Notes

TA Guide for

ASTR 310 Tutorial: Human Orrery

ver. 110116

Description

An orrery is a mechanical model of the Solar System. When you turn a crank, the planets and moons orbit the Sun at correctly-scaled distances with correctly-scaled periods.

In this tutorial, the students build a scale model of the Solar System by marking the locations of the visible planets, Mercury, Venus, Earth, Mars, Jupiter and Saturn, at regular intervals of time. Then, when they step from location to location, they reproduce the motion of the planets both in position and in time – a human orrery!

The best way to get an idea of how to run this activity is by watching the video we made in January, 2009. Go to YouTube and search for "ubc orrery".

Learning Goals

After this tutorial, together with lecture materials, students should be able to

- describe the "geography" of the Solar System by listing the planets and other significant bodies in order from the Sun
- compare terrestrial, solar, interstellar scales
- interpret Kepler's 3rd Law ($a^3 = P^2$) qualitatively (the farther out a planet, the longer it takes to orbit the Sun and the slower it travels through space)

Set-up 20 minutes

This tutorial requires a lot of stuff. Once everything is assembled, like during the week before the tutorial, preparing for each day's activity is pretty simple, especially if the previous TA "re-sets" everything.

Pre-tutorial week preparation [coming soon]

Apparatus and materials:

- The construction work is divided into 13 teams. Each team gets a ziploc bag containing: blueprint, string, planet markers (see below). Replace any markers that are missing or critically wrecked.
- giant protractor
- wooden stick with Sun ball-bearing
- (for running activity inside) wooden base for protractor and Sun-stick. Use 2-sided foam tape to stick the base to the floor.
- 100-metre measuring tape
- pictures on metre sticks: Sun, all the planets, Pluto, Eris, Voyager
- handouts

- (one per student) Page 1
- (one per student) Page 2 – there are 3 different versions (with the questions cycled so the students spread out over the orrery)

- Planet Markers **Jan 2011 update** We've switched to octagonal markers, rather than circles, because they are so much easier to prepare. Also, since the planets' markers are different colours, we haven't bothered to write "M1, M2,..." but just "1, 2,..." on the markers. We've included a "title marker" like "Mercury 1–11" that can remain in the sandwich bag. Finally, the markers with the starting positions have big circles on them, so students can easily move to the starting positions with instructed.

Team	String	Markers
Mercury	0.39 m	1 – 11
Venus	0.72 m	1 – 14
Earth 1	1.00 m	1 – 12
2		13 – 23
Mars 1	1.52 m	1 – 15
2		16 – 30
3		31 – 43
Jupiter 1	5.20 m	1 – 14
2		15 – 27
Saturn 1	9.54 m	1 – 17
2		18 – 34
3		35 – 51
4		52 – 67

Part 0: Introduction and Motivation — 5 minutes

When you arrive in the Foyer of the IKBLC, place the base with the protractor and Sun-stick directly under the huge, hanging sculpture – this is kind of the center of the Library, the center of the Solar System. Be careful to orient the protractor so that Saturn (and Jupiter, too, if possible) is down the corridor and not in a location blocked by furniture. Stick it to the ground with a few strips of 2-sided tape after orienting the protractor so angle 0 points ___________________________.

Gather the students together around the Sun. It's never a bad idea to let the students know why they are doing this. The purpose of the activity is to give the students a first-hand, personal experience with the size, scale and motion of the objects in the Solar System. It's one thing to see a picture in the text or read a table of numbers; it's another to actually orbit the Sun like Earth or walk out to Pluto.

Tell the the planets' orbital radii have been scaled so 1 metre represents 1 AU, which means this model is 150 *billion* times smaller than the real Solar System. The ball bearing at the top of the Sun-stick is at the correct scale – that ball bearing is the Sun.

Part 1: Construction — 15 minutes

Ask them to get together in groups of 2 or 3 and give each student a copy of Page 1. It's a good idea **not** to hand out Page 1 until now or else they'll read the paper and completely ignore you, missing the background and motivation.

Hand-out Page 1

Use the materials from one kit (like Earth 1) to demonstrate locating a couple of markers: loop the string over the center Sun-stick, pull it straight, look at the angle on the protractor under the string, place the marker on the ground so the center of the marker is at the bead on the string. As you move to the next marker, explain that the it represents the location of Earth **16 days later**. The markers for all the inner planets are spaced at 16-day intervals; the markers for Jupiter and Saturn are 10 times longer, at 160-day intervals.

There are tasks for 13 groups. Rather than asking for volunteers ("Who wants to be Mars?") it seems to work better when TA-B walks around handing out kits to each group. Proceed with construction.

If there are not enough groups to build the complete model, just build the sections of Jupiter and Saturn that contain the current locations of the planets. And if groups finish quickly (often Mercury and Venus) ask them to work on Jupiter and Saturn.

Part 2a: Dance of the Planets — 10 min

When the construction is complete, gather all the students in the asteroid belt between Mars and Jupiter.

Ask for volunteers to be play the planets. (If you're having trouble getting volunteers, have TA-B walk around handing out the metre sticks with the planet pictures.) Send them to starting locations: these are the locations of the planets for the week of the activity.

To find these locations, make a map of the Solar System at `www.fourmilab.ch/solar` for, say, Wednesday of the week of the tutorial. If you print that map onto an overhead, it's simple to compare it to the orrery "blueprint" to find a set of planet markers that sufficiently match the planets' locations.

