Procedure

CA1 4.11: Factor-label conversions

The introductory activity is included here so that you can show students how to convert from one unit of measurement to another. In and of itself you may choose to construct the dome as designed, and thus no conversions are required. However, for comparing the dome size to the sun, the factor-label method of conversion is perfect. Take the planned size of the dome and set it proportional to the size of the sun. Then your students can calculate the size of the earth on the same scale using the following factor-label setup:

$$\text{scale size of earth (m)} = \frac{\text{size of dome (m)}}{\text{size of sun (m)}}\,\text{size of the earth (m)}$$

The size of the sun and earth in meters can be found in the Appendices.
Factor label conversions can also be used to convert from inches to centimeters and vice versa, and will be a good exercise for students constructing the dome.

The assessment section of this lesson gives several other suggested activities to apply the factor-label conversion method after the dome is constructed.

CA1 4.13: A large Geodesic Dome

This culminating activity takes several days, but will be very exciting for your students and a lot of fun as well. There are basically two problems to solve. A dome must be constructed, and a projector assembled or purchased. If you plan to purchase a projector, there are a number of commercially available star projectors suitable for use in a homemade dome. I recommend the Star Theatre II home planetarium, which is available for $30-40 from a number of online and school suppliers.

This project is documented rather thoroughly online at the web site :
http://www.cccoe.net/stars/. The web site documents the construction process for a large planetarium dome. This particular project was funded by the Contra Costa County Office of Education and the Dean and Margaret Lesher Foundation in Contra Costa County, California.

Buckminster Fuller developed the geodesic dome and showed it had the maximum internal volume in comparison to the amount of material used to construct it of any known design. This is because the volume of a sphere compared to the area of a sphere is a larger ratio than for any other shape. Geodesic domes are used in home construction, stadiums, amusement parks, and even in chemistry with the development of buckminsterfullerene, a geodesic sphere of carbon atoms which continues to find a variety of applications.

CA1 4.13: Lessons in a Planetarium

The Content Background will be dedicated to showing how to use the planetarium and projector once you have constructed it. You may not want to do all these activities at one time, scattering them throughout the course as appropriate after you have constructed your planetarium.

Content Background

This section consists of a step-by-step review of the material listed in CA1 4.13. You can either present these yourself, or assign individual lessons to specific students and have them present the concept within the planetarium.

Observations (No Deep Sky objects included)

- Constellations, Stars and Asterisms
  - Circumpolar (visible all year)
    - Ursa Major (Big Dipper)
    - Ursa Minor (Little Dipper)
    - Polaris
    - Dubhe, Merak, Mizar, Alcor
    - Cassiopeia
  - Fall
    - Cygnus, Lyra, Aquila
    - Pegasus, Hercules
    - Sagittarius, Scorpius
    - Deneb, Vega, Altair, Antares
  - Winter
    - Orion, Gemini, Taurus, Perseus
    - Betelguese, Rigel, Capella, Castor, Pollux, Procyon, Sirius, Aldebaran
  - Spring
    - Leo, Libra, Bootes, Hercules, Corona Borealis, Gemini
    - Regulus, Arcturus, Spica, Denebola

Comment: Learning constellations in a planetarium should be done in short lessons over time, rather than all at once. Remember, it will be dark and your students cannot take notes. It is best to construct a planisphere and have students use it to identify constellations prior to going in the planetarium, so they have seen the shapes you will attempt to draw for them. You can also use Starry Night both to project star maps on the planetarium dome or to practice prior to going in the dome.

CA1 4.13: Lessons in a Planetarium

"Landmarks in the sky"

Summer Triangle – This is the asterism formed by the stars Vega, Deneb, and Altair in the constellations Lyra, Cygnus, and Aquila. Connect the brightest star in each constellation together to see the figure.

Pointer Stars on the Big Dipper –The two stars on the bowl farthest from the handle are the pointer stars. Draw a line from the bottom to the top of the bowl on this size, and extending the line will lead you to the North Star or Polaris.

Arc to Arcturus – Follow the arc of the Big Dipper's handle beyond Ursa Major, heading south. Continue in a curving, arc motion as you do so, following a roughly fixed radius of curvature...sounds complicated, but you basically sweep your arm in a circle to find the next bright star, which is Arcturus.

Spike to Spica- Continue past Arcturus in the same direction and you will "Spike to Spica."

Winter Football – Several bright stars and constellations in the winter sky take the approximate shape of a football. These include Orion, Canis Major (Sirius), and others illustrated in the observing guide.

Planetarium Demonstrations

Coordinate Systems

Zenith and Nadir and meridian –Zenith is a point straight overhead for an individual observer. In a planetarium dome this is the point at the top of the dome. Due to perspective this point may not be directly over the heads of everyone, especially those sitting near the edge of the dome.

Altitude and Azimuth angles – Altitude is measured from the horizon (bottom edge of the dome not counting the support ring) to the zenith. Negative altitude values are below the horizon. 90 degrees is straight up. Most people underestimate altitude angles when measuring without instrumentation.

Right Ascension and Declination-Right Ascension is measured from the point where the ecliptic crosses the celestial equator moving north. If your planetarium projector shows two large intersecting Great Circles (circles which are coplanar with the center of the sphere) then these will be the two lines being projected. The 0h mark for Right Ascension is located where the tilted line crosses the flat line, and has a negative slope. Right Ascension proceeds from this point and increases to the left. 6 hours of RA is 90 degrees to the left of this point, and 12 hours is in the opposite direction where the lines cross again. All of these angles are measured along the celestial equator, even though it is the ecliptic that defines the directions.

The seasons are defined by the sun's position on the ecliptic. when the sun is at the highest point on the ecliptic, at 6 h RA, it will be the first day of summer, or the summer solstice. At 12 h RA, the sun will be in position for the first day of autumn, or the autumnal equinox. A 18 hours RA, the sun is in its lowest position throughout the year and we call this the first day of winter or the winter solstice. At 0 h RA, the sun is in the vernal equinox position and it is the first day of spring.

The angle between the ecliptic and celestial equator is 23.5 degrees, which is the same angle as the often-quoted tilt of the earth's rotation axis compared to its orbit. This is of course caused by the fact that the ecliptic represents the earth's orbit, and it is tilted the same amount because the tilt of the earth's axis also tilts its equator.

A protractor can be held up to the projected lines to show that the angle is in fact 23.5 degrees (in a properly built planetarium projector.)

Declination is like sky latitude. It works identically to altitude or latitude measurements; 90 degrees is the maximum, negative values are in the opposite direction. 0 degrees declination is on the celestial equator. If thousands of people stood on the equator and pointed flashlights straight up, they would be pointing at the earth's celestial equator. 90 degrees declination points to the north star. Large negative declinations such as –80 degrees are not visible from the mid-northern hemisphere.

Ecliptic Coordinates –Ecliptic coordinates are measured along the ecliptic in degrees. They are most useful for finding positions of the planets. The difference between ecliptic coordinates and equatorial coordinates is that ecliptic coordinates are measured along the ecliptic. Heliocentric coordinates are similar, except they use the sun as the center of the coordinate system instead of the earth. Ecliptic coordinates can be roughly translated into zodiac constellation positions. Ecliptic coordinates are usually measured in degrees.

Galactic coordinates – The solar system is tilted with respect to the galaxy. If you can see the Milky Way, the plane of the galaxy is defined by the center of the Milky Way's band across the sky. This introduces a fourth Great Circle used to define positions. Galactic coordinates are usually used on objects far beyond the solar system, when it is necessary to define its position in three dimensional space. It is probably beyond the scope of this course to do more than merely introduce the concept as galactic coordinates are used only in specialized applications of astronomy.

The Effects of Latitude

Position of the North Star -The altitude of the north star is identical to your latitude. If your planetarium projector is adjustable, you can illustrate this by showing the north star projected at zenith (as if you were on the north pole), at an intermediate angle (like where you live) and on the horizon (showing the sky as seen from the equator.)

Motion of stars through the heavens-Stars rise in the east and set in the west, just like the sun and moon. While observing the north star, this means the sky appears to rotate clockwise.

Definition of the arctic circle/polar days and nights –You can demonstrate the effect of sunrise and sunset in polar regions like this: Set the projector with the north star straight up at zenith. Point a laser pointer or small flashlight about 23 degrees above the horizon. As the sky rotates the sun will move around the observer at a nearly constant altitude, never setting all day long. This is what happens on June 21 at the north pole. Each day after this, the sun progresses a little farther along the ecliptic, moving to the left about 1 degree and a bit farther down each day. When the sun reaches the horizon, it will spin around the horizon for a day or two, then set for six months. Six months later it will rise again and slowly crawl back up to its original position. While demonstrating the effect, it will appear as if the sun is moving in a helix (like a slinky). Having a slink handy to illustrate the point would be helpful.

The arctic and Antarctic circles are defined as those places where the sun can stay up for 24 hours at least one day out of the year. If we consider the first day of summer at the north pole, the sun is as high as it ever gets. It will be 23.5 degrees above the horizon. If the observer then walks south, the sun will look lower and lower until it just grazes the horizon-when the observer is at a latitude of 23.5 degrees. Tilt your projector this much, and you can then say anyone who lives inside of this circle of latitude of the earth will have at least one day with 24 hours of sunlight (and one day with no sunlight at all.) This line is the artic circle.

A similar definition works for the Tropics of Cancer and Capricorn, which are also 23.5 degrees above and below the earth's equator. These lines are defined by those places on earth where the sun can appear to be straight overhead at least one day out of the year.

The Annual Motion of the Sun

Definition of the zodiac – The zodiac is the collection of constellations the sun passes through as it moves through the ecliptic. The ecliptic is the plane of the earth's orbit projected into space. Interestingly, using the modern definitions of constellations, the sun passes through a constellation called Ophiuchus, making 13 constellations in the astronomer's zodiac, while astrologers still use 12. Most planetarium projectors can show this by using a fixed constellation and a sun projector (turned down) at the same time. As the simulated days progress, the sun is shown to shift to the left (as viewed in the northern hemisphere facing south.)

Daily vs. annual motion –The sun's daily motion is to rise in the east and set in the west. It's annual motion is to backtrack against this motion, 1 degree per day towards the east from the west. This makes the sun gradually change position with respect to the background stars.

The analemma –The analemma is best shown with a computer simulation set for the same clock time, jumping one solar day at a time, in a fixed direction. The sun will gradually describe a figure 8 shape.

The Shifting Position of the Sun at Sunrise and Sunset – This is a little tricky to set up. You should set the sun to its seasonal positions and show the sun rising on the first day of winter, summer, spring and fall. Most projectors (except homemade ones) will have these positions marked. If you don't have a projector capable of this, you can simulate it with a flashlight which you shine on the dome in three arcs: one from due east to due west, tilted at an intermediate angle (not passing straight overhead), representing spring and autumn. A higher arc starting in the northeast and setting in the northwest represents summer. The sun's position should be somewhat north of east when you begin. A smaller arc starting in the southeast and setting in the southwest represents winter.

If you illustrate just the rising and setting positions, this can be shown by oscillating the sun's position back and forth along the horizon, centered on due east and moving north and south roughly 30 degrees. The exact amount of the oscillation depends on your latitude.

The Moon's Phases –The moon's phases are shown as the sequence new to first quarter, to full, etc. A reasonably sophisticated projector is needed to illustrate this. If a computer projector with Starry Night is available, set it for a fixed view, facing south, 180 degree field of view. Set the time for 6 PM or sunset so the sun is not visible just below the western horizon. Then move in jumps of one day until a crescent moon appears. Using jumps of one day afterwards, you can show a cycle of phases until the moon reaches new; then you can reset the time to sunrise, and the cycle will reverse.

Eclipses

Solar and Lunar – Most planetarium software such as Starry Night will provide built-in simulations of solar eclipses. This can be simulated in the planetarium by having the star projector on with a flashlight to show the sun; turn the sun off (simulating the eclipse) and the stars come out.

Partial and Total-Somewhat trickier to project, you can build a simulator using an overhead projector with a black piece of paper covering the projection surface. A circular hole can then represent the sun in the projection. Take the hole you cut out, slide it across the opening, and you will have a reasonable depiction of a partial eclipse.

Inferior/Superior Planets

Maximum Elongation–Set the projector to sunset. Using a laser pointer, show how the position of Venus starts near the sun, moves away from the sun out to about 45 degrees, and then comes back. If you are simulating the rate of motion, Venus moves fastest when nearest the sun, and very slowly at maximum elongation. Mercury exhibits the same behavior, but doesn't go out as far as Venus.

Inferior/Superior Conjunction-Conjunctions occur when a planet is aligned with something. For inferior planets: inferior conjunction occurs when the planet is between the earth and the sun. Superior conjunction occurs when the planet is on the opposite side of the earth from the sun. For superior planets: Conjunction occurs when the planet is aligned with the sun. Opposition occurs when the planet is in the opposite direction from the sun.

Retrograde Motion of Superior Planets

The Retrograde Loop-This is easily demonstrated with a laser pointer used to make a zigzag or curly-Q as the planet reaches opposition with the sun. The loop takes many weeks or months to occur, and cannot be seen in a single night of observing.

The Phases of Venus –Traditional projectors cannot show the phases of Venus, but you can show the position of Venus when it appears to look like a large crescent (near inferior conjunction); half lit (at maximum elongation) and a small, gibbous or full view (near superior conjunction).

Meteor Showers

Determining a radiant-Meteors can be simulated with special projectors, or with a laser pointer used to draw lines appearing to radiate from a particular constellation (Geminids, for example, appear to radiate from Gemini.) Surprisingly, most planetarium software does not simulate meteor showers (although it could easily if designed to do so.)

Precession-Precession of the equinoxes occurs because the earth wobbles as it spins. Over the course of thousands of years, the earth's axis changes direction. Once upon a time it pointed at the star Thuban in Draco, which might be worth pointing out. This causes the coordinate system of Right Ascension to change over time, which requires astronomers to specify the epoch (date) upon which the coordinates being stated are based.

Assessment

There is a practice page of factor-label conversions following the handout on that topic. This can be used for homework to reinforce the concept.

Following the completion of the dome, you can ask students to generate a number of calculations based on the size and shape of the dome. It will make a dramatic point about the size of the earth compared to the sun, for example, if you hold up a racquetball inside the dome and state that this is the size of the earth compared to the size of the sun. A beach ball would be approximately the size of Jupiter.

Consider the following computations you can ask students to do as an exercise:

Determine the volume and surface area of the dome:

The dome, as designed, is a short cylinder with a hemisphere on top. The volume of the cylinder is $\pi r^2 h$, where r is the radius of the dome and h is the height of the base wall. The volume of the dome is $\frac{1}{2}(\frac{4}{3}\pi r^3)$, where r is the radius of the dome. The formula for the volume of a sphere is multiplied by 1/2 because the dome is only half a sphere.

The area of the dome can be estimated by finding the area of the two types of triangles and multiplying by the number of triangles in the design.

You can even have students derive the value of pi by computing the area in this way, using the triangle area formula Area = $\frac{1}{2}bh$, then comparing the total area for all the triangles added together to $\frac{1}{2}(4\pi r^2)$. Solving for pi will give you a sense about how precisely the geodesic dome shape approximates a sphere.

A dome built with a higher frequency will approximate the volume and area of a sphere more precisely.