# A Human-Powered Orrery: Connecting Learners with the Night Sky

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## 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. Then, in 2005 we saw an article and a poster about a Human Orrery constructed at the Armagh Observatory in Northern Ireland (Bailey, et al. 2005a, b, c). However, it was several years before we had the idea and the opportunity for making a Portable Human Orrery we could take with us to a variety of venues. Thanks to a SEED (Simple Effective Education and Dissemination) grant in 2010 from the Astronomical Society of the Pacific (www.astrosociety.org, supported by NASA, the Herschel Science Center and the Planck Mission), the Girl Scouts of Southern Arizona, in collaboration with the James Webb Space Telescope's NIRCam (Near-Infrared Camera) E/PO team, created a Portable Human Orrery for use at astronomy events, our twice-yearly Astronomy Camps for Adult Girl Scout Volunteers and Staff, and science and science



Figure 1: Girl Scouts from Amphitheater Middle School built an orrery using aluminum pie pans (left), personalizing some of the pie pans with artwork (right). Credit: Larry Lebofsky.

education conferences.

Early on, most of our programs were directly related to our Girl Scout programs and the original model was built by Girl Scouts from a local middle school (Fig. 1). This article describes how we have used the orrery with Girl Scouts and adults who work with Girl Scouts, as well as elementary and middle school teachers.

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 (see Fig. 2). 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 (see Fig. 3), modern orreries can also be computer-generated.

Orreries can be fairly simple, they can be works

Figure 2: Antikythera mechanism (ca 125 BCE) found in a wreck in 1900. Credit: Wikimedia Commons.

of craftsmanship, or even 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. All models have their limitations, and presenters who use models should make their audience aware of the model's limitations (Lebofsky et al. 2012).

## Background on Human Orreries

There are several "human orreries" that show the correct relative scale distances between the planets and give participants themselves 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 (2005a, b; http://www.arm.ac.uk/orrery/). The Armagh Observatory model has elliptical orbits and is able to show the correct relative positions of the planets on any given date (see Fig. 4).

## A Portable Human-Powered Orrery

The scale of our model is 1 m = 1 AU. 1 AU, an Astronomical Unit, is the mean distance from the Sun to the Earth. We have created models that are made out of felt, vinyl, and rip-stop nylon and have found that the nylon works best (durable and easily transportable). Circles are numbered 1, 2, 3, etc. in a counterclockwise direction to denote the various positions of the planets Mercury, Venus, Earth, and Mars. The separations of the circles are related to the motions of each of the planets around the Sun. For Venus, Earth, and Mars, each circle represents 16 days of orbital motion (11, 14, 23, and 43 circles respectively for Mercury, Venus, Earth, and Mars). Because Mercury moves much faster in its orbit, the circles are separated by 8-day intervals. For Jupiter we use 80 days and for Saturn 160 days for the intervals.

We chose 16-day intervals, as used by Armagh Observatory. This interval minimizes the accumulation of errors in the positions of the planets, whose orbital periods are not commensurate with a single time interval. An example of the orrery in use is seen in Figure 5. In the left image, the 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.

We have also created a table top version of the orrery that is again to scale and 1/10 the size of the Human-Powered Orrery (Fig. 6). We use wooden figures called Meeples (from the board game Carcassonne, http://en.wikipedia.org/wiki/Carcassonne_(board_game), http://en.wiktionary.org/wiki/meeple) to represent people for this model.

## Key Concepts

With the Human-Powered Orrery, our primary goal is to connect the activity with actual observations of the night sky. We have designed a series of activities that address the following key concepts. Participants will be 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



Figure 3: 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)

Figure 4: Armagh Observatory orrery (Credit: Armagh Observatory)

– Asking participants to name the planets and using this to assess prior knowledge as well as for choosing initial Sun and planets participants

