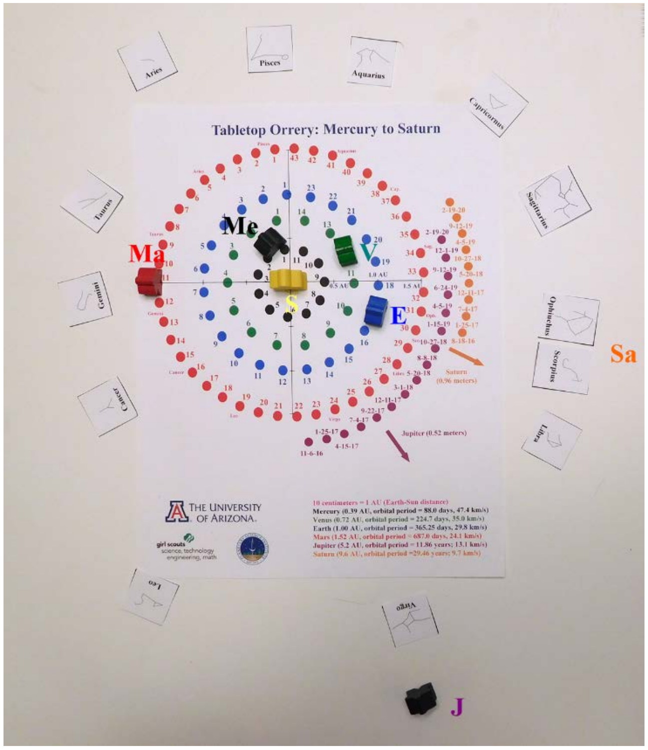


Fig. 7c. Planetary positions on June 2, 2017: Mars is very low in the west and may not be visible in the glow at sunset. Jupiter is in the south at sunset and sets after midnight. Saturn is rising in the late evening. Venus is visible in the east well before sunrise in the east. Mercury is still visible in the east before sunrise.

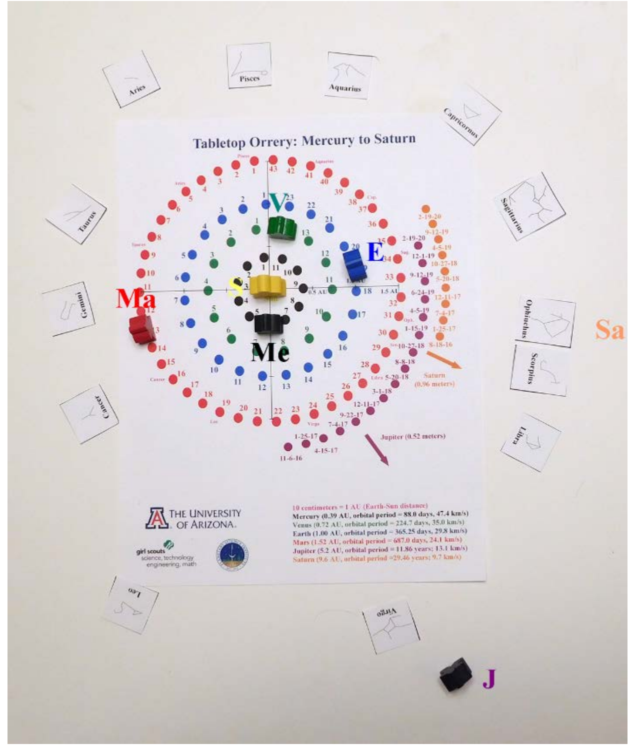


Fig. 7d. Planetary positions on July 4, 2017: Mars is now lost in the glare of the Sun. Mercury is now just appearing in the west after sunset. Jupiter is in the west after sunset and sets around midnight. Saturn is visible all night. Venus is still visible well before sunrise in the east.

Relative motions of the planets in their orbits

Now that the girls who represent the six planets have been moving around the Sun, ask them if they have noticed anything about the motions of the planets. For example, Mercury takes less time to go around the Sun because its orbit is shorter, but at the same time, it is moving faster than the other planets; Jupiter and Saturn, with much larger orbits, are moving much more slowly in their orbits.