Current dates:

Planet	Starting Marker
Mercury	
Venus	
Earth	
Mars	
Jupiter	
Saturn	

Have a look at the current configuration of the Solar System. Here are some questions you might try to help the students see what's important:

Question What planets can people on Earth see right now?

Answer (Get the students to realize how Earth must be standing so it's "night" (facing away from the Sun) or "day" (facing towards the Sun). Then observe which planets can be seen at night (the ones away from the Sun) and which cannot be seen because they're in the direction of the Sun. If the students have already done the Moon phases tutorial, they should be familiar with the orientation of Earth at sunrise and sunset, so you might be able to explore more than just "day" and "night".

Explain that the planets will step to the next plate as you count out loud. Remind Mercury to skip a plate when stepping to the next plate and Jupiter and Saturn to move on the 10th step. Ask asteroids to watch what happens. Start counting, loud and clear – don't worry about the noise, we have permission to be there – at about 1 beat per second. Count to around 30, giving Earth a chance to make one complete orbit.

Part 2b: Patterns in the motion — 5 minutes

Ask the students some questions. Remember, you're not giving a lecture here: ask them the questions, get some answers, and repeat the correct answers and expand on them if necessary.

Question Did you notice any patterns or rules for how the planets move in the Solar System?

Answer You could get something like Kepler's Laws: the planets move in nearly-circular orbits around the Sun; the farther out the planet, the longer it takes to orbit the Sun. Some students might also notice that the farther out a planet, the slower it moves along it's orbit – *awesome!*

Question How big do you think the planets would be if we included them in the model?

Answer They're not the size of the markers. Remember the ball bearing at the center is the Sun. Jupiter and Saturn are about 1 mm in diameter, about the size of the head of a pin. The inner planets are much smaller still. Ask them to look down at the grains of sand and dirt on the ground – that's like the inner planets and asteroids.

Question How likely is a collision?

Answer Very unlikely, the planets are very small targets in the middle of large, empty spaces.

Part 2c: Beyond Saturn	10 minutes

Ask for 5 more volunteers and give them metre sticks with Uranus, Neptune, Pluto, Eris and Voyager.

Give the end of the 100-metre tape to TA-B who stands at the Sun holding the Sun picture. Slowly walk away from the Sun, with the entire class following along, unreeling the measuring tape. Drop off each planet as you pass its distance (see Table.) Announce the objects and distances to the group. Note: Voyager will end up 112 metres from the Sun (according the `heavens-above.com`), so be sure to walk in a direction with enough space!

Object	Distance (AU, metres)
Uranus	19
Neptune	30
Pluto	40
Eris	68
Voyager	116 (Jan 2011, 16 steps beyond the end of the tape)

When you are standing out at Voyager's location, mention it takes about 15 hours for light to travel from the Sun to Voyager. Then bring everyone back to the Sun, reeling in the measuring tape.

Part 3: Questions	remainder of tutorial

When everyone has returned from the outer Solar System, hand out the worksheet. Remember there are 3 versions but they all have the same questions. Tell them they should work in groups of 2 or 3 but each student must hand in their own worksheet. Instruct them to explore the scale of the Solar System by doing each of the tasks on the sheet.

Hand out Question sheet

Saturn question Before you help anyone with this question, make sure they're standing out on the orbit of Saturn. If they're not, drag them out there. If they're having trouble determining how much farther Saturn has to travel, ask them, “What’s the distance around a circle called? [circumference] How does it depend on radius? [$2\pi r$] So if the radius is 10 times bigger, how much bigger is the circumference? [10 times]”

To get the speeds, they should estimate the distance between the Saturn markers (or measure with a metre stick): about 1 metre. So if we’d used 16-day markers instead of 160-day markers, they’d be about 10 cm apart. They should estimate (or measure) that the Earth markers are about 30 cm apart. Saturn is moving slower, about 3 times slower.

And here’s the amazing part: Saturn has 10 times farther to go and it moves 3 times slower. Together, that means Saturn takes about 30 times longer to orbit the Sun – 30 years instead of 1 year!

Jupiter question Before you help with this question, make sure one student is standing at Jupiter holding up the worksheet and the others are at Earth. It’s practically impossible to see Jupiter in the figure. We see it at night, though, when it’s bright against the night sky. The Galilean moons are also impossible to see...unless you use a telescope like Galileo did (almost exactly 400 years ago!)

Mars question If they’re not there, drag the students over to the orbits of Earth and Mars. One partner stands on an Earth marker and the other stands on the closest Mars marker. They’re about 0.5 metres (or AU) apart. Since light takes 8 min/AU, Earth and Mars are about 4 minutes apart. Send the Mars student to the far side of the Solar System. Now Mars is 2.5 AU away or about 20 minutes. That’s 5 times longer than the close configuration.

Proxima Centauri question The star would be 267 800 m or 267.8 km away, like Seattle. If the students are, “Yeah, whatever...” then ask them to imagine what it really looks like: Here we are in Vancouver standing next to a little ball bearing (the Sun). There is *nothing* except empty space until you get to Seattle, where there’s another little ball bearing. *That’s* what interstellar space looks like – almost completely and perfectly empty, with little bits of matter scattered around.

Clean-up

As groups hand in their worksheets, and as long as there are not other groups still working on the planets, ask them to start picking up the Post-it notes - in order, please.

Take a few minutes after the tutorial to “reset” the equipment for next time: untangle the strings and put them in bags with the blueprints and markers (replace any missing ones). Gather up all the metre sticks with planet pictures. It helps to go through the checklist to make sure everything is ready for next time.