• Scale of the Solar System
  – Discussing the scale of the model and the relative sizes of the Sun and planets
• Rotation and day and night
  – Having the person representing the Earth rotate and discussing noon, sunset, etc.
• Relative positions of the planets in the night sky
  – Having the person representing the Earth and the other planets discuss their positions in the sky and when they can be seen (only at night)
• Predicting the night sky
  – Looking at the locations of the planets relative to the constellations to predict what they will see when they go out after sunset to observe the real sky
• Revolution of the Earth and seasonal

constellations
  – Revolution (orbit) of the Earth and the visible constellations
• Revolution and motion of the planets in the night sky and relative motions of the planets in their orbits
  – Motion of the planets over time and their speeds relative to each other
• Retrograde motion (advanced)
  – Observing Mars relative to the background constellations
• Phases of the Moon and Venus (advanced)
  – Modeling the phases of the Moon and using the orrery to model the phases of Venus
• Length of day vs. period of rotation (advanced)
  – Modeling why the two are not the same for the inner planets

**Connecting the Orrery to the Next Generation Standards:**

As of the writing of this document, the Next Generation Science Standards had just been released for its second public review. While there may be some changes made in response to this review, the Standards will still be aligned with the Core Ideas of the NRC's Framework for K-12 Education (2011) and while some details may change, it is unlikely that there will be many major changes made before the final release in March, 2013.

In fifth grade, one of the Performance Expectations states: "Identify evidence that supports explanations for how the position of stars, constellations, and planets in the sky change in consistent patterns as the Earth rotates and orbits the sun along with the other planets." In middle school, the Performance Expectations include the following: "Use models of the Earth-sun-moon system to support explanations and predict the cyclic pattern



Figure 5: Positions of the planets during a teacher workshop in July, 2011 (Credit: Larry Lebofsky)

of tides, eclipses, and observable constellations" and " Construct and use scale models of the solar system to support the explanation of the motions of the planets as observed from Earth." The Human Orrery and its related activities are ideally suited for modeling these Performance Objectives and the related Disciplinary Core Ideas.

**Lessons Learned and Model Limitations**

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.

As with any model, there are some things that we are modeling accurately, such as the scale of the distances of the planets from the Sun, and other

things that we are not, such as the fact that the planet orbits are elliptical. Model limitations should be discussed and you should be prepared to answer some other questions. The two questions that generally come up are: 1) how "off" are the planets due to the assumption of circular orbits (generally about the size of one of the circles or less) and 2), 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). Another question that may come up is why the Sun's position is not the same as the zodiacal Sun sign (precession).

Another modeling inaccuracy comes from the placing of the constellations. As can be seen in Figure 6, the constellations on the Table Top Orrery lie just outside the orbit of Mars. Even with the Human Orrery, because of space limitations, the
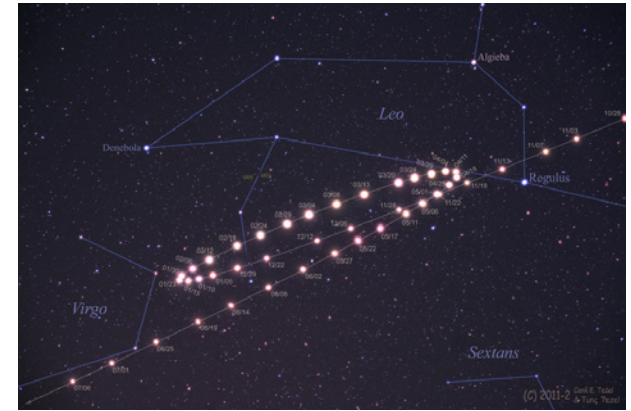


Figure 7: *Mars in the Loop*, Cenk E. Tenzel and Tunç Tezel (The World at Night), 2012; published on the Astronomy Picture of the Day Site, 2012 (APOD, authors and editors: Robert Nemiroff [MTU] and Jerry Bonnell [UMCP])

constellations are generally closer to the Sun than either Jupiter or Saturn. If time allows, their true distances and their 3D nature can be discussed during the activity. Because the constellations are not far off relative to their true distances, the planets may be as much as a whole constellation off (viewed on the orrery vs. the true sky). However, if you can put the constellations fairly far from the orrery itself, you have the opportunity to model retrograde motion, the apparent loops, relative to the distant stars, that the planets beyond the Earth make as the Earth moves past them in its orbit (Fig. 7).