Table 2: Basic information on the Sun and planets

Sun Planet	Distance From Sun (AU)	Length of Year	Period of Rotation	Length of Day	Diameter (kilometers)	Diameter (scale model) Large (Small)
Sun	0.00	N/A	24.47 days	N/A	1,392,000	0.9 mm
Mercury	0.38	87.97 days	58.65 days	175.94 days	4,880	0.003 mm
Venus	0.72	224.7 days	-248.02 days	116.75 days	12,104	0.009 mm
Earth	1.00	365.26 days	23.93 hours	24.00 hours	12,756	0.009 mm
Mars	1.52	1.88 years	24.62 hours	24.66 hours	6,792	0.005 mm
Jupiter	5.20	11.86 years	9.92 hours	9.92 hours	142,980	0.1 mm
Saturn	9.58	29.46 years	10.54 hours	10.54 hours	120,540	0.08 mm
Uranus	19.23	84.32 years	-17.24 hours	17.24 hours	51,120	0.03 mm
Neptune	30.10	464.79 years	16.11 hours	16.11 hours	49,530	0.03 mm
Pluto	39.26	248.09 years	-6.39 days	6.39 days	2,306	0.0015 mm

Lessons Learned and Model Limitations

Engaging girls

What is critical with any model is to engage the participants—if at all possible, everyone should participate. A big part of any modeling needs to be a discussion about the types of models (mechanical, mathematical, computer-generated, etc.) and their limitations. This helps to identify and rectify misconceptions and helps to avoid creating new ones.

Model limitations

As with any model, there are some things that we are modeling accurately (the scale of the distances of the planets from the Sun), and other things that we are not (the elliptical orbits of the planets). Model limitations should be discussed; be prepared to answer some other questions. Two questions that generally come up: 1) since it is assumed that the planet years are an even multiple of 16 days (8 for Mercury), how long is it before you have to correct for this (4 or 5 years/orbits for Earth and less often for the other planets) and 2) why is the Sun's position is not the same as the zodiacal Sun sign (precession, the change in the direction of the Earth's axis of rotation over a 26,000 year period; the Earth wobbles like a top). Another question that may come up is why there are 13, not 12, zodiacal constellations. We discuss this below. Here is a good article on the subject of precession and the zodiacal constellations.

http://earthsky.org/space/what-is-the-zodiac

Another modeling inaccuracy comes from the placing of the constellations. As we mentioned above, the distances to the stars and constellations cannot be modeled accurately. Even with the Human Orrery, because of space limitations, the constellations are generally closer to the Sun than either Jupiter or Saturn. This can lead to further discussions of their true distances. The stars in the constellations we use are generally from a few tens of light-years (the distance light travels in a year, 63,241 AU) to hundreds of light-years away and some are over a thousand light-years away. On the scale of the orrery, this implies that the stars in our constellations are hundreds of kilometers away! Because the constellations in this model not at their actual scale model distances, the planets may be as much as a whole constellation off (viewed on the orrery vs. the true sky).

Model limitation, Kepler's Third Law

The planet positions in the model differ from their true orbital positions because of Kepler's Third Law. An individual planet in its elliptical orbit moves faster when it is closer to the Sun and slower when it is father away from the Sun. Since the orrery uses circular orbits and mean motions, sometimes the orrery position will be ahead or behind the true position. This is most evident with Mars in its orbit and was one of the great mysteries of astronomy that could not be resolved until Kepler developed his Laws!

Why are there 13 zodiacal constellations?

The zodiacal constellations mark the apparent path of the Sun through the sky because of the Earth's orbit around the Sun. The Sun actually passes through 13 constellations! The astrological signs of the zodiac date back about 2,500 years ago. The Babylonians divided the path of the Sun into 12 equal 30-degree intervals of about 30 days each. However, these do not match the actual sizes of the individual constellations and left out one constellation, Ophiuchus. In reality, the Sun spends only seven days in Scorpius (known as Scorpio in horoscopes) and 43 days in Virgo.

