AMERICAN MUSEUM OF NATURAL HISTORY

Science Research Mentoring Program

SOLAR SYSTEM

This course covers the types and properties of the objects within the Solar System, its formation, and the tools we use to study it. Additional topics include classification and scale modeling.

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Session One: The Grand Tour

LEARNING OBJECTIVES

Students will learn what conditions can lead to planet formation; tour the history of the universe; determine how high they could jump on the Moon; and be introduced to the research tools of planetary science.

KEY TOPICS

- Molecular cloud
- Nebula
- Star formation
- Accretion disk
- Protoplanetary disk
- Planet
- Moon
- Kuiper Belt
- Oort Cloud
- Gravity
- Mass
- Telescope
- Spacecraft
- Rover
- Sample return
- Meteorite

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
30 minutes	**Registration/ Pre-Assessment**	Check-in for students, including all paperwork, plus a pre-assessment test of course knowledge. (Post-assessment for the last class should be identical.)
10 minutes	**Class intro**	Hand out student syllabus. Introduce instructors and students.
30 minutes	**Intro to the Solar System**	Briefly describe how the Solar System formed out of a molecular cloud, and the major objects within it. Include descriptions and images of clouds (the Eagle Nebula, Carina Nebula, Orion Nebula, etc.) where stars and planets are currently forming. Follow with a basic review of the types of objects within the Solar System: the Sun, planets, moons, asteroids, comets, the Kuiper Belt, the Oort Cloud, etc. Use images to point out some common features: e.g. rocks, gasses, gravity, mass, size.
20 minutes	**TOUR: Big Bang Theater/Cosmic Timeline Tour**	Take students to an exhibit on the history of the Universe. At AMNH, we use the Big Bang Theater and Cosmic Timeline to discuss the history of the Solar System and Universe as a whole. Pay particular attention to the timelines and overall trends toward stability. Alternately, many videos, readings, and websites summarize the history of the Universe that students could watched or read and then discuss, and many timeline-type activities that can be done in class.
20 minutes	**ACTIVITY: How would you jump on the Moon?**	Students measure the height and distance they can jump on Earth, and translate that into distances on the Moon. Follow with a brief discussion of gravity.
10 minutes	**How Do We Know All Of This?**	Briefly describe a few ways in which we obtain knowledge about the Solar System: key missions, observations, samples, and other broad research techniques. Show images sent from different spacecraft. Explain that analyzing samples (lunar, meteorite) and analyzing data from telescopes and spacecraft, helps us understand the formation of and conditions within the Solar System.

Session One: The Grand Tour (continued)

MATERIALS

Copies of the student syllabus, copies of the pre-assessment, meter sticks, masking tape, calculators. OPTIONAL – any additional materials needed for the tour.

PREP WORK

If an exhibit tour is unavailable, determine a suitable alternate.

HALLS USED

Big Bang Theater, Cosmic Timeline

A/V NEEDED

Laptop and projector / screen

HOMEWORK

Have students watch and be prepared to discuss episode 5, "Infinitely Reasonable" of James Burke's "The Day the Universe Changed," available on YouTube - http://www.youtube.com/watch?v=I_7IkHe_3RI

Session One: The Grand Tour

TOUR: Big Bang Theater/Cosmic Timeline

Take students into the Big Bang Theater and watch the four-minute show that explains the beginning of the Universe as we understand it. Take students down the Cosmic Timeline, pointing out key events. Stress that the Universe is 13.7 billion years old, and that each step they take represents about 100 million years of cosmic history.

Suggested stopping points:

- Formation of the Milky Way
- Formation of the Sun and the Solar System
- Heavy bombardment
- Life forms on Earth
- Oxygen atmosphere on Earth
- Multicellular life on Earth
- The Cambrian Explosion
- Dinosaurs go extinct (K/T boundary)
- Humans appear

The final stop is a strand of hair representing all of recorded human history.

If time allows, point out the big model of the Moon, noting the craters on its surface and that its chemical content is very similar to Earth's

ACTIVITY: How high would you jump on the Moon?

Begin by asking students what factors on Earth affect their weight. Elicit at least three answers (Earth's mass, our distance to its center, and our own mass). If necessary, briefly review the difference between mass and weight.

Ask students whether they would weigh anything on the Moon. Accept all answers. Often students think the answer is "no," and it's good to follow up with a question – does the Moon have mass? Point out that all objects with mass exhibit gravity.

Since we know the Moon's mass and size, we can easily determine its surface gravity. Astronauts who visited the Moon also measured this gravity. So we've determined that the Moon has approximately 1/6 of the gravity of Earth.

Ask students how having one sixth as much gravity pulling at us would affect our ability to jump. Elicit the response that it would allow us to jump six times higher or farther—but not off of the Moon. Then ask students to form small groups and measure how high and how far each one can jump. Multiply these answers by six to determine the distances they would be able to jump on the Moon.

Compare these distances.

EXTENSION – Show video from an Olympic (or other) long jump and high jump competition, and ask students to determine how far/high those athletes would be able to jump on the Moon.

EXTENSION – Ask students to think about how they would have to adapt activities if they lived on the Moon, including leisure activities like sports.

Session Two: History of Western Astronomy

LEARNING OBJECTIVES

Students will discuss some trends in the history of Western astronomy; understand how celestial objects move; be able to describe the difference between the geocentric and heliocentric models; perform analyses similar to those of Galileo and Kepler.

KEY TOPICS

- Prograde motion
- Retrograde motion
- Geocentric model
- Epicycles
- Heliocentric model
- Galileo's observations and analysis
- Ellipses
- Tycho Brahe's observations
- Kepler's analysis

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
10 minutes	**Reading Discussion**	Discuss the assigned reading (or video), paying attention to conditions at the time of Aristotle and Copernicus.
15 minutes	**Ancient History and Geocentric vs. Heliocentric**	Starting with ancient astronomy (Pyramids, Stonehenge, etc.), discuss the way structures doubled as calendar systems. Describe and show examples of prograde and retrograde motion, and the way this informed early models of the Universe (including geocentric models with epicycles, and heliocentric models), from Aristotle through Copernicus. Discuss each interpretation.
10 minutes	**ACTIVITY: Geocentric Retrograde Motion**	Students model epicyclic motion as a model for retrograde motion, through a short kinesthetic activity.
10 minutes	**Galileo**	Show examples of Galileo's observations, including the phases of Venus, the Moons of Jupiter, and the mountains on the Moon. Briefly discuss how these changed views of the "perfect" heavens, and were contrary to the geocentric model. If time allows, discuss how Galileo's work influenced the beginning of experimental science.
10 minutes	**ACTIVITY: Moons of Jupiter**	In this brief activity, students will use a set of simulated observations of the Galilean moons of Jupiter to recreating Galileo's analysis.
15 minutes	**Brahe, Kepler, and Newton**	Discuss Tycho Brahe and his observatory, Uraniborg, and how Johannes Kepler used Tycho's data to deduce that Mars' orbit was elliptical. Kepler devised three laws of planetary motion, which were followed up by Isaac Newton's famous laws of motion.
40 minutes	**ACTIVITY: Orbit of Mercury**	In this activity, students plot a rough version of Mercury's orbit from which they measure the eccentricity of the orbit.
10 minutes	**ACTIVITY: Heliocentric Retrograde Motion**	Students walk in orbits around the Sun, and observe the geometry that leads to retrograde motion.

Session Two: History of Western Astronomy (continued)

MATERIALS

Copies of the Moons of Jupiter activity sheet, optional copies of the Moons of Jupiter activity answer sheet, markers or colored pencils, drawing compasses, metric rulers, calculators, copies of the Eccentricity of Mercury's Orbit activity sheets, spherical objects (balloons, styrofoam balls, sports balls, etc.)

PREP WORK

The Heliocentric model of Epicyclic Motion requires a good amount of space for students.

HALLS USED

None

A/V NEEDED

None

HOMEWORK

Find a reading about the Titus-Bode Law. You may also ask students to finish the Moons of Jupiter activity.

Session Two: History of Western Astronomy

ACTIVITY: Geocentric Retrograde Motion

Students work in groups of two. Each pair receives one spherical object (balloon, ball, etc.). One student stays stationary and acts as "Earth." Another students "orbits" the Earth, as in the geocentric model, holding the sphere as the "planet." Ask the Earths whether the planets appear to undergo retrograde motion. (They should not.) Add an epicycle – explain that the planet will now orbit the student AS the student orbits Earth. This can be accomplished simply by having students circle the sphere around their head; more intrepid students may try to spin with the sphere at arms length, while orbiting the Earth. Now asks the Earths how the motion of the planet appears. (It should be moving forward at some times and backwards at others. This is retrograde motion in the geocentric model! Allow students to swap places and see for themselves.

ACTIVITY: Moons of Jupiter

In this activity, students will recreate the analysis that Galileo performed after observing and recording the moons of Jupiter. His daily record allowed for the determination of the timing of the orbits, and is not trivial without a computer.

Hand out a Moons of Jupiter sheet to all students along with colored pencils or markers. Explain that this is a simulation of Galileo's data. (In fact, this is an idealized simulation, in that the data are given every 12 hours exactly, and there are no "cloudy" days where observations could not be made.) One data point does include an eclipse, when one of the moon's shadows falls on Jupiter.

Ask the students to determine how each object has moved over this time period by tracing it in color. The farthest moon (Callisto) should be very easy for most students, and the third moon (Ganymede) should also be simple. But, determining the two inner moons' motions should present a challenge. Allow them to try before offering suggestions, but if necessary, suggest that they pay attention to the vertical position of the moon. If any students make zig-zags of their orbit without it crossing Jupiter, consider asking them what that would mean the moon is doing.

After a few minutes, stop the class and ask the students about their findings. Accept all results, and point out that Galileo did this without knowing that these were moons, and that conventional thought at the time was that objects should not be orbiting anything except Earth. Also discuss how this data is idealized, and why repeated observations and analysis are important to scientific experimentation.

An answer key is included.

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury

Students will plot the orbit of Mercury on polar graph paper, much the way that Kepler used Brahe's data to plot the orbit of Mars. However, in this case, the data have been reduced to the polar coordinates, and we use Mercury because its orbit is more eccentric than Mars.

This lab uses an approximation to find the geometric center of the orbit, and only requires a few points to be plotted. The instructions bring the students through some background information, labeling the graph, plotting points, and then the analysis of the data. It includes an additional query about how close this orbit is to a circle; this can be optional or left to students who finish early.

Note that the Mercury data is included as an Excel file as well. It has positions for Mercury over one entire orbit of the Sun, in polar coordinates with the Sun at the origin.

Data courtesy the NASA JPL Solar System Dynamics Group, http://ssd.jpl.nasa.gov/

(Free) Polar graph paper generated from http://incompetech.com/graphpaper/. Permission granted for reproduction by site owner.

ACTIVITY: Heliocentric Retrograde Motion

Students will orbit the location marked as the Sun. It's easy to do in groups of three, and with enough space, can be extended to groups of four or five.

Have students walk circular orbits around the Sun, with those closer to the Sun walking fastest (in both actual speed and angular speed?), and those farther walking slowest. Explain that the walls will act as students' "immovable" stars. As students move in their circles, ask them to watch what happens to planets both inside and outside their own orbits. As they start to lap an outer planet, students should pay close attention to the appearance of the planets, against the background of stars. (The planet will appear to move in retrograde.) Inner planets will zip in both directions across the Sun. Encourage students to swap positions to see all the possible perspectives, and monitor the speeds at which students are moving. (This works best when everyone is moving relatively slowly.)

Session Two: History of Western Astronomy

HANDOUT: Moons of Jupiter

d	h
0	0
0	12
1	0
1	12
2	0
2	12
3	0
3	12
4	0
4	12
5	0
5	12
6	0
6	12
7	0
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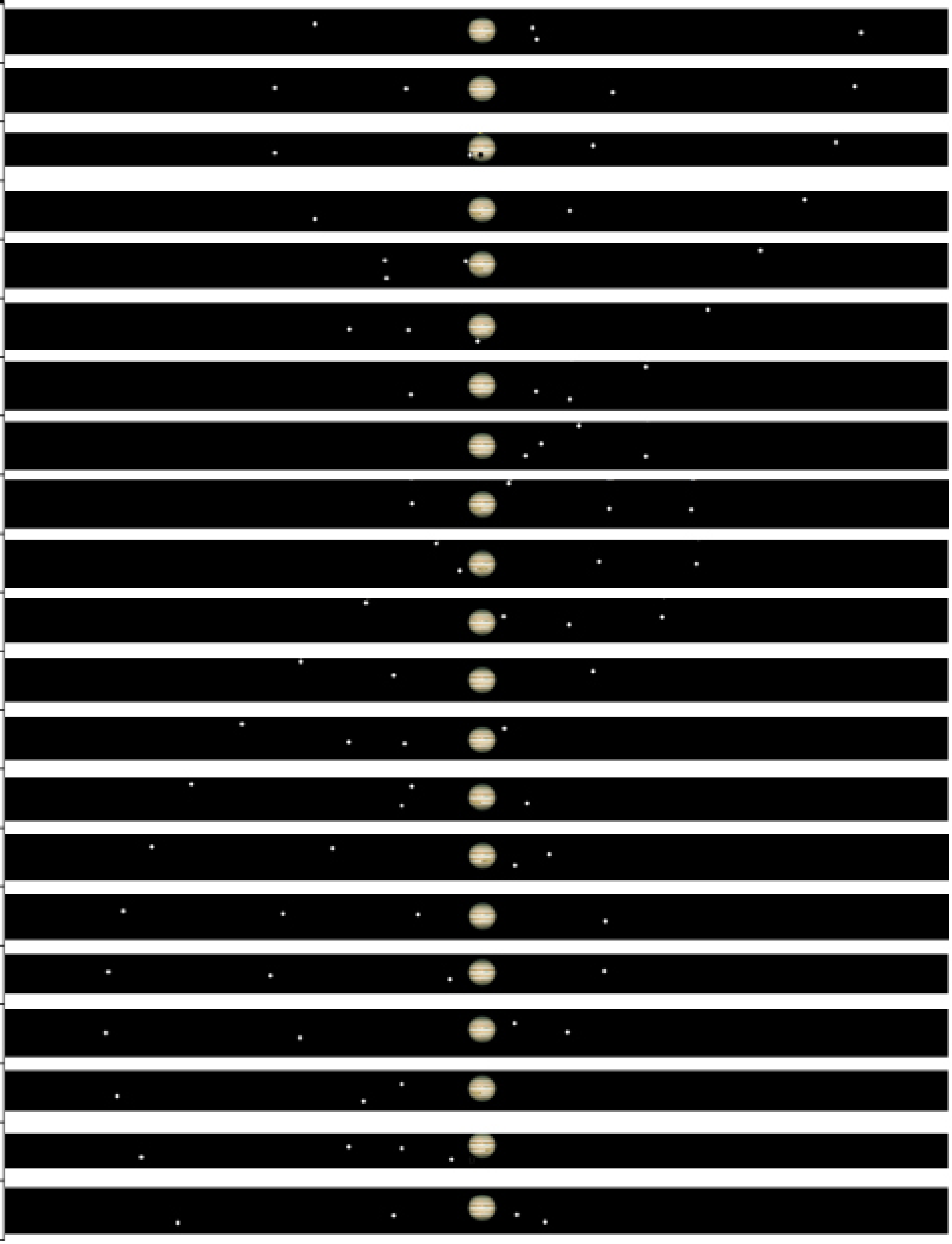
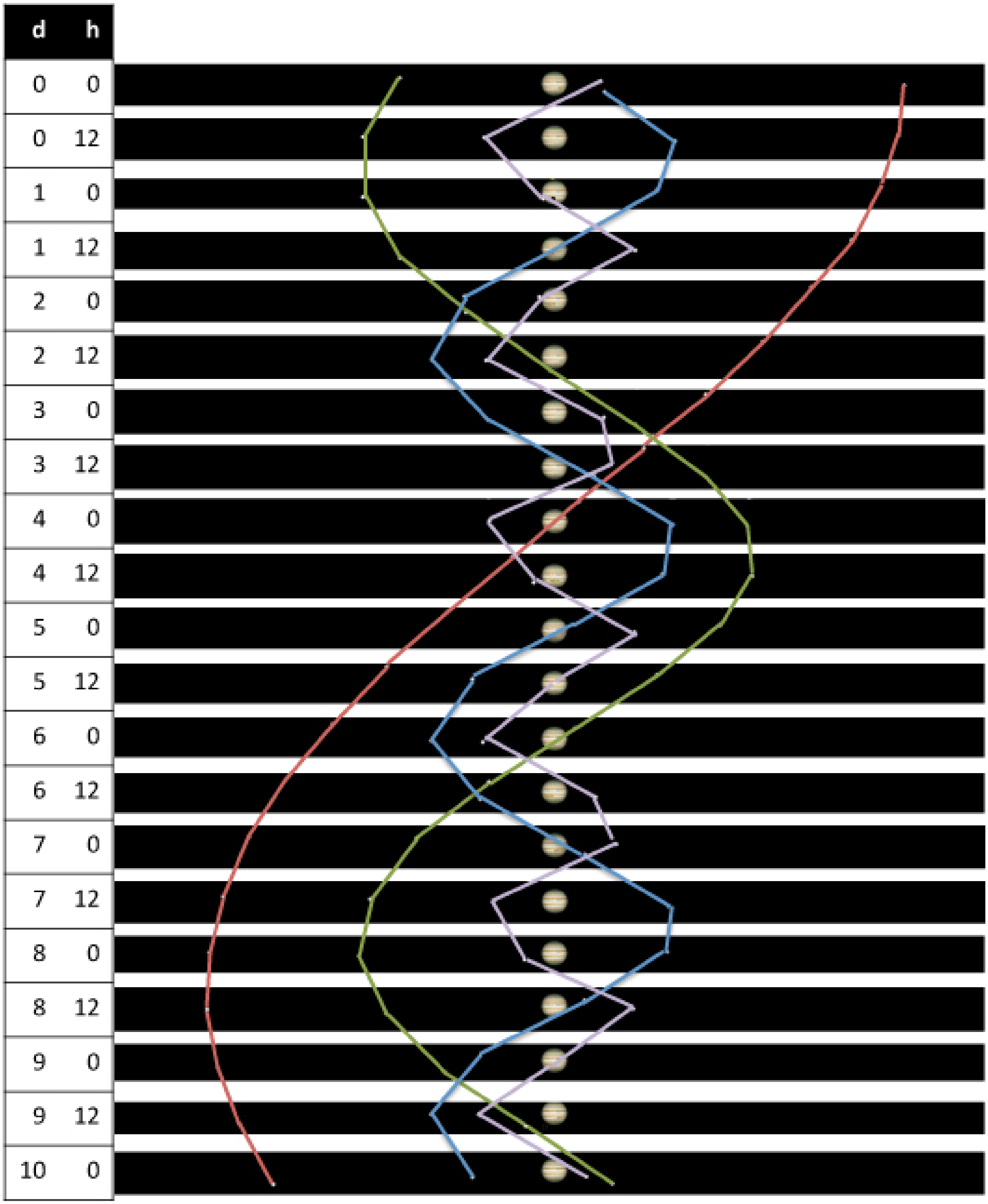
8	12
9	0
9	12
10	0



Images captured from open source app at http://www.shallowsky.com/jupiter/

Session Two: History of Western Astronomy

HANDOUT: Moons of Jupiter: Answer Key



Images captured from open source app at http://www.shallowsky.com/jupiter/

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury

MATERIALS

- Polar graph paper
- Mercury data sheet
- Sharp pencil
- Metric ruler
- Compass
- Calculator

BACKGROUND INFO

- An Astronomical Unit is the average distance from Earth to the Sun: about 93 million miles (150 million km). This is often abbreviated as "1AU." If an object is at twice the distance of Earth, it would be at a distance of 2AU. If an object is at a quarter of the distance of the distance between Earth and the Sun, that distance is 0.25AU.
- Most graphs you've seen probably had Cartesian Coordinates – they have an x-axis and a y-axis. All positions can be described using two coordinates: x and y. Today, you will be using Polar Coordinates. Polar graphs also use two coordinates to describe positions, they are r (radius) and θ (theta, the angle). All distances are relative to the center point, and increase outward. All angles are measured relative to the 0° marker, and increase counter clockwise.

  On your graph paper, each circle outward from the center represents 0.02AU farther. There are 25 circles, so graph goes out to a distance of 0.5AU from the Sun.

PLOTTING PROCEDURE

1. Label some representative radii (r) on your graph. The center point (r = 0) is the Sun. Increasing outward, label 0.1AU, 0.2AU, and on out to 0.5AU.
2. The "Mercury's Orbit in Polar Coordinates" data table gives Mercury's orbit in polar coordinates during early 2013. Choose 8 – 10 evenly spaced data points along Mercury's orbit and plot those points carefully on your polar graph paper. Label each point with its date.

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury (continued)

ANALYSIS

1. Find the geometric center of the orbit.

   - Is the Sun in the center? How can you tell? Explain below.

     Using the points you chose, find the average distance from Earth to the Sun. Show your work below.

   - Using your compass, set the radius of the arc to the average distance you established above. Place the point of your compass in the first point that you chose. Lightly draw an arc towards the center of Mercury's orbit; you do not need to draw a full circle.

   - Repeat for each of your data points.

   - When you're done, you should have a set of arcs that will almost intersect each other. The center of this intersection approximates the geometric center of the ellipse. Mark and label that point.

2. Determine the eccentricity of Mercury's orbit.

   - Now that you know the geometric center, the eccentricity of the orbit is easy to calculate.

   - Draw the major axis of this ellipse. This goes from one side of the orbit, through both the Sun and the center, to the opposite edge.

     HINT: You may want to determine the date along the orbit that your line intersects, and plot additional points.

   - Measure the major axis in cm, and record it below. Also determine the semi-major axis, which is half of the major axis.

   - The eccentricity of the orbit is easy to calculate as the ratio of two distances: the distance from the center of the orbit to the Sun, divided by the semi-major axis. Measure the "center to Sun" distance and show your work below.

3. How close is this orbit to a circle?

   - Set your compass to the average distance of your original points, and lightly draw a circle centered on the geometric center that you found in question 1e.

   - Using the original points, which point are farthest from the circle? Express your answer in AU.

   - What is the percent difference between the farthest distances (calculated in step b) and the average distance?

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury (continued)

Date	θ (theta)	r (in AU)
2013-Jan-01	249	0.465
2013-Jan-02	251	0.466
2013-Jan-03	254	0.467
2013-Jan-04	257	0.467
2013-Jan-05	260	0.467
2013-Jan-06	262	0.466
2013-Jan-07	265	0.466
2013-Jan-08	268	0.465
2013-Jan-09	271	0.463
2013-Jan-10	274	0.462
2013-Jan-11	276	0.460
2013-Jan-12	279	0.458
2013-Jan-13	282	0.456
2013-Jan-14	285	0.453
2013-Jan-15	288	0.450
2013-Jan-16	291	0.447
2013-Jan-17	294	0.444
2013-Jan-18	297	0.440
2013-Jan-19	300	0.436
2013-Jan-20	303	0.432
2013-Jan-21	307	0.428
2013-Jan-22	310	0.424
2013-Jan-23	313	0.419
2013-Jan-24	317	0.414
2013-Jan-25	321	0.409
2013-Jan-26	324	0.404
2013-Jan-27	328	0.398
2013-Jan-28	332	0.393
2013-Jan-29	336	0.387
2013-Jan-30	340	0.381
2013-Jan-31	344	0.376

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury (continued)

Date	θ (theta)	r (in AU)
2013-Feb-01	348	0.370
2013-Feb-02	353	0.364
2013-Feb-03	358	0.358
2013-Feb-04	2	0.352
2013-Feb-05	7	0.347
2013-Feb-06	12	0.342
2013-Feb-07	17	0.336
2013-Feb-08	23	0.331
2013-Feb-09	28	0.327
2013-Feb-10	34	0.323
2013-Feb-11	40	0.319
2013-Feb-12	46	0.316
2013-Feb-13	52	0.313
2013-Feb-14	58	0.311
2013-Feb-15	64	0.309
2013-Feb-16	70	0.308
2013-Feb-17	77	0.307
2013-Feb-18	83	0.308
2013-Feb-19	89	0.309
2013-Feb-20	96	0.310
2013-Feb-21	102	0.312
2013-Feb-22	108	0.315
2013-Feb-23	114	0.318
2013-Feb-24	120	0.322
2013-Feb-25	126	0.326
2013-Feb-26	131	0.331
2013-Feb-27	137	0.335
2013-Feb-28	142	0.340

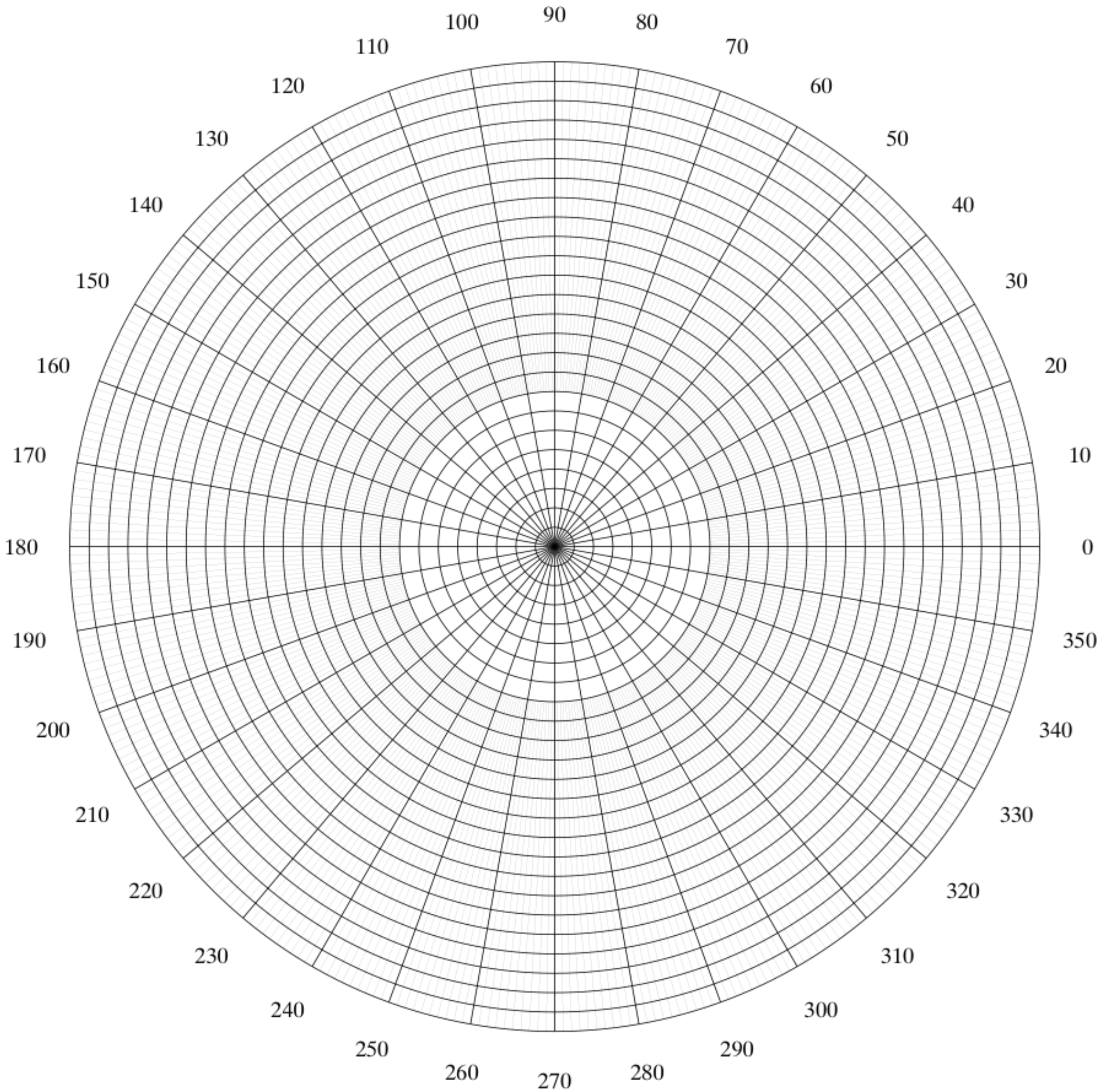
Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury (continued)

Date	θ (theta)	r (in AU)
2013-Mar-01	147	0.346
2013-Mar-02	152	0.351
2013-Mar-03	157	0.357
2013-Mar-04	161	0.363
2013-Mar-05	166	0.369
2013-Mar-06	170	0.374
2013-Mar-07	175	0.380
2013-Mar-08	179	0.386
2013-Mar-09	183	0.392
2013-Mar-10	187	0.397
2013-Mar-11	190	0.403
2013-Mar-12	194	0.408
2013-Mar-13	197	0.413
2013-Mar-14	201	0.418
2013-Mar-15	204	0.423
2013-Mar-16	208	0.427
2013-Mar-17	211	0.432
2013-Mar-18	214	0.436
2013-Mar-19	217	0.440
2013-Mar-20	220	0.443
2013-Mar-21	223	0.447
2013-Mar-22	226	0.450
2013-Mar-23	229	0.453
2013-Mar-24	232	0.455
2013-Mar-25	235	0.458
2013-Mar-26	238	0.460
2013-Mar-27	240	0.462
2013-Mar-28	243	0.463
2013-Mar-29	246	0.464
2013-Mar-30	249	0.465

Session Two: History of Western Astronomy

ACTIVITY: Orbit of Mercury (continued)



Session Three: Scale of the Solar System

LEARNING OBJECTIVES

Students will continue to learn about the discovery of objects in our Solar System; make a scale model of the Solar System; realize that the Solar System is quite large; and use the transit of Venus to learn about the measurement of 1AU.

KEY TOPICS

- Ceres and Asteroid belt
- Kuiper Belt
- Scale models
- Orbital characteristics
- Astronomical Unit

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
20 minutes	**History of the Solar System**	Discuss the discovery of additional objects in the Solar System, namely the rings and moons of Saturn, the planets Uranus, Neptune, Ceres, and the dwarf planet Pluto. Note that both Ceres and Pluto were considered planets until more of each type of object (asteroids and Kuiper Belt Objects, respectively) were discovered.
10 minutes	**Distance in the Solar System**	Display the distances to each object, in comparison to the Earth-Sun distance (1 Astronomical Unit, or 1AU). Discuss the distances in light years as well.
20 minutes	**HALL TOUR: Scales of the Universe**	Using the Scales of the Universe exhibit, bring students through relative scale models of the Universe, Galaxy, stellar clusters, stars, and the Solar System. If you do not have access to an exhibit of this sort, use a "Powers of Ten" video or website that provides a similar tour.
40 minutes	**ACTIVITY: Making a scale model of the Solar System**	Students use Google Earth to construct a large-scale model of the Solar System within Google Earth. These will be circular orbits, with the size of the orbit measured as the semi-major axis.
20 minutes	**Calculating 1AU**	Discuss the transits of Mercury and Venus, and how the geometry of Venus transits can be used to make fairly accurate measurements of the size of 1AU. This can be done as an activity.
10 minutes	**Orbital Characteristics in the Solar System**	Describe the various classes of orbits of objects in the Solar System – from the hardly eccentric and in-the-plane planets to the most eccentric and out-of-the-plane asteroids, KBOs, etc. If available, use software that can project these orbits on a screen.

Session Three: Scale of the Solar System (continued)

MATERIALS

Large round object (>10m) to act as the scale Sun, spreadsheet – Solar System to Scale, scientific calculators, .kmz file – Solar System to Scale, computers with Google Earth installed, long metric tape measures or meter sticks

PREP WORK

Find a large round object to act as the Sun, preferably outdoors and visible in Google Earth.

HALLS USED

Scales of the Universe

A/V NEEDED

None

HOMEWORK

Ask students some questions involving the size of the Solar System, for instance: How long would it take to drive to the Sun? Where would the Voyager Satellites be in your scale model? Etc. If there's been any recent solar activity, assign an article about it.

Session Three: Scale of the Solar System

HALL TOUR: Scales of the Universe

Students visit the Scales of the Universe exhibit, which shows the relative sizes of objects in the Universe, from the far reaches of the visible Universe down to the hydrogen atom. At each stop, the 26m Hayden Sphere is used as a point of reference, while another object is shown at that scale. For example, if the Hayden sphere represents the entire visible Universe, a model of the Virgo Supercluster is shown to scale at the first stop. At the second stop, the sphere now represents the Virgo Supercluster, and there is a model of the Local Group to scale. This continues through a few dozen orders of magnitude.

If a resource like this is unavailable, you may use a movie like Cosmic Voyage (http://www.imax.com/movies/m/cosmic-voyage/), or websites like The Scale of the Universe (http://scaleofuniverse.com/). Both cover a wide range of scales from the very small to the very large.

ACTIVITY: Making a Scale Model of the Solar System

Students to make a scale model of the Solar System using a large object as the Sun, preferably one that is accessible and students can measure (e.g. a baseball diamond, water tower, local round building). This activity was originally designed using the Scales of the Universe exhibit at the American Museum of Natural History, in which the scale Sun is 26m across. The exhibit shows the scale sizes of the 8 planets, but does not indicate their scale distance.

The activity includes two files, both titled "Solar System to Scale" and referencing the scale size of the Sun above. One is an Excel spreadsheet that, calculates the scale size and average distances between the Sun and objects in the solar system; the second is a Google Earth file that shows a circle in place of the sphere from the exhibit, and the average scale orbits of the eight planets plus Pluto and Eris. Students can use this as their starting point, but you can make your own circles to represent orbits around an object closer to your classroom by using the KML Circle Generator for Google Earth (http://www.thesamestory.com/kmlcircle/).

(For reference, if the 26m sphere at the Museum were the size of the Sun, then Earth would be about the size of a person's head in Times Square, about 2 miles or 2.8 km away.)

To make the scale model:

1. Have students measure the size of the object selected as the Sun. This can be done in person with a measuring, or by using the ruler function in Google Earth.
2. Ask students to determine the scale factor of this model – how much smaller it is than the real Sun. This is done by dividing the two sizes when expressed in the same unit.
3. Apply this scale factor to the other objects in the Solar System, reducing their sizes and distances.

Session Three: Scale of the Solar System

ACTIVITY: Making a Scale Model of the Solar System (continued)

4. In Google Earth, have students find and label the scale model of the Sun. Then have them either use the KML Circle Generator to make orbits or use the ruler function in Google Earth to pick representative locations for each object.
    a. If using the Circle Generator, students can also generate circles that represent each object at the correct size.
    b. If using the ruler function, students can choose a representative object (e.g. human head, baseball, etc.) to label the location with.

Afterwards, take the class through the tour if time permits. Students can save their work as a .kml file, which can be loaded in Google Earth on the instructor computer, if necessary.

Optional extensions to this activity are many. A few include:

- Have students pick their own object within Google Earth as the Sun.
- Ask students to add additional objects (Oort cloud, Ceres, Voyager satellites, the closest stars). This is a good HW question as well.
- Choose a relatively small object such that the orbits of the first few objects might be walkable.
- Create a Google Earth "tour" of the Solar System that jumps from location to location, looking back towards the model Sun.
- Have students calculate the light-travel times from the Sun to each object and add this to their model.

Ask students questions that elicit the big idea: the Solar System is very large, likely much larger than they assumed. Additional questions should concentrate on what this model is appropriate for, and other applications (e.g. masses or compositions) for which it would not be appropriate.

If computers are unavailable for your students, the work can be done using printouts from Google Earth. Print maps at 3 – 4 distances away from your (labeled) Sun model. Make sure these maps show the scale bar, and attempt to keep these scale bar distances round – e.g. 2km, 20km, 200km. Using compasses, students can draw in the orbits. Suggestions include:

- First hand out a print-out that allows for only the terrestrial planets to be drawn in, expanding the view when students start to complain that Jupiter won't fit.
- Request that students draw in the largest previous orbit when switching to a new map. In other words, if Mars fits on the previous map, but not Jupiter, draw Mars' orbit in on the next map as well.
- If the maps are printed with street/town labels on, students can pick the precise locations of their scale objects.

For a classic version of this activity, see the NOAO version, the Thousand-Yard Model (or The Earth as a Peppercorn): http://www.noao.edu/education/peppercorn/pcmain.html

Session Four: The Sun

LEARNING OBJECTIVES

Students will learn about the Sun by gathering data; deduce the bulk composition of the objects in the Solar System; learn how various missions have studied the Sun; and calculate the scale mass of objects in the Solar System.

KEY TOPICS

- The Sun
- Outer layers of the Sun
- Solar activity
- Solar wind
- Chemical abundance
- Missions – Voyager, SOHO, SDO, STEREO
- Gas giants
- (Hydrostatic equilibrium)

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
20 minutes	**The Sun – general info**	Ask students what they know about the Sun, and take any/all answers. Describe in light detail the outer layers of the Sun – the photosphere, chromosphere, and corona.
20 minutes	**ACTIVITY: Solar Activity**	Take students to the Hall of the Universe and watch images/movies of the Sun. Alternately, use images and movies available on various Solar mission websites. Discuss what sorts of activity students are seeing.
20 minutes	**ACTIVITY: Building Blocks of the Solar System**	Given the overall chemical abundance of the Sun, students will deduce the bulk compositions of the objects within the Solar System.
20 minutes	**Solar observatories**	Discuss the NASA space-based observatories that monitor the Sun, including the Solar and Heliospheric Observatory (SOHO), Solar Dynamics Observatory (SDO), and Solar Terrestrial Relations Observatory (STEREO). Show representative images from each, mentioning the false-coloring used for images taken in the infrared, ultraviolet, and other bands. Voyager is also interesting here, as it has by some accounts reached an "edge" of the Solar System, the Heliosheath.
30 minutes	**ACTIVITY: Scale Mass of the Sun**	Students will determine the scale mass of objects in the Solar System.
10 minutes	**Gas Giants**	Discuss the bulk properties of Jupiter and Saturn in relation to stars. These two objects are the most chemically similar to the Sun, but are also approximately the same size as the newly discovered class of low-mass objects, brown dwarfs. If time allows, discuss the hydrostatic equilibrium that keeps stars and large objects round.

Session Four: The Sun (continued)

MATERIALS

copies of the Chemical Composition of the Sun, mass model of the Sun, scales (measure to 0.1g or better), bathroom scale, cups of different sizes, water, calculators, image/movies of the Sun.

PREP WORK

Determine a scale mass model for the Sun. A person's weight works well for this.

HALLS USED

Hall of the Universe

A/V NEEDED

None

HOMEWORK

Find an article on atmospheric pressures or decompression sickness ("the bends"), and/or some other article dealing with interior or atmospheric pressures.

Session Four: The Sun

ACTIVITY: Solar Activity

Students see images and movies of activity on the Sun, without descriptions. You may wish to mention that in many of these images, false-colors are used to represent data that is not visible to human eyes – i.e. it is outside of our visible range (infrared, ultraviolet, etc.). This should also build on any reading assigned in Session Three.

Start by asking the students to describe the shape and surface of the Sun. Take all answers, and then show images/movies of flares, prominences, sunspots, coronal mass ejections, magnetic looping above the surface, etc. Allow students to describe what they observe about each phenomenon these it each. Try to include some of the many images available on the web that show an image of the Earth to scale within giant flares and sunspots.

ACTIVITY: Building Blocks of the Solar System

Students will identify some of the basic building blocks of the Solar System, based on data about the chemical composition of the Sun. The eight most abundant elements in the Sun by mass are:

Hydrogen (73.46%)
Helium (24.85%)
Oxygen (0.77%)
Carbon (0.29%)
Iron (0.16%)
Neon (0.12%)
Nitrogen (0.09%)
and Silicon (0.07%)

The handout contains a 999-element grid (37x27) filled in with the approximate abundances. Students should receive a copy and should start "making" molecules; atoms cannot be used more than once. Remind them that this is what the Sun is made of, and make up the most abundant elements in the Solar System as well.

Discuss their results. Students should have come up with several molecules: at least H_2, H_2O, NH_3, CH_4, CO_2. They should also have noted that plenty of He remains available, as well as some Ne, Si, and Fe. While the He and Ne will remain inert, the Si and Fe chemically combines with oxygen in particular, and forms a lot of the solid material within the Solar System.

Ask students what state the simple molecules they have made would be in. (We think of many as gasses.) Elicit that this will depend on distance from the Sun. On Earth, carbon dioxide is a gas, but it's often solid on Mars. Similarly, methane and ammonia are gaseous on Earth, but farther from the sun they will freeze out. Depending on the distance from the Sun, several solid materials– iron, silicon, carbon compounds, and ices — can be used as building blocks. We also have gasses that will appear in atmospheres – water vapor, carbon dioxide, neon, helium, hydrogen, methane, etc. Studies of the objects within the solar system exactly corroborate the students' findings.

Session Four: The Sun

ACTIVITY: Building Blocks of the Solar System (continued)

Discuss the rough bulk makeup of the planets with respect to distance from the Sun. Point out that the terrestrial planets in particular, have relatively little atmosphere, as gasses are easily expelled due to the Sun's heat and solar wind. However, they are made of differentiated materials – mostly iron, with some nickel (in the core), silicates (in the mantle) and carbon and silicates (in the crust). Jupiter's core is likely rocky, but it was able to accumulate a lot of surrounding gas. The same is probably true of Saturn, and both likely have mantles of metallic hydrogen and an abundance of ammonia in their clouds, giving them a brownish/yellowish color. Uranus and Neptune have the same rocky cores, but mantles of ices. Ammonia has frozen out of their atmospheres, and their bluish/greenish colors come mainly form methane (still a gas at this temperature). Moons out at Jupiter and beyond can have lots of solid water on their surface, and can act very similarly to rocks here on Earth.

ACTIVITY: Scale Mass of the Sun

Students use a large object (preferably a person) to represent the scale mass of the Sun, and then determine the scale masses of other objects in the Solar System. They use water to represent the other objects in the Solar System, as it approximates the density of the human body. Note that this is not a valid way to determine the size of objects in the Solar System, as densities vary widely.

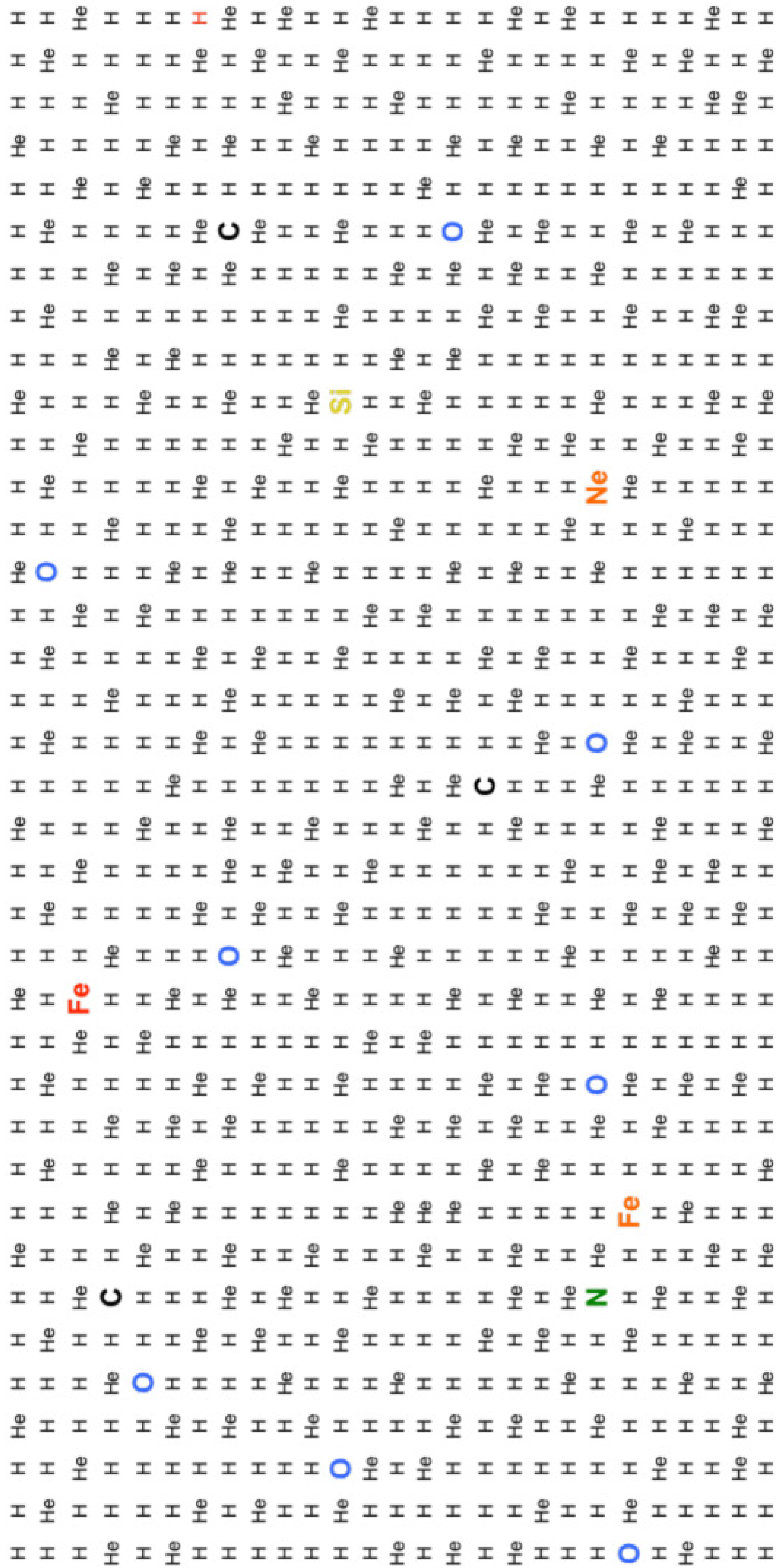
Students start with the scale mass of the Sun. The directions include instructions to convert the weight of the scale mass Sun into grams, using a pounds scale. Instruct students otherwise if your scale shows grams or kilograms.

Students approximate the scale mass of each object, then use a calculator to arrive at the actual values.

Finally, students determine percentages of the mass of the Solar System contained in the Sun, Earth, and Jupiter, and assess the flaws in this model (e.g. when calculating density, at noted above).

Session Four: The Sun

Chemical Composition of the Sun



Session Four: The Sun

WORKSHEET: Scale Mass of the Sun

Students will scale the masses of Jupiter and the Earth, using a model for the mass of the Sun. These other objects in the solar system will be represented by sand.

MATERIALS

- Sun model (one for the class)
- Bathroom scale
- Digital scale
- Water
- Cups

BACKGROUND INFO

- On the surface of Earth: 453.6g = 1 pound
- The Sun has a mass of 2.0 × 1033 g
- Jupiter has a mass of 1.9 × 1030 g
- Earth has a mass of 6.0 × 1027 g
- Saturn's mass is 5.7 × 1029 g
- The Moon has a mass of 7.4 × 1025 g
- Uranus has a mass of 8.7 × 1028 g
- Mercury has a mass of 3.3× 1023 g

PROCEDURE

1. The Sun

   a. Identify the class' Sun model: ______________________________

   b. Determine its weight: __________________

   c. Convert the weight to grams. Mass of the Sun model (g): ______________________

2. Using the "background info" above, approximately what masses would Jupiter and Earth, in proportion to the Sun? No calculators, just do this in your head!

3. Scale Factor

   a. Weigh the bowling ball. Determine how many times greater than the Sun's mass is the bowling ball. Divide the Sun's mass by the model Sun's mass. This is your scale factor.

Scale factor: ______________________

Session Four: The Sun

WORKSHEET: Scale Mass of the Sun (continued)

4. Scale masses – Use the scale factor to determine the scale mass of each object.

5. Scale mass models – using the scales and water, measure out an appropriate scale mass for each object.

QUESTIONS – SHOW AND EXPLAIN YOUR WORK.

1. Using the data above, roughly estimate the total mass of the Solar System.

2. What percentage of the mass of the Solar System is contained in:

a. The Sun?

b. Jupiter?

c. Earth?

3. In what key ways does our model fail? In other words, can you think of anything that is drastically wrong with it?

If time allows, create scale mass models of the other objects listed in the background info, or look up other objects in the Solar System and make scale mass models of those.

Session Five: Giants

LEARNING OBJECTIVES

Students will learn about the bulk properties of the gas giant and ice giant planets; describe Earth's atmospheric pressure; distinguish between force and pressure; and learn about phases of matter in relation to pressure and temperature.

KEY TOPICS

- Pressure
- Gas giant – Jupiter and Saturn
- Ice Giants – Neptune and Uranus
- Force
- Triple point
- Phase diagrams
- Rings

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
10 minutes	**Reading discussion**	Discuss the effects of working underwater in a high-pressure environment.
30 minutes	**Giants**	Introduce the gas and ice giants, including atmospheres, bulk properties, moons, and observable properties including storms and peculiarities. Show some images and data from missions to these planets – Voyagers, Cassini, Galileo, New Horizons, etc.
20 minutes	**ACTIVITY: Weight of the Atmosphere**	Students will calculate the weight of the atmosphere on their hands.
10 minutes	**Interiors**	Show a phase diagram for water or simple substance (hydrogen, ammonia, methane, etc.), and discuss the triple point. Discuss additional phases of matter as pressure increases by several orders of magnitude. Point out that this is why the interiors of giants probably contain metallic hydrogen.
30 minutes	**ACTIVITY: Force vs. Pressure**	Students investigate the differences between their weight (force) and the pressure applied by that weight.
20 minutes	**Rings**	Introduce the rings of all four giant planets. Discuss ring formation, why Saturn's rings are so prominent, the Roche limit, etc. Show images of shepherd moons, ring spokes, and other interesting phenomena. If time allows, describe the discovery of Saturn's rings, and the Voyager spacecraft discovering the rings around both Jupiter and Neptune.

Session Five: Giants (continued)

MATERIALS

Bathroom scale, calculators, graph paper, balloon, clay, wooden blocks (approximately 20cm x 20cm x 2 cm, flat like plywood), plastic knives, scrap paper, cm rulers, copies of the Force vs. Pressure worksheet

PREP WORK

Cut sheets of wood if necessary.

HALLS USED

None

A/V NEEDED

None

HOMEWORK

NASA Spacemath, "Tidal Forces – Let 'Er Rip!" You may wish to add questions about additional materials, and ask students to predict the density a moon would have at a given distance from Saturn. As a follow-up to the Force vs. Pressure activity, assign the following question, asking students to make assumptions or look values up online: "Which exerts more pressure – an elephant standing on one foot, or a human standing on one high heel?"

Session Five: Giants

ACTIVITY: The Weight of the Atmosphere

Students will determine the weight of the atmosphere on their hands. Do not mention that the atmosphere exerts pressure in all directions.

Have sheets of graph paper available for all students. The smaller the squares the better, but any size will work as long as the size of the squares is known. (Many websites will print custom graph paper.) Options for dealing with pressure units are listed below.

Ask students to close their hands flat (fingers touching, like a mitten) and trace their hands. Then ask them to establish the approximate area of their hand by counting boxes.

Give students the air pressure on Earth. This can be expressed in multiple ways:

- 1atm = 14.7 pounds/inch^2
- 1atm = 2.3 pounds/cm^2
- 1atm = 10.1 N/cm^2

Have students calculate the force that the atmosphere exerts on their hands. It should come out to hundreds of pounds or Newtons. Act surprised! Holding your arms straight out, approximate the surface area of your arms and point out that you're holding up thousands of pounds! Ask how is this possible?! Elicit that the air pressure works in all directions, not just downward. Discuss the similarities to water pressure and other forms of pressure.

Show students a balloon that is inflated, and ask what the pressure is inside the balloon. (It's open to the air, so the pressure should be equal to the pressure outside). Blow it up and tie it, and ask how the internal air pressure changed as you were inflating the balloon. The students should recognize that the rubber was forced outward as the internal air pressure increased. Now that the balloon is tied closed, what about the air pressure inside? Elicit that since it is not changing size, the two pressures – the internal pressure forcing the balloon outward, and the external air pressure compressing the balloon in every direction — even out.

Session Five: Giants

ACTIVITY: Force vs. Pressure

Students stand on wooden blocks on clay. The clay should be uniform and the pieces of wood should be fairly relatively thin but sturdy enough to support the weight of the student. If possible, use sticks of modeling clay of uniform thickness and give the students two strips each, which they can cut in half across the width to obtain four equal pieces.

These instructions assume a scale that measures in pounds. If you have access to a scale measuring in Newtons, your students can skip the conversion; all other steps remain the same.

Students first attach one strip of clay to the bottom of the wood. After making some measurements, they step evenly (this is not a jump) onto the clay and then off. Protect the floor with scrap paper.

In the second trial, students attach three times as much clay to the bottom of the wood. The blocks of clay should be spread out along the wood so that each can squish down independently of the others. Again, each student steps on and off. Each piece of clay will be squished less than the first trial.

This demonstrates the difference between a force (weight due to gravity) and a pressure. The weight is the same but the surface upon which that force acts increases, and thus there is less pressure. Discuss this with students, and introduce the homework problem comparing the pressure exerted by an elephant's foot to that of a person in high heels.

Session Five: Giants

WORKSHEET: Force vs. Pressure

You will investigate the difference between a force (in this case "weight") and pressure. One person will be the weight used in the measurements, and the group will determine the amount of pressure exerted on blocks of clay.

MATERIALS

- Bathroom scale (one for the class)
- Wooden block
- 2 strips of clay
- Plastic knife
- 2 pieces of scrap paper
- Ruler

BACKGROUND INFO

- A weight is a force – a mass is pulled down by a certain amount by gravity.
- For this activity, we are using the metric measure, Newtons (N). 1N is the gravitational force felt (i.e. the weight) of approximately 0.1kg of mass, on the surface of Earth.
- 1 pound = 4.45 N

PROCEDURE

1. One person (an instructor, if no student volunteers) needs to be weighed on a bathroom scale and be the test subject. If no one is interested, ask one of the instructors to volunteer instead.

   Record the subject's weight in your notebook. Convert the weight into Newtons, and record that figure.

2. a. Carefully cut the clay into four equal pieces. Only reform the clay if necessary – the four pieces need to be as equal as possible.

   b. Using a cm ruler, measure one of your blocks of clay and sketch it in your notebook.

3. a. Carefully stick one of the pieces of clay on the "bottom" of the wooden block. Sketch the orientation of the block and clay in your notebook.

   - NOTE – in the next step you will be sticking 3 sticks in the same orientation, so make sure there will be enough room.

   b. Gently place the block, clay side down, on the scrap paper on the floor.

   c. The test subject should GENTLY step on the block directly over the clay with his or her full weight, then carefully step off.

   d. Sketch the squished clay, and measure and record its dimensions.

4. a. Clean the block.

   b. Place all three unused pieces of clay on the block, spaced apart so that the clay has space to expand. The three pieces should be in the same orientation as the single piece was.

   c. Repeat steps 3c and 3d.

Session Five: Giants

WORKSHEET: Force vs. Pressure (continued)

REFLECTION QUESTIONS

1. How does the total force exerted on the clay in Step 3 compare to the total force exerted in Step 4?

2. How does the force per area exerted on the clay in Step 3 compare to Step 4?

ANALYSIS

Determine how much force per area (square cm) was exerted. To do this, note that the surface area of the clay in contact with the floor was different. Keep good notes, and record every step in your notebook.

REFLECTION QUESTIONS

3. Pressure is the force per area. Make at least two general statements regarding the force on an object and the pressure on an object.

4. What would you expect the pressure to be within Earth, under many layers of rock? Why?

5. How do you think the pressure on an object would change as it moved up through the atmosphere? Explain.

Session Six: Terrestrial Planets and the Habitable Zone

LEARNING OBJECTIVES

Students will understand the bulk properties of the terrestrial planets; view some of the building blocks of terrestrial planets; calculate habitable zones around stars with known exoplanets; and understand tides and tidal locking.

KEY TOPICS

- Differentiation due to density
- Mercury's density
- Habitable zone
- Greenhouse effect
- Tides and tidal locking

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
30 minutes	**Terrestrial Planets**	Discuss bulk properties of the terrestrial planets (e.g. differentiation by density with an iron/nickel core, silicate mantle, carbon-silicate crust); craters; atmospheres; a few moons. Discuss Mercury's extreme density as an indicator of a probable massive impact. Include images from relevant space missions
20 minutes	**TOUR: Cullman Hall of the Universe, and Gottesman Hall of Planet Earth**	Observe the meteorites in the Cullman Hall of the Universe and basalt in the Gottesman Hall of the Planet Earth, showing the building blocks of the terrestrial planets. Follow with a tour of the Gottesman Hall of the Planet Earth focusing on the habitability of Earth. If you do not have access to these or similar exhibitions: 1. View a video on the habitability of the Earth and/or, the search for life on Mars. 2. Show samples of rocks that could not have been made without living things (banded iron, various sedimentary rocks, etc.). 3. Read and discuss an article on deep sea vents ("black smokers"), or other places where life exists under extreme conditions.
20 minutes	**Habitable Zone and the Greenhouse Effect**	Discuss the habitable zone as the region around a star where temperatures naturally allow for liquid water, assuming atmospheric pressure is above that of the triple point. Point out that an atmosphere traps heat, which can allow for some flexibility in the "edge" of the habitable zone; in particular, if the atmosphere on Mars were more dense, it could support higher average temperatures and the pressure could support liquid water.
30 minutes	**ACTIVITY: Alien Habitable Zones**	Provide a formula that approximates the temperature around a star at different distances. Students will choose stars from use the online exoplanet catalog and look for exoplanets within the habitable zones.
5 minutes	**Other Habitable Zones**	Briefly discuss Europa. This moon, while covered in a layer of water ice, is pulled and tugged at by Jupiter's gravity and the other moons, and is believed to have an underground ocean of liquid salt water due to this tidal heating.
15 minutes	**Tides and Tidal Locking**	Use Europa and the moons of Jupiter to demonstrate how objects can get locked into orbits together. Extend this to the Earth-Moon system, in which the Moon orbits and spins with the same period. Therefore the same side of the Moon always faces Earth.

Session Six: Terrestrial Planets and the Habitable Zone (continued)

MATERIALS

Computers with internet access, copies of the Mission cards homework, materials as needed for the TOUR section

PREP WORK

Determine what you will do for the TOUR section.

HALLS USED

Cullman Hall of the Universe, Gottesman Hall of Planet Earth

A/V NEEDED

Depends on the TOUR section

HOMEWORK

Mission cards

Session Six: Terrestrial Planets and the Habitable Zone

TOUR: Cullman Hall of the Universe, and Gottesman Hall of Planet Earth

This tour has two parts: viewing some of the building blocks of the terrestrial planets and the habitability of Earth.

Building Blocks of the Terrestrial Planets: Escort students to the Willamette meteorite, explaining its history as needed. Ask what it's made of (iron/nickel, with more iron than nickel; students should at least know that it is metal). Elicit that iron was a relative abundant building block in the early Solar System, as discussed. Explain that the planets were molten, and materials could easily move around. Elicit that since it is denser than other early materials, iron would sink to the center, and explain that the core of terrestrial planets is indeed made of iron.

Take students to the slab of a stony/iron meteorite displayed at the north end of the hall. Point out the crystals within it that are made of olivine, a mineral containing iron and silicon and similar in composition to Earth's mantle. Elicit that, in the early Solar System, temperatures were hot enough that most materials were molten, and that in this environment, large enough objects would have separated out to form core, mantle, and crust structures. "Leftover" pieces would also have differentiated, and while they may not have formed planets, they would have been differentiated and asteroids formed.

To conclude the first part of the tour, take students into the Volcanic section of the Gottesman Hall of Planet Earth and point out the basalt and other volcanic material. This is the lightest of the materials that make up the crust, mantle and core, and forms the crust of the terrestrial planets. Note that Mercury's iron/nickel core is larger than that of the other planets, and there are signs that a large impact stripped away these outer layers once they had differentiated and cooled substantially

Habitability of Earth: Start with the stromatolites, talking about the layers of these rock-like structures built up over long periods. Banded iron formed when oxygen, released by living things, interacted with iron in the oceans to form layers of iron oxide, until the seawater eventually ran out of iron. And be sure to visit the deep sea vents ("black smokers") and talk about the extreme conditions under which life can thrives, even without any sunlight.

ACTIVITY: Alien Habitable Zones

Students will use real and current data available at http://exoplanet.eu to hunt for exoplanets in habitable zones around other stars. The data approximates the temperature of a planet at a certain distance from a star of a given size and temperature. Using this equation, students will compare the distances between exoplanets and their host stars, with some leeway for the habitable zone.

Session Seven & Eight: Interplanetary Missions

LEARNING OBJECTIVES

Students will be able to explain different types of interplanetary missions; understand what powers interplanetary spacecraft; and present a slideshow about an interplanetary mission.

KEY TOPICS

- Mission types
- Power sources
- Entry, descent, and landing
- Mission objectives
- Extended missions

CLASS OUTLINE, SESSION 7

TIME	TOPIC	DESCRIPTION
30 min (more if videos are used)	**Missions overview**	Discuss missions and mission planning, including: • Mission types (landers, rovers, orbiters, colliders, sample return, etc.) noting that a mission may span several types • Mission objectives – the minimum that the mission is required to do • Extended missions that can be planned beyond the initial operational period for the spacecraft • Research tools (cameras, altimeters, data transmission equipment, sample collection/analysis, software, spectrographs, grinders, etc.) • Energy sources, namely RTG (radioactive thermoelectric generators) and solar panels • Entry, descent, and landing (parachutes, powered rockets, airbags, etc.) Optionally, watch whole or parts of videos about specific spacecraft. Highly recommended: NOVA's "Mars: Dead or Alive" about the Spirit and Opportunity rovers.
15+ minutes	**Current spacecraft**	Use NASA's Eyes on the Solar System, which allows for realtime rendering of current interplanetary missions, and describes some historic events. http://eyes.nasa.gov/
Remaining	**ACTIVITY: Interplanetary Missions Slideshows**	Students work in small groups (~2 people) to research a chosen spacecraft, including its research tools, objectives, findings, history, etc. in order to develop a ~3 – 4 minute-long presentation. Allow more time during the following session.

CLASS OUTLINE, SESSION 8

TIME	TOPIC	DESCRIPTION
75 min	**ACTIVITY: Interplanetary Missions Slideshows (continued)**	Allow students to continue working on presentations.
45 min	**ACTIVITY: Present Interplanetary Missions Slideshows**	Students present their slideshows. Audience takes notes.

Session Seven & Eight: Interplanetary Missions (continued)

MATERIALS

Computers with internet access, slideshow presentation software (e.g. PowerPoint, Keynote, Google Drive)

PREP WORK

Determine whether to use a video to introduce the concepts above. Learn how to use NASA's Eyes on the Solar System (http://eyes.nasa.gov/).

HALLS USED

None

A/V NEEDED

Projection of video (optional), of Eyes on the Solar System, and of student projects

HOMEWORK

Session 7 – Continue background research on a spacecraft.

Session 8 – Have students choose a favorite instrument or technique used by the landers/rovers, and find/read two or more articles on that subject.

Session Seven and Eight: Interplanetary Missions

ACTIVITY: Interplanetary Missions Slideshows

This is a very open ended slideshow about a planetary mission. Information gathered should include the type(s) of mission, dates, mission objectives, secondary/extended objectives, important (or intended) discoveries, propulsion and energy systems, instrumentation, etc. If possible, students should include images taken by their spacecraft. Additional interesting topics include the cost of the mission, funder, and the principal investigators and their affiliations.

Often students will ask whether they can include video, which can dominate their research and have limited audio capabilities. Often it makes sense to suggest that they find a shorter video or edit it down to relevant highlights (e.g. simulations of entry, descent, and sanding; animated gifs of images taken by spacecraft; launch or return; etc.).

To start, have students survey this NASA list of interplanetary missions, past and present: http://nssdc.gsfc.nasa.gov/planetary/projects.html.

You may want to give a short primer about effective presentations. Suggestions like “not too much text” and “don’t read off of the slideshow” go a long way. It can be even more helpful to create a “bad” mock presentation and have students comment on what they should do instead.

ACTIVITY: Present Interplanetary Missions Slideshows

Students present their slideshows. Students in the audience should take basic notes on the missions.

Session Nine: Giant Moons and the Grand Tour

LEARNING OBJECTIVES

Students will learn about the major moons of the Solar System; design a research mission to one of these moons; and experience the 3D nature of the Solar System.

KEY TOPICS

- Icy moons
- Geysers and Volcanism on moons
- Mission design

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
45 min	**Moons**	Introduce students to the various large moons in the Solar System using lots of images. Include interesting surface and subsurface features like impact craters, geysers, volcanism, ices, liquids, coloration, atmospheres. Include: • Our Moon and its similar chemical makeup to that of Earth • Europa with its icy surface and possible liquid subsurface ocean • Ganymede with its icy/rocky surface, possible subsurface liquid ocean, and fully differentiated interior with a liquid iron core • Io and its volcanism • Titan and its thick atmosphere and liquid surface methane acting like water does on Earth's surface (erosion, rain, etc.) • Enceladus with its icy geysers If time allows, other interesting moons include Callisto, Triton, Mimas, Tethys, Miranda, Iaepetus, Hyperion, Charon.
45 min	**ACTIVITY: Moon Mission**	Students outline a mission to one of these moons that involves at least one new idea. Computers can be used for background research.
30 min	**Digital Tour of the Solar System**	Using the planetarium, take students on a "Grand Tour" of the Solar System, discussing distance scales, orbital times, extent of the influence of the Sun, spacecraft locations, etc. If no planetarium is available, NASA's website Eyes on the Universe or the software Celestia.

MATERIALS

Computers, software to project the Solar System, if necessary

PREP WORK

Choose a digital tour, and learn any appropriate software.

HALLS USED

Hayden Planetarium

A/V NEEDED

Projection for the digital tour

HOMEWORK

Ask students to determine if Titan and Europa should be moons, planets, or something else, and to explain why.

Session Nine: Giant Moons and the Grand Tour

ACTIVITY: Moon Mission

Group students into groups of 2 – 3. Ask the groups to pick a moon and sketch out a plan for a mission to this moon. This is completely conceptual – no drawings or slideshows needed. Allow students to assume that their missions can run for an infinite time on an infinite budget – this allows them to be creative.

Ask students to come up with one new or innovative idea for their mission. Feel free to suggest tools like drills, submarines, a multitude of mini surface data collectors, or topics like climate studies or earthquake detection.

Computers can be used for background research, but there is no need to type up anything. Allow about 30 minutes for design, and ask the groups for their ideas during the final 15 minutes.

ACTIVITY: Digital Tour of the Solar System

In this tour, emphasize the 3D structure of the Solar System as well as its scale. If your software/projection system allows, show the entire system, from the Sun to the Oort cloud. Here are some possible topics:

- Orbital time periods of the planets and/or the Galilean Moons of Jupiter
- "Landing" on Mars or other bodies
- Surface features on Mars (Olympus Mons, Valles Marines, ice caps)
- Locations of the Voyager or other spacecraft
- Near Earth and Potentially Hazardous Asteroids
- Earth orbiting satellites
- Flatness of the planets
- Orbits of the dwarf planets

Session Ten: Minor Planets

LEARNING OBJECTIVES

Students will learn about the small objects in the solar system; differentiate between meteorite types; and define a planet.

KEY TOPICS

- Comet
- Halley's comet
- Asteroid
- Ceres
- Minor planets
- Pluto
- Eris

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
15 minutes	**Discovering Comets**	Discuss the history of discovery of comets, and their bulk composition (ices, organics), and structure (coma, dust tail, ion tail). Use Halley's comet as an example, as Edmond Halley uses Newton's laws to accurately predict its return Show images and data from missions to Halley's comet in 1986, and other comet missions (Deep Impact, Stardust).
10 minutes	**Discovering Asteroids**	Discuss the history of discovery of asteroids, and their bulk composition (rocks, minerals, metals). Use Ceres as an example, called a planet until others were discovered in the same region – the asteroid belt. Many more were discovered, at an exponential rate.
30 minutes	**TOUR: Hall of Meteorites**	Look at chemical composition, types, cooling and the Widmanstätten pattern, chondrules, formation of terrestrial planets, impacts. If a meteorite hall is unavailable, try to acquire some samples. NASA's Lunar and Meteorite Disk Program loans out meteorites - http://ares.jsc.nasa.gov/ares/lmdp
30 minutes	**Minor Planets**	Introduce the IAU Minor Planet Center (http://www.minorplanetcenter.net/) which tracks minor planets. The number of objects in the Solar System is astounding, and published on their front page. There are plenty of minor planets to discuss, including missions like the Dawn mission which orbited Ceres and Vesta, and the Galileo mission that passed by Ida and Dactyl . Additional topics include orbits, evidence of a larger body that broke up through the distribution of minor planets (a concentration between 2 and 3.5AU), Pluto and the discovery of Eris and other objects at similar distances, the New Horizons mission to Pluto.
5 minutes	**Science Fiction and Asteroid Belts, and the HW**	Find images from science fiction of ships traveling through asteroid belts (which almost always show asteroids clustered so densely that ships have to steer around them rapidly). For homework, students will estimate the average distance between objects in the asteroid belt.
30 minutes	**ACTIVITY: Define a Planet**	Students formulate their own definition of a planet, and test it out. After some research, students refine and retest their definition.

Session Ten: Minor Planets (continued)

MATERIALS

Meteorites, copies of the Define a Planet worksheet

PREP WORK

Determine if you can visit a meteorite exhibit, or if meteorites are available for your classroom.

HALLS USED

Ross Hall of Meteorites

A/V NEEDED

None

HOMEWORK

Looking up the number of Main-Belt Asteroids on the Minor Planet page, and an estimate that the moons of Mars (Phobos and Deimos) can be thought of as "typical" asteroids, ~20km across, students estimate the distance between asteroids in the asteroid belt, from about 2 – 3.5AU. (The solar system can be thought of as flat.)

Session Ten: Minor Planets

TOUR: Arthur Ross Hall of Meteorites

Start in the center of the hall and discuss the dense, heavy iron meteorites on display. Move left to the composition of meteorites and their basic constituents – chondrules, calcium aluminum inclusions, matrix, metals, minerals. Continue on to discuss spectroscopy and the ability to measure the chemical composition of an asteroid from afar, or a meteorite when it is in the lab. This has allowed us to match up some fallen meteorites with some of the larger asteroids, particularly Vesta.

Remind students that asteroids and meteorites are samples of the building blocks of the planets. Show samples of each distinct type of meteorite and how it matches the core, mantle, and crustal materials of terrestrial planets. Additionally, talk how molten material differentiate by density, and the slow cooling (as low as 1°C/million years) that allows for crystals (the Widmanstätten pattern) to form unlike any on Earth.

Move to the section on impacts, the display of Meteor Crater in Arizona and the samples of meteorites from it, known as the Canyon Diablo meteorite. Point out samples kicked off the surface of Mars by an impact. Reiterate that we know this in part from chemical analysis, which shows their composition to be identical to the surface composition of Mars.

If time allows, students may be allowed to explore on their own.

If you do not have access to a similar hall, show samples of meteorites in your classroom. Many of the same topics can be discussed, depending on what samples are available. Stress the "building blocks" nature of meteorites and their ongoing collection and analysis. Many images of the Widmanstätten pattern are available online, if none are available on samples that you have access to.

ACTIVITY: Define a planet

In groups of 2 – 3, students will define what a "planet" is. Some may be familiar with the IAU's definition of a planet from 2006. They then test this definition on the 8 planets, Ceres, Pluto, and Neptune, and our Moon.

Follow with a detailed history of defining planets, including the classification of "trans-neptunian objects." The reading details the IAU's 2006 definition of a planet, and some of the issues it raised.

Invite students refine their definitions. Provide a list of objects, including the those defined on their first pass, this time with short descriptions of each. Students apply their definition to this list, which intentionally includes some Earth-similar exoplanets and large moons.

Finishing up, students reflect and can revise to their definitions a final time. There is no correct answer. Encourage discussion between groups, and lead a group discussion at the end to review the various definitions and the issues students faced.

Session Ten: Minor Planets

WORKSHEET: Define a Planet

Define "planet":

Use your definition to determine if the objects below are planets or not:

Object	Planet? (Y/N)	Explanation (if needed)
Mercury		
Venus		
Earth		
The Moon		
Mars		
Ceres		
Jupiter		
Saturn		
Uranus		
Neptune		
Pluto		
Eris		

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 2

Pluto has long been a thorn in the sides of astronomers. Unlike Uranus and Neptune, which are quite "obviously" massive planetary bodies, Pluto came to seem less and less planet-like. Pluto's orbit crosses Neptune's; its orbit is in a stable resonance with Neptune (for every three orbits of Neptune, Pluto orbits twice); and it is 1/10 the mass of the Moon. Still, it is a unique object, and the astronomical community largely resisted changing its status.

In 1992, the object (15760) 1992 QB1 was discovered out past the orbit of Neptune. Pluto was no longer unique. More "trans-neptunian" objects were discovered, until the object 2003 UB313 (eventually called "Eris") was discovered, and shown to be larger and more massive than Pluto. The International Astronomical Union (IAU) had to make a call on Pluto (again).

When the IAU met in 2006, it had a few options:

1. Planets are the current nine planets, because astronomers don't care what things are called.
    - This ignores the problem entirely, as the IAU had done up till then.
2. A planet is an object large enough for gravity to make it spherical.
    - Mike Brown (discoverer of Eris) notes that this would mean there are over 50 planets. http://web.gps.caltech.edu/~mbrown/eightplanets/
3. A planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.
    - A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.
    - All other objects, except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies"." (http://www.iau.org/static/resolutions/Resolution_GA26-5-6.pdf)
    - (A rejected additional resolution would have created the category of "Double Planet" for pairs of objects that would each qualify as Planets or Dwarf Planets - Pluto and Charon would be a double dwarf planet.)

The IAU went with option 3. The Solar System now has 8 planets and several dwarf planets: (134340) Pluto; (136199) Eris; (1) Ceres; (136108) Haumea; and (136472) Makemake.

This has caused problems. Pluto's demotion has irritated many scientists and the general public. Also, since 1992, no less than 853 extrasolar planets (as of 12/13/12, stated on http://exoplanet.eu/) have been discovered orbiting other stars. But they do not orbit the Sun, so the IAU definition says they are not planets.

"Cleared the neighbourhood" is vague. Many asteroids cross the orbits of the planets; one of them killed the dinosaurs. Pluto crosses Neptune's orbit. Comets cross the orbits of ALL the planets. Jupiter, Neptune, Mars, and Earth have "Trojan asteroids" that sit at stable resonance points 60 degrees ahead of and 60 degrees behind the planets in their orbits. That said, Earth vastly outmasses all the objects that cross its orbit; Pluto does not.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 3

With all this in mind, how would you now define "planet?"

Apply your definition to the following objects.

MERCURY

No atmosphere, no moons. Elliptical orbit (0.21). Partially tidally locked (3:2, three "days" every two "years") to the Sun. 1/20th of the mass of Earth.

Is it a planet? ________ Explain below if needed.

VENUS

Slightly smaller and less massive than Earth, spins backwards slowly. 93x thicker atmosphere than Earth, no magnetic field, no moons.

Is it a planet? ________ Explain below if needed.

EARTH

Orbited by a satellite 1/81th of its mass, will become a "double planet" when the Moon recedes to the point that the center-of-mass is above Earth's surface. Substantial atmosphere, strong magnetic field, one moon, life.

Is it a planet? ________ Explain below if needed.

THE MOON

Tidally locked to Earth. 1/80th the mass of Earth. As seen from the Sun, the orbit seems to be petal shaped, always pointing toward the Sun and never looping on itself.

Is it a planet? ________ Explain below if needed.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 4

MARS

Currently the fourth planet. Thin atmosphere, two moons, probably both captured asteroids. 1/10 the mass of the Earth, 1⁄2 the radius.

Is it a planet? ________ Explain below if needed.

(1) CERES

Formerly the fifth planet (1801-1850s?), now Dwarf Planet. The only Main Belt object with enough mass to definitely be spherical. 1/3 the mass of the Main Belt, 4% the mass of The Moon.

Is it a planet? ________ Explain below if needed.

JUPITER

More massive than the rest of the Solar System put together. Thick gas atmosphere with no solid core, rings, many moons.

Is it a planet? ________ Explain below if needed.

SATURN

Thick gas atmosphere with no solid core, rings, many moons. It's less dense than water, and spins fast enough that it's slightly flattened, almost a sphere.

Is it a planet? ________ Explain below if needed.

URANUS

Thick gas and ice atmosphere, possibly a solid core. Spins on its side (technically backwards), rings, many moons.

Is it a planet? ________ Explain below if needed.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 5

NEPTUNE

Thick gas and ice atmosphere, possibly a solid core. Slightly more massive (17 Earth masses) but smaller radius than Uranus. Rings, several moons.

Is it a planet? ________ Explain below if needed.

(134340) PLUTO

One of many objects in a 3:2 resonance with Neptune. Mutually tidally locked to its massive moon Charon, in a 6 day orbit. Tilted on its side. Elliptical orbit (0.25), out of the plane of the Solar System, crosses Neptune's orbit (from 1979-1999 it was technically the 8th planet). Kuiper Belt object. Very weak atmosphere, which it may not have for its entire orbit around the Sun, and which may extend to Charon. Five moons.

Is it a planet? ________ Explain below if needed.

(136199) ERIS

Elliptical orbit (0.43) well above the plane of the Solar System. Kuiper Belt Object. 340 times less massive than Earth.

Is it a planet? ________ Explain below if needed.

HD 80606 B

A four Jupiter-mass object that has an elliptical orbit of 0.93 (roughly like Halley's Comet); distance from HD 80606 ranges between .84 AU and .03 AU. Surface temperature ranges from 980 F to 2240 F. The star HD 80606 is a binary system with another star HD 80607 (separation 1200 AU), but the planet only orbits HD 80606.

Is it a planet? ________ Explain below if needed.

2MASS J1207-3239 B

A 5 Jupiter-mass object, orbiting a 25 Jupiter-mass brown dwarf. The 25 Jupiter-mass object is not massive enough to fuse regular hydrogen in its core like a star, though it is capable of fusing deuterium (heavy hydrogen).

Is it a planet? ________ Explain below if needed.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 6

CFBDSIR2149-0403

A 4-7 Jupiter mass object floating on its own through space.

Is it a planet? ________ Explain below if needed.

GLIESE 876 B

A 2.5 Jupiter-mass object orbiting the nearby red dwarf star Gliese 876. Due to a quirk of the way planets behave when mass is added, its radius is probably smaller than Jupiter's. 60 day circular orbit (in a 2:1 resonance with Gliese 876 c).

Is it a planet? ________ Explain below if needed.

GLIESE 876 C

A 0.7 Jupiter-mass object in orbit of the nearby red dwarf Gliese 876. 30 day circular orbit (in a 2:1 resonance with Gliese 876 b).

Is it a planet? ________ Explain below if needed.

KEPLER 64 B

Discovered by amateur astronomers with Planet Hunters. Kepler 64 is a quadruple star system arranged as two pairs of two stars (Aa+Ab, Ba+Bb), separated by 1000 AU. Aa and Ab orbit each other every 20 days, and Kepler 64 (Aab) b, which is 6 Earth radii and 20-50 Earth masses, orbits that pair every 138.3 days.

Is it a planet? ________ Explain below if needed.

GANYMEDE

Larger but less massive than Mercury. Tidally locked to Jupiter. In a 4:2:1 resonance with Europa and Io. Has its own magnetic field, tidal forces probably keep its core liquid. 7 day orbit. 1/40th of the mass of Earth. No atmosphere.

Is it a planet? ________ Explain below if needed.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 7

TITAN

Larger but less massive than Mercury. Tidally locked to Saturn. Titan has methane rivers, possibly methane oceans, and methane rain. It also has a substantial atmosphere (Earth-like pressure).

Is it a planet? ________ Explain below if needed.

PSR 1257+12 B

A half-mercury-mass object in a 25 day orbit around a pulsar (the remains of a supernova). Probably formed after the supernova. We have no idea what it's made of.

Is it a planet? ________ Explain below if needed.

TRITON

Moon of Neptune, probably a captured Kuiper Belt Object, in which case it is the most massive currently known. Retrograde rotation, atmosphere, volcanoes, tipped on its side.

Is it a planet? ________ Explain below if needed.

(2060) CHIRON/95P CHIRON

~230 km wide icy asteroid that orbits between Saturn and Uranus. It has probably been knocked inward from the Kuiper belt, and interactions with Saturn will eventually either fling it out of the solar system or into the inner solar system. It was discovered as an asteroid, and later turned out to be a comet- the largest currently known. It may be hydrostatically round.

Is it a planet? ________ Explain below if needed.

(624) HEKTOR

One of Jupiter's "Trojan"s. Locked in a 1:1 resonance with Jupiter, held in Jupiter's L4 (Greek) Lagrange point. May be a contact binary asteroid. Has its own moon.

Is it a planet? ________ Explain below if needed.

Session Ten: Minor Planets: WORKSHEET: Define a Planet - Page 8

(216) KLEOPATRA

A binary asteroid with two moons: it appears to be composed of two equal-sized asteroids possibly almost in contact with each other, orbited by two other, smaller moons.

Is it a planet? ________ Explain below if needed.

1/P HALLEY ("HALLEY'S COMET")

Eccentricity 0.97, above the plane of the Solar System, orbits the sun backwards (retrograde). Maximum distance from the Sun ~36 AU. As it reaches its closest approach (0.6 AU) to the Sun, surface ices vaporize. Surface gravity is low enough the gas flies off into space forming a giant tail, called a 'coma'. "Nucleus" is 16x8x8 km in size.

Is it a planet? ________ Explain below if needed.

And finally – do you think your definition of planet is a good one?

Do you need to make any final revisions? Why?

Session Eleven: Impacts and the Formation of the Solar System

LEARNING OBJECTIVES

Students will discover that the Solar System is mostly empty; simulate and learn about collisions; and be able to explain theory of how the Solar System formed.

KEY TOPICS

- Impacts and collisions
- Formation of the Solar System
- Protoplanetary disc
- Data simulation
- Migration
- Near Earth Asteroids

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
30 minutes	**ACTIVITY: Impacts!**	Students use a website that shows the results of an impact of a meteor on the Earth, given initial conditions. Editable constraints include type, mass, angle, location of impact, etc.
10 minutes	**Early formation**	Start by asking what is currently in the Solar System and would need to be formed in any model of the formation of the Solar System, and elicit all the various objects, chemical compositions, etc., it contains. Remind students of the chemical abundance activity from session 4. Show images of, and discuss properties of, giant molecular clouds (e.g. the Eagle Nebula). Ask what might cause a cloud like this to contract. Take all answers, eliciting scenarios like supernova shockwaves, passing star clusters, etc. Ask, how can we study formation? Elicit that we must learn from "snapshots" from objects in space, since processes occur over vast periods of time. Explain that scientists can use computer models to simulate the physics of formation over long time periods, and compare the results to what we see in the 'snapshots.' Show simulations of star formation out of giant molecular clouds, like those by Matthew Bate (see below). Stars start forming when matter clumps and forms a disc, rotating slowly at first. Within the disc, matter clumps and gravity pulls clumps toward other clumps, forming the proto-planetary objects of a stellar system as the protostar builds up pressure and temperature and starts burning hydrogen into helium. (It becomes a star.) See additional simulations below.
30 minutes	**SPACE SHOW: Cosmic Collisions**	Examples of impacts and collisions in the Universe, including the formation of Earth's Moon, the impact that killed the dinosaurs, and galaxy collisions. If this is unavailable, use a variety of the Astrophysics simulations on the AMNH Science Bulletins website, http://www.amnh.org/explore/science-bulletins/(category)/24937. Additional simulations of galaxy collisions are available online.

CLASS OUTLINE - CONTINUED ON NEXT PAGE

Session Eleven: Impacts and the Formation of the Solar System (continued)

TIME	TOPIC	DESCRIPTION
20 minutes	**Late formation**	Discuss why impacts are important, and the connection between temperatures and materials and the formation of the planets and moons. Discuss scenarios that would lead to a variety of stellar systems – including where the giants form, systems that form too fast and are made only of debris, etc. Show data from the Kepler mission and the variety of planetary systems it has discovered Additionally, use simulations (see below) to discuss the formation and possible migration of the gas giants.
10 minutes	**Modern impacts**	Show images and/or video from impacts that have occurred in recorded human history. Include Tunguska and the 2013 Russian meteor. Include Meteor Crater, which is one of the largest visible craters on the Earth. Discuss the rarity of contemporary impacts, and efforts to catalog all Near Earth Asteroids.
10 minutes	**Debate prep**	Inform students that in the next and final class, they will debate a topic of interest. Suggestions: • Which are more cost effective – robotic missions, or missions with humans? • Where should we send the next big mission – Venus or Uranus? (Or choose any two objects of particular interest.) • Should we send people back to the Moon or onward to Mars? • Should we mine asteroids? • Given a large sum of money, should we send out a flagship style mission (like Cassini) or several smaller missions? Choose one topic, assign students to a "side," and hand out readings for homework. Students should find additional readings as well.

MATERIALS:

Computers with internet access, copies of the Impacts! worksheet, simulations of star formation to project, Cosmic Collisions space show, readings on the debate topic.

PREP WORK

Find simulations of star formation (suggested – those of Matthew Bate from the University of Exeter, http://www.astro.ex.ac.uk/people/mbate/) and of migration (suggested - http://planets.utsc.utoronto.ca/~pawel/planets/movies.html). Determine whether you can see the Cosmic Collisions show. If not, clips and other simulations are available on the AMNH Science Bulletin website, http://***********. Decide on a debate topic and prepare readings for each side.

HALLS USED

Hayden Planetarium

A/V NEEDED

Projection of the space show, and of the stellar formation simulations

HOMEWORK

Prepare for debate.

Session Eleven: Impacts and the Formation of the Solar System

ACTIVITY: Impacts!

Students will enter parameters and initial conditions for an object on a collision course with Earth. They should come up with parameters that produce certain scenarios. Most of the scenarios can be accomplished in different ways – encourage students to explore.

At the end, discuss the effects of the impacts that the students simulated, and also the likelihood of such events. Many impacts would melt the Earth and/or create a new asteroid belt with. The site also gives the average time between impacts.

Session Eleven: Impacts and the Formation of the Solar System

HANDOUT: Impacts!

Using the site http://impact.ese.ic.ac.uk/ImpactEffects/, we will be looking at how devastating certain types of impacts are.

When you open the site, you will be asked for some input. Some values and explanations are suggested. (The Distance from Impact seems to not affect much except one small output; I just was using 100km for it...)

YOUR GOALS:

Find and record the parameters of an impact that:

1. Causes a 9.0 earthquake

Diameter ______________________________ Density __________________________

Impact velocity _______________________ Impact angle _____________________

Target type ____

How frequent is this? ____

Notable effects:

2. Happens about 10 times per year

Diameter ______________________________ Density __________________________

Impact velocity _______________________ Impact angle _____________________

Target type ____

How frequent is this? ____

Notable effects:

Session Eleven: Impacts and the Formation of the Solar System

HANDOUT: Impacts! - Page 2

3. Happens once every 1000 years

Diameter ____________________________ Density _________________________

Impact velocity _____________________ Impact angle ____________________

Target type ____

How frequent is this? ____

Notable effects:

4. Makes a noticeable change in the tilt of the Earth's axis

Diameter ____________________________ Density _________________________

Impact velocity _____________________ Impact angle ____________________

Target type ____

How frequent is this? ____

Notable effects:

5. Melts the Earth entirely

Diameter ____________________________ Density _________________________

Impact velocity _____________________ Impact angle ____________________

Target type ____

How frequent is this? ____

Notable effects:

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HANDOUT: Impacts! - Page 3

6. Creates a 10m crater

Diameter ______________________________ Density ___________________________

Impact velocity _______________________ Impact angle ______________________

Target type ____

How frequent is this? ____

Notable effects:

7. Creates a 10km crater

Diameter ______________________________ Density ___________________________

Impact velocity _______________________ Impact angle ______________________

Target type ____

How frequent is this? ____

Notable effects:

8. Hits deep water (3000m), but still creates a 1km crater

Diameter ______________________________ Density ___________________________

Impact velocity _______________________ Impact angle ______________________

Target type ____

How frequent is this? ____

Notable effects:

Session Eleven: Impacts and the Formation of the Solar System

HANDOUT: Impacts! - Page 4

9. Causes a mass extinction. (The impact that killed off the dinosaur was from a 12km asteroid that made a 180 km diameter crater.)

Diameter ____________________________ Density _________________________

Impact velocity ______________________ Impact angle ____________________

Target type ____

How would a dinosaur in NYC (about 2400km away) be affected by this impact?

Other notable effects:

10. You decide! ____

Diameter ____________________________ Density _________________________

Impact velocity ______________________ Impact angle ____________________

Target type ____

How frequent is this? ____

Notable effects:

Session Twelve: Debate Prep

LEARNING OBJECTIVES

Students will prepare for and conduct a debate.

KEY TOPICS

- Varies

CLASS OUTLINE

TIME	TOPIC	DESCRIPTION
30 minutes	**ACTIVITY: Debate prep**	Outline the debate (see below) and allow students to convene and prepare their arguments. Internet access is helpful but not necessary.
45 minutes	**ACTIVITY: Debate**	Students debate the chosen topic. Instructor(s) ask questions and will pick the winner.
45 minutes	**Post Assessment**	Post-assessment testing (should be identical to pre-assessment from the first class).

MATERIALS:

Computers with internet (optional), copies of the post-assessment

PREP WORK

Have two debate “officials” available to moderate.

HALLS USED

None

A/V NEEDED

None

HOMEWORK

None

Session Twelve: Debate Prep

If you haven't already done so, split the class into two groups. Explain the structure of the debate (see below), and allow them to discuss and prepare.

ACTIVITY: Debate

There are many possible ways to set up this debate. One suggestion:

1. Have each side give a short opening statement.
2. Have each moderator ask the opposing team a question. Allow each team time to answer, and to rebut the opposing argument.
3. Allow teams to ask each other one or more questions.
4. Give each team a short closing statement.

A more detailed outline might look like the following:

Time	Section	Notes
10 min	Intro	Split up teams, show them the schedule, determine order
30 min	Prep work	(Teams get iPads and time to talk, look things up
3 min	Opening – Team A	
3 min	Opening – Team B	
3 min	Response to a question from Brian – Team A	
2 min	Rebuttal – Team B	
3 min	Response to a question from Brian – Team B	
2 min	Rebuttal – Team A	
3 min	Response to a question from Adric – Team B	
2 min	Rebuttal – Team A	
3 min	Response to a question from Adric – Team A	
2 min	Rebuttal – Team B	
5 min	BREAK	Teams have a chance to think of questions for each other
3 min	Team A asks Team B a question	
2 min	Team A responds to Team B's answer	
3 min	Team B asks Team A a question	
2 min	Team B responds to Team A's answer	
3 min	Closing – Team A	
3 min	Closing – Team B	