**Conclusions**

The Human Orrery is an ideal interactive tool useful with a wide grade-range, from upper elementary through adults. Educators can use the Human Orrery to model the constellations and locations of the planets when preparing for a family science night and to enhance the teaching of Solar System content at both elementary and middle school levels.
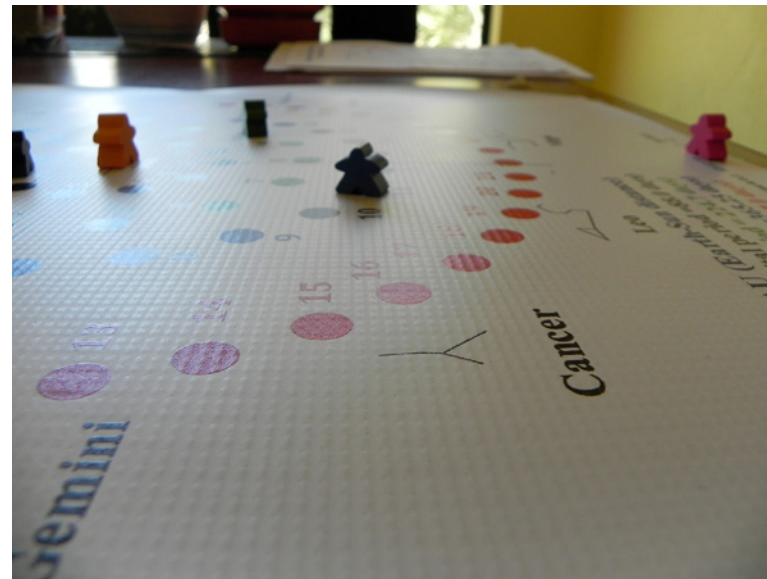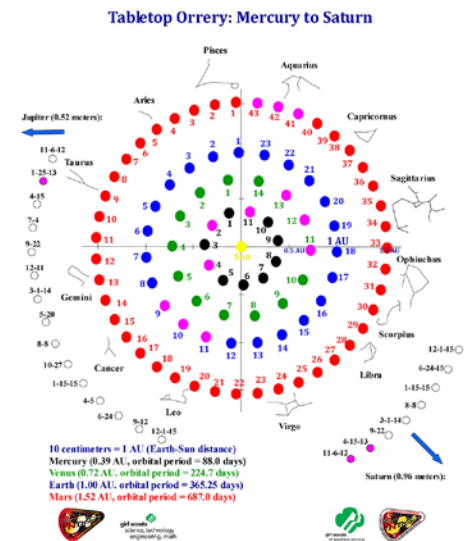


Figure 5: Positions of the planets during a teacher workshop in July, 2011 (Credit: Larry Lebofsky)

## Human Orrery Instructions and Activities

Download the complete instructions, table of planet positions, and set of activities for constructing and using your own Human Orrery. A brief survey prior to downloading the file will give you the opportunity to participate in providing feedback to the authors on the use of the Human Orrery with learners and in the classroom. You can also download a pdf version for a Table Top Orrery with instructions for its use.

Please feel free to contact the first author at: lebofsky@lpl.arizona.edu with questions and/or comments about the Human Orrery.

## References

Bailey, M. E., Asher, D. J, and Christou, A. A., The Human Orrery: Putting the Solar System in Perspective. *Sky and Telescope* pp 107-111, May 2005.

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National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press, 2011.

## Other Orrery Related Activities for the Classroom

Sky Time from Kinesthetic Astronomy, Activity B10 in *The Universe at Your Fingertips 2.0*

Mars Opposition Dance, activity C11 in *The Universe at Your Fingertips 2.0*

A somewhat different version of the Human Orrery from NASA's Kepler Mission and found in the GEMS Space Science Sequence for grades 6-8: http://kepler.nasa.gov/files/mws/HumanOrrerySSSmsGEMS.pdf