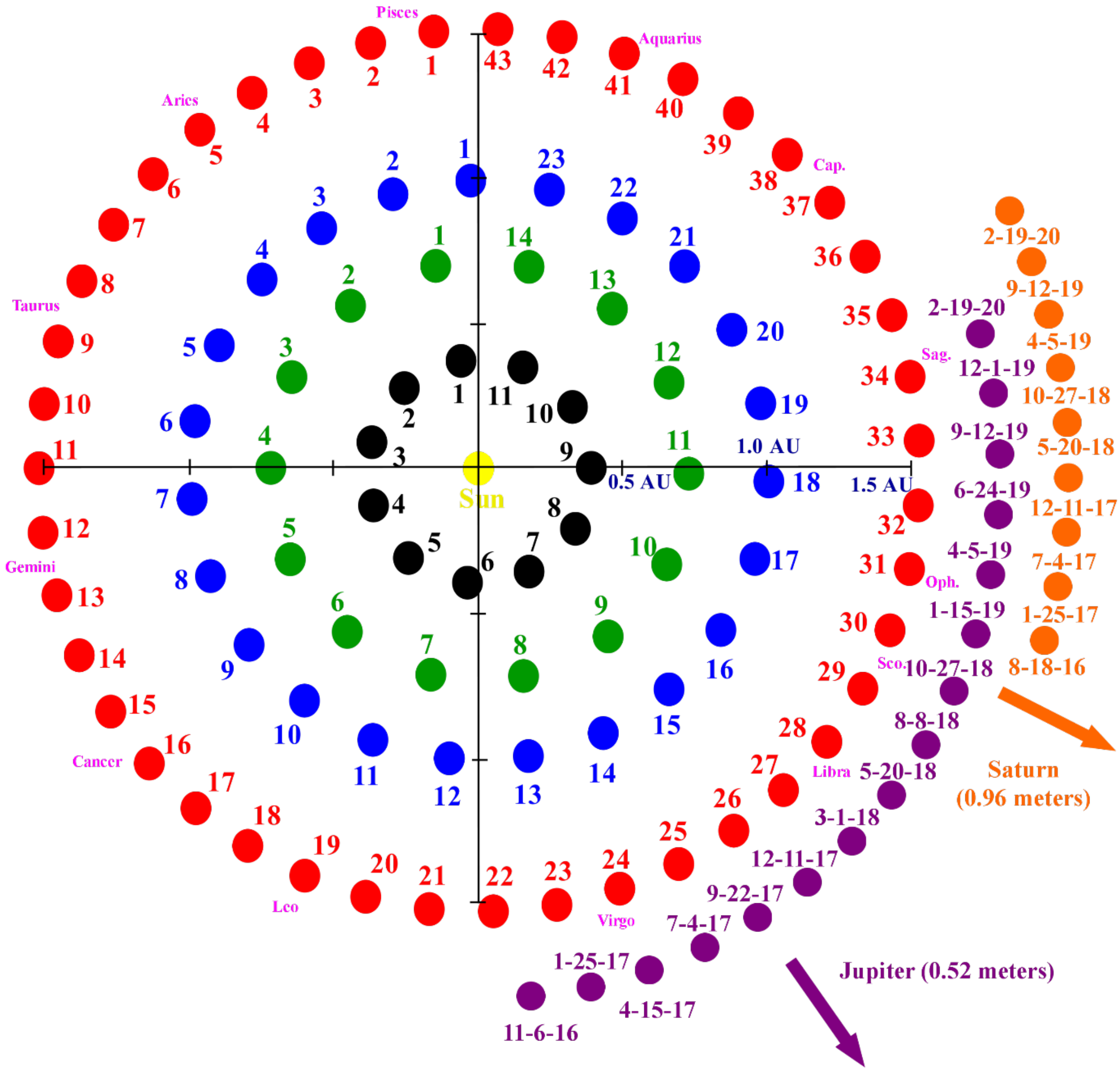
Connecting the Orrery to the Next Generation Standards:
The *Next Generation Science Standards* (NGSS, Achieve, Inc., 2013) was released in June 2013. While specific mention of constellations was eliminated in the final version, the Human Orrery still aligns well with the NGSS Performance Expectations.

In the Fifth Grade Storyline, “Students are expected to develop an understanding of patterns of…day and night, and the seasonal appearance of some stars in the night sky. The crosscutting concepts of patterns; cause and effect; scale, proportion…and systems and systems models are called out as organizing concepts for these disciplinary core ideas. In the fifth-grade performance expectations, students are expected to demonstrate grade-appropriate proficiency in developing and using models, planning and carrying out investigations, analyzing and interpreting data…evaluating, and communicating information; and to use these practices to demonstrate understanding of the core ideas.” While the students are no longer expected to identify constellations (eliminated after the final public review), one could argue that students would not be able to identify any seasonal star patterns without the aid of constellation patterns!

In the Middle-School Timeline, “students can examine the Earth’s place in relation to the solar system, Milky Way galaxy, and universe. There is a strong emphasis on a systems approach, using models of the solar system to explain astronomical and other observations of the cyclic patterns of eclipses, tides, and seasons.” Again, the Tabletop Orrery is an appropriate tool for connecting the girls to the real motions of the Earth and the other planets of the Solar System.

> **Note on planets, etc.:** Because Uranus, Neptune, and Pluto (some of us still consider Pluto to be a planet) move more slowly through the constellations, we have just given the constellations they are in for the two years covered by the tables on page 4, Pisces, Aquarius, and Sagittarius, respectively.

Tabletop Orrery: Mercury to Saturn



THE UNIVERSITY OF ARIZONA

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10 centimeters = 1 AU (Earth-Sun distance)
Mercury (0.39 AU, orbital period = 88.0 days, 47.4 km/s)
Venus (0.72 AU, orbital period = 224.7 days, 35.0 km/s)
Earth (1.00 AU, orbital period = 365.25 days, 29.8 km/s)
Mars (1.52 AU, orbital period = 687.0 days, 24.1 km/s)
Jupiter (5.2 AU, orbital period = 11.86 years; 13.1 km/s)
Saturn (9.6 AU, orbital period =29.46 years; 9.7 km/s)

Fig. 8. Half-scale orrery: 5 centimeters = 1 AU; Jupiter = 0.26 meters, Saturn = 0.48 meters