Learning Technologies, Inc.

www.starlab.com

Digital STARLAB

Teacher's Manual

©2007 by Learning Technologies, Inc., 40 Cameron Avenue, Somerville, MA 02144. www.starlab.com. All rights reserved.

Table of Contents

About the Digital STARLAB System 5
About the Starry Night™ Small Dome Software 6
Using This Guide 7
Lesson 1 — Night and Day 8
NSES Connections & Background 8
Pre-Visit Activities 8
Daytime/Nighttime Images 8
Ring Around The Students 9
The Digital Lesson: Night and Day 10
1. Introduction 10
2. Daytime 10
3. Horizon 11
4. Reason for Day and Night 12
5. Earth and Sun 13
Starry Night High School Link 13
Extending the Lesson 13
Day/Night Model 13
Shadow Sticks and Sundials 13
Sunspotter Solar Telescope 14
Lesson 2 — Moon Phases 15
NSES Connections & Background 15
Pre-Visit Activities 16
Moon Phase Flip Book 16
Moon Phases and Cultural Events 16
The Digital Lesson: Going Through a Phase 17
1. Introduction 17
2. Moon Appearance 17
3. New Moon 18
4. Waxing Moon 19
5. First Quarter Moon 19
6. Waxing Gibbous Moon 20
7. Full Moon 20
8. Waning Moon 21
9. Phase Cycles 21
10. Phase Cycles from Space 22
11. Predictions 22
Starry Night High School Link 23
Extending the Lesson 23
Moon Phase Model 23
Moon Calendar 24
Lesson 3 — Finding Your Way Around the Sky 25
NSES Connections & Background 25
Pre-Visit Activities 26
Dot Puzzles 26
Longitude and Latitude 26
Angular Measurement 26
Using an Astrolabe 26
The Digital Lesson: Finding Your Way Around the Sky 27
1. Introduction 27
2. Forming Star Patterns 28
3. Asterisms 28
4. Unchanging Star Patterns 29
5. Circumpolar Stars 29
6. Polaris 30
7. Stars from the North Pole 31
8. Changing Latitude — Northern Hemisphere 31
9. The Equator 32
10. Changing Latitude — Southern Hemisphere 32
11. The South Pole 33
12. Star Hopping 34
13. Reasons for Navigating with Stars 35
Starry Night High School Link 35
Extending the Lesson 35
Making a Dipper Finder 35
Using Star Maps 37
Lesson 4 — Constellations and Star Lore 38
NSES Connections & Background 38
Pre-Visit Activity 39
Constellation Creations 39
The Digital Lesson: Constellations and Star Lore 40
1. Introduction 40
2. Sky Pictures 40
3. Connecting the Dots 41
4. The Greek Sky 41
5. Aries the Ram 42
6. Orion the Hunter 42
7. The Myth of Orion 43
8. Scorpius the Scorpion 43
9. Sagittarius the Centaur 44
10. Draco the Dragon 44

11. Northern Circumpolar Constellations 45
Starry Night High School Link 45
Extending the Lesson 45
Constellations Around the World 45
Myths and Morality 45
Modern Day Myths 46
Lesson 5 — Seasonal Change 47
NSES Connections & Background 47
Pre-Visit Activities 47
My Favorite Season 47
Sun Angle and Radiation 48
Tracking Hours of Daylight 48
The Digital Lesson: A Change of Season 49
1. Introduction 49
2. Earth's Orbit 49
3. Predicting Sunrise and Sunset in Winter 50
4. Understanding Horizon, Zenith and Meridian 50
5. Predicting Sunrise and Sunset in Summer 51
6. Sun's Path Comparisons 52
7. Earth's Axis 53
8. Axis and Sunlight 53
9. Sun Position in Autumn 53
10. The Sun at Noon 54
11. Analemma 55
Starry Night High School Link 55
Change of Seasons Data Chart for Use in the Planetarium 56
Extending the Lesson 57
Sunshine Model 57
The Analemma 57
Lesson 6 — Solar and Lunar Eclipses 58
NSES Connections & Background 58
Pre-Visit Activity 59
Umbral and Penumbral Shadows 59
The Digital Lesson: Solar and Lunar Eclipses 60
1. Introduction 60
2. Solar Eclipse 60
3. Solar Eclipse Totality 61
4. Partial Eclipse 61
5. Demonstrating a Partial Eclipse from Space 62
6. Lunar Eclipse 63
7. Lunar Eclipse Totality 64
8. A Solar vs. Lunar Eclipse 64
Starry Night High School Link 65
Extending the Lesson 65
Eclipse Models 65
Web Search for Future Eclipses 65
Eclipses of the Past 65
Eclipse Photos 65
Lesson 7 — Overview of the Solar System 66
NSES Connections & Background 66
Pre-Visit Activity 67
Road Map of the Solar System 67
The Digital Lesson: An Overview of the Solar System 68
1. Introduction 68
2. Our Solar System 68
3. The Sun 69
4. Planetary Motion 69
5. Planetary Orbit 69
6. Asteroids 70
7. Planetary Orbits from Space 70
8. The Ecliptic and Kuiper Belt 71
9. The Planet Mercury 71
10. The Planet Venus 71
11. The Planet Mars 72
12. The Planet Jupiter 72
13. Moons of Jupiter 73
14. The Planet Saturn 73
15. The Planet Uranus 74
16. The Planet Neptune 74
17. Pluto 74
Starry Night High School Link 75
Extending the Lesson 75
Planetary Travel Brochures 75
How Did the Planets Get Their Names? 75
The Great Planet Debate 75
Lesson 8 — The Motion of the Planets 77
NSES Connections & Background 77
Pre-Visit Activity 78
Observing Planets 78
The Digital Lesson: Moving Out — The Motion of the Planets 79
1. Introduction 79
2. Wanderers 79
3. The Power of Prediction/Geocentric Earth 80
4. Retrograde Motion 81
5. Demonstrating Retrograde Motion 81
6. The Heliocentric Model 81
7. Planetary Speed 82
8. Elliptical Orbit 82
Starry Night High School Link 83
Extending the Lesson 83

Retrograde Motion Model 83
Research Kepler, Copernicus, and Galileo 83
Lesson 9 — Meteors, Asteroids and Comets 84
NSES Connections & Background 84
Pre-Visit Activity 85
Moon Maps 85
Craters on Earth 85
Asteroids and Comets 85
The Digital Lesson: Meteors, Asteroids and Comets 86
1. Introduction 86
2. Defining Meteors, Asteroids and Comets 86
3. Finding An Asteroid 87
4. Asteroid Belt 87
5. Toutatis 88
6. Comets 88
7. Comet Hale-Bopp 88
8. Halley's Comet 89
9. The Orbit of Comets 89
10. Meteor Showers 90
Starry Night High School Link 91
Extending the Lesson 91
Dates of Meteor Showers 91
Make a Model Comet 91
Lesson 10 — Seasonal Constellations 92
NSES Connections & Background 92
Pre-Visit Activity 93
Rotation vs. Revolution 93
Astronomy vs. Astrology 93
The Digital Lesson: A Calendar in the Stars — Seasonal Constellations 94
1. Introduction 94
2. Ancient Constellations 94
3. Constellations in Motion 94
4. Orion 95
5. As the Earth Turns 96
6. Seasonal Constellations 96
7. Winter 96
8. Spring 97
9. Summer 97
10. Circumpolar Constellations 98
11. The Zodiac 98
12. Sun Sign 98
13. Conclusion 99
Starry Night High School Link 99
Extending the Lesson 99
Zodiac Model 99
Origins of the Zodiac 100
Star Shift 100
Lesson 11 — Properties and Life Cycles of Stars 101
NSES Connections & Background 101
Pre-Visit Activity 102
Using the H-R Diagram 102
The Digital Lesson: Star Light, Star Bright — Properties and Life Cycles of Stars 103
1. Introduction 103
2. Star Descriptions 103
3. Star Brightness 104
4. Apparent Magnitude 104
5. Absolute Magnitude 105
6. Star Size 105
7. Star Color 106
8. Nebula 106
9. Star Life Cycle 107
10. Supernova 107
11. The Sun 108
12. The Future 108
Starry Night High School Link 109
Extending the Lesson 109
Making a Magnitude Scale 109
Researching Star Types 110
The Life of our Sun — Using the H-R Diagram 110
Lesson 12 — The Milky Way Galaxy 111
NSES Connections & Background 111
Pre-Visit Activity 112
Understanding Light Years 112
Modeling the Expanding Universe 112
The Digital Lesson: The Milky Way Galaxy 113
1. Introduction 113
2. The Milky Way in Winter 113
3. Light Pollution 114
4. The Milky Way in Summer 114
5. Constellations 114
6. Measuring Distance 115
7. Shape of the Milky Way 115
8. The Andromeda Galaxy 116
Starry Night High School Link 117
Extending the Lesson 117
Observing the Milky Way 117
Hubble Classification of Galaxies 117
Modeling the Milky Way 117

About the Digital STARLAB System

The Digital STARLAB system features a compact, manually-operated, user-friendly planetarium projector designed to produce the highest quality starfield images of any projection system in its price range for portable and small fixed domes. The projector features a custom fisheye lens (patent pending) capable of depicting an accurate, high-contrast, simulated night sky with the capacity to explore a multitude of motions and displays eliminating the need for additional slide projectors, video projectors, sound systems or computers. Covering a full 180° on the dome, the small bright stars remain spherical right down to the horizon. There are no cutouts or blind spots along the horizon. The projector is compact and lightweight and is, therefore, easily transported and/or stored.

Using a laptop interface, powered by a customized version of the renowned Starry Night™ software from Imaginova called Starry Night Small Dome™, users can choose from the 12 pre-scripted, national standards-based lessons described in this guide as well as two additional curriculum modules that are included with the system.

The first additional module is based on *Astronomy of the Americas* from Volume 11 of the *Planetarium Activities for Student Success* series. It explores five Native American cultures and their knowledge and beliefs about solar and lunar astronomy. The second module, *Giant Leaps*, is based on *The Powers of 10* — a valuable tool for teaching and understanding the universe through the concept of scale — useful for studying earth science, math and more. Additional lessons and modules based on Learning Technologies' existing archives of teacher-created lessons will be available on an ongoing basis.

In keeping with the philosophy of existing products from Learning Technologies, the Digital STARLAB system encourages interactivity and hands-on, minds-on learning through its curriculum, activities and programs.

About the Starry Night™ Small Dome Software

The Digital STARLAB projector is specifically configured to run the Starry Night Small Dome™ software produced by Imaginova Ltd. This software is a specially adapted version of the premier desktop astronomy package on the market today featuring the complete 3D Hipparcos, Tycho 2 and database of 16 million stars. In addition, the program features thousands of famous deep space objects with detailed descriptions from Messier and Caldwell catalogs, Herschel catalog of 400 deep sky objects, and corrected NGC/IC catalogs with over 13,000 deep sky objects.

Starry Night Small Dome™ comes pre-loaded with the twelve lessons found in this guide plus two additional curriculum modules. In addition to running the pre-scripted lessons, you can also run the software manually programming it yourself to customize the view to see the sky how it will appear from any point on the Earth for any date and time from 10,000 BC to 100,000 AD. You can also magnify images of planets, moons, comets and a whole host of deep space objects so you can see how they would appear through a telescope and you can even leave Earth and view our solar system from the Sun, another planet or even outside our Milky Way galaxy. The Starry Night Small Dome™ software even allows you to get on-line updates so that the database on the Digital STARLAB projector is always current. Complete instructions on running and customizing the images using the built in features of Starry Night can be found in the off-line user's guide which can be accessed by clicking on the word 'Help' at the top of the Starry Night window. Instructions on how to begin to run the Starry Night software on the Digital STARLAB Projector can be found in the User's Guide that comes with the projector.

Using This Guide

This guide is designed to be a companion to the 12 lessons that come pre-loaded on the Digital STARLAB Projector. Each lesson has a detailed narrative written in italics that is displayed on the computer screen next to the render box screen that shows the view on the dome. Rather than read the narrative verbatim, it is suggested that you review the 'script' before conducting the lesson and then present the material in your own words. Suggested questions for students along with some typical answers are also included in the narrative. **Specific directions for the instructor are written in bold face type.** These instructions will tell you when to start, stop and/or re-set the program using the Starry Night navigation bar.

In addition to the program narrative, each of the 12 modules contains background information on the topic as well as pre-visit and follow-up activities that can be conducted with students outside the planetarium dome. As an additional follow-up, we have provided you with the lesson reference which links to the Starry Night™ High School curriculum (available from Learning Technologies, Inc.) should you or your students have access to it. Finally, all of the lessons have been correlated to the US National Science Education Standards.

Lesson 1 — Night and Day

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- The Sun provides the light and heat necessary to maintain the temperature of the Earth.
- Objects in the sky have patterns of movement. The Sun appears to move across the sky in the same way every day, but its path changes slowly over the seasons.
- Most objects in the solar system are in regular and predictable motion. Those motions explain day and night.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

From an early age, students are taught that the phenomenon of day and night is caused by our Earth rotating in space while the Sun stays motionless in the sky. In most cases, they simply accept this 'fact' without questioning its validity, yet when they are asked to present evidence to support it, they are hard pressed to do so. The truth is, based on observational evidence alone, the idea that we are living on a spinning Earth can be difficult to defend. Each morning, the Sun appears to rise, move across the sky and set. At night, the stars do the same. In both cases, because our planet is so massive, we cannot feel the Earth moving which often has led people to falsely believe that we are sitting still and everything is moving around us. The fact that this was the accepted model for thousands of years bears out just how strong the observational evidence is.

In this lesson, students are presented with the observational evidence as it appears from the surface of the Earth and they are asked to present their own ideas about what causes day and night. They visually see the Sun rise, move across the sky and set. With the help of the Digital STARLAB projector, they are transported out into space to see an expanded view of the Earth/Sun system. From this perspective, they can see the rotating Earth and how the Sun only lights one half of the planet at a time.

Pre-Visit Activities

Daytime/Nighttime Images

For younger students, a simple way of introducing the concept of day and night is to build on what they already know. On the chalkboard, make two columns, one titled 'Day' and the other 'Night'. Starting with the 'day' side, ask students to describe some of the things that happen — in particular, what they do — during the day. Then move to the night side and repeat. Ask them to explain what the main difference between day and night is and what they think is causing it. Finally, give them a blank

piece of paper with one side labeled 'day' and the other 'night'. Ask them to draw what the sky looks like during the day and then do the same for night. After they have finished their drawings, discuss the pictures and then explain that they are going to a special place called a planetarium where they will discover more about why we have day and night.

Ring Around The Students

For older students, a good way of introducing the idea of relative motion in the sky is to play a game so they can see how day and night can be simulated in two different ways. To conduct the activity you need a large open space such as the school yard, the gym or even the classroom with the desks moved out of the way. Give each student a large blank index card and have them write the word 'DAY' on one side and 'NIGHT' on the other. Tell them that they are going to make a model of how the Sun and Earth move. Their job is to be planet Earth. Ask a student volunteer to come forward and be the Sun. Give the volunteer a large ball (basketball, soccer ball) to represent the disc of the Sun. Have the class stand up and spread out so that they are all facing in the same direction. Have the student with the ball stand directly in front of the class. Tell the class that as long as they can see the ball, it is daytime. When this happens they should hold their cards with the word DAY facing forward. When they no longer can see the ball, they should flip the card over to the side that says NIGHT.

Begin by having the students in the class stand still and ask the 'Sun' to slowly walk around the class in a big circle. Remind the class not to move their bodies. Repeat the procedure two more times and then have 'the Sun' return to the place where he or she started. Now ask the student representing the Sun to stand still and ask the rest of the class to slowly spin in place reminding them to switch their cards from day to night when they lose sight of the Sun. Have the class complete three full rotations.

Explain that during both activities, the Earth went through three day/night cycles. During the first part of the activity, the Sun moved and during the second part, the Earth moved. In both cases, the results were the same. Ask the students to explain which motion best explains why we have day and night on Earth. After a brief discussion, explain that they are going to take a trip to a planetarium where they will discover what's really happening in the sky to produce day and night.

The Digital Lesson: Night and Day

The *Night and Day* lesson is designed to introduce students to the concept of Earth rotation by having them relate observed changes in day and night from here on Earth with a view of Earth rotating in space. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is in use. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning / afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. In fact, during today's lesson, we're going to take a look at what causes day and night here on Earth.

The planetarium is like a time machine. We can set it to show you the sky for any date and time here on Earth.

Take a look at the sky around you. Right now, is it showing you daytime or night? How do you know?

[Students should recognize that it is daytime since the sky is bright and the Sun is visible in the sky.]

Everyone point to the Sun in the sky. The Sun is very special for us here on Earth.

What do we get from the Sun?

[Earth gets most of its light and heat from the Sun.]

2. Daytime

If we didn't have the Sun, our Earth would be a very cold dark place! Now let's speed up time a little and see what happens.

> **Action**
>
> *Press the* ▶ *button. Press the* ■ *button when the Sun gets near the horizon and the clock shows about 7:30 PM.*

What happened to the Sun?

[The Sun moved across the sky and got close to the ground.]

If we speed up time again, what do you think will happen?

[The Sun will go down below the Earth and the sky will get dark.]

Action

Press the button again and watch what happens. Stop again when the clock says about 11:00 PM.

Look at the sky now. Is it daytime or night? How do you know?

[The Sun is gone, the sky is dark and the stars are out.]

If we speed up time again, you'll see the stars appear to move across the sky.

How will you know that it is daytime again?

[The sky will begin to get bright, the stars will slowly fade away and eventually you'll see the Sun rise up again.]

Let's speed up time again and see what happens. Everyone say 'stop' when you see the Sun in the sky again.

Action

Press the button again and stop when the students say to. The clock should read about 4:00 AM.

Here we are back in the daytime. The Sun is just starting to rise and the sky is bright. Take a look at where the Sun is rising in the sky.

Is it in the same place where it set the night before?

[The Sun is actually rising in the opposite side of the sky compared to where it set.]

3. Horizon

The place where the sky and ground meet is called the ***horizon****. If you look carefully, you'll see that along the horizon there are little letters like E, W, S and N.*

Does anyone have an idea what these letters stand for?

[The letters represent directions. E is East, S is South, N is North and W is West.]

Each of these letters or combination of letters represents a different direction along the horizon. Let's try a little game. Everyone point north. Now point south. Now point northeast. Northeast is half way between North and East. You can tell which direction it is because the horizon is marked NE.

What letters would tell you where northwest is? Everyone point that way.

[Northwest would be NW.]

Okay, so let's go back to our Sun. In which direction is the Sun rising?

[It rises in between northeast and east.]

Let's speed up time again and watch the Sun.

Action

Press the button again and stop it when the clock is about 12:00 PM.

Now it's about 12:00 noon. In which direction is the Sun?

[South.]

If we continue to speed up time, can anyone guess what direction the Sun will set in? Everyone point which way you think the Sun will set.

[The Sun will set in between the northwest and the west.]

Okay, let's see how many people got it correct. Here we go again.

Action

Press the button again and stop when the Sun gets close to the horizon again, when the clock is about 7:30 PM.

We just followed the Sun for one complete day. A full day takes 24 hours and includes both the daytime and the nighttime. People figured this out a long time ago, but one thing was very confusing. As you watch the Sun, it looks like the Sun is moving across the sky. This is what people used to believe. They thought the Earth was in the center and the Sun, stars and Moon all went around us. These days, scientists have another idea of what's going on. The reason that the Sun appears to move across the sky is because our Earth is spinning, just like a top. Since we're riding on the Earth, we see the stars and Sun move but it's really we who are moving!

4. Reason for Day and Night

Back in 1543, a famous scientist named Nicholas Copernicus came up with the idea that the Earth moved, but many people did not believe it because they did not feel the Earth move. Today, we know that we can't feel the Earth spinning because it's so big. Let's see how the Earth's motion controls day and night.

Action

Click on the word 'Show' to change the setting to see the Earth in Space.

Here we are, about 11,000 kilometers out in space looking back at the Earth. Does the Earth look the same on both sides?

[No, half the Earth is lit and the other half is dark.]

Why do you think that one side of the Earth is bright?

[The Sun is shining on half of the Earth. It is bright where the sunlight hits.]

Half of the Earth is being lit by the Sun's light. On that part of the Earth it's daytime. For the half of the Earth that is in darkness, it's night. Everyone point in the direction of the Sun.

Now watch what happens when we move forward in time.

Action

Press the button. This will cause the Earth to rotate in space.

Can anyone tell me what's happening to the Earth now?

[It's spinning.]

The motion that you are seeing is called rotation. Even though we don't feel it, our Earth makes one complete rotation every 24 hours. 24 hours is one full day. Watch the continents as the Earth spins.

Can you see when they are in day and night?

[Yes.]

Based on the way the Earth is lit, point to where you think the Sun is in space. Let's see if you are correct.

5. Earth and Sun

Okay, now let's move a little farther out into space.

Action

Click on the words 'Click here' to zoom out farther into space.

Now we're way out in space — over 200,000,000 kilometers from Earth.

Here you can see where the Sun is. Were you pointing in the right direction? Based on what we saw today, can anyone explain why we have day and night on Earth?

[Day and night happen because the Sun shines on only half of the Earth at a time. The side that is lit is daytime and the side that is dark is night. As the Earth rotates, different places move into the lit or dark areas.]

Have students recap their observations and present their ideas. The main concepts that they should be able to relate are: 1) Day and night happen because the Sun shines on only half of the Earth at a time. 2) The side that is lit is daytime and the side that is dark is night. 3) As the Earth rotates, different places move into the lit and dark areas.

Starry Night High School Link

Students who have access to the Starry Night™ High School computer program should refer to Lesson A1 — Day and Night Cycle.

Extending the Lesson

Day/Night Model

Students can demonstrate how the day/night cycle works here on Earth by constructing a simple model using a bright light source (a flashlight, overhead projector or a desk lamp with the shade removed) to represent the Sun and a globe to represent the Earth. If you do not have a globe, a large ball with drawings of the continents taped to it will work. Make the room as dark as possible (or you can do this in the planetarium with the lights turned out). Hold the globe in front of the light so that one side is illuminated and the other is dark. Explain that the line that separates night and day is called 'the terminator'. Ask students to describe what continents are experiencing day and which are experiencing night. Then ask, based on what they discovered in the planetarium, what would have to happen to the Earth to change the position of day and night. [The Earth would have to rotate.] Slowly spin the globe so that the terminator sweeps over a new set of continents.

Shadow Sticks and Sundials

A good way for students to track the apparent motion of the Sun is to set up a shadow stick in the school yard. Select a location that is out in the open away from any buildings or trees that might block the Sun. Any straight stick about a meter long will work. If you have grass in the yard, the stick can be pushed into the ground. If the surface is cement or blacktop, you can support the stick by placing one end in a large lump of clay. You will need a second stick to mark the position of the shadow

and a timing device (watch or clock). Once you have the shadow stick set up lay the second stick down on the ground directly on top of the shadow. Wait 10 minutes and have the students come back and look at how the position of the shadow changed. Have them record their observations and then ask them to predict where they think the shadow will be if they wait another 10 minutes. Return to the spot to see how accurate their predictions are. Repeat the procedure several more times until they see that there is a definite relationship between the position of the shadow and the elapsed time. Explain that in the days before mechanical or electric clocks, people used the apparent motion of the Sun to tell time. To further extend the activity, you can have them research and build their own sundials. Please note that this activity will only work on a bright sunny day when there are few, if any, clouds.

Sunspotter Solar Telescope

While most telescopes are used during hours of darkness, a Sunspotter is designed for use during the day. As the name suggests, the Sunspotter is specifically constructed for observing the Sun giving students the opportunity to take a close up look at our local star. In addition to allowing you to see features on the surface of the Sun, the Sunspotter is also useful in showing students just how fast the Earth is rotating. After centering the Sun in the field of view, students will observe it slowly move off the viewing platform due to Earth's rotation. By timing how long it takes to move from the center of the field to the edge, students can get a sense of just how fast the Earth is spinning. (Sunspotters can be purchased through many different science supply companies or they can be ordered directly from Learning Technologies at 800-537-8703 or by logging onto www.starlab.com.)

Lesson 2 — Moon Phases

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements. The Moon moves across the sky on a daily basis much like the Sun. The observable shape of the Moon changes from day to day in a cycle that lasts about a month.
- Most objects in the solar system are in regular and predictable motion. Those motions explain phases of the Moon.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

One of the most common astronomical misconceptions pertains to why the Moon goes through phases. People often attribute this phenomenon to shadows or clouds covering the Moon, but the truth is that it all comes down to simple geometry. Unlike the Sun and stars which produce their own light (they are luminous bodies), the Moon gets all of its light from the Sun (it is an illuminated body). Half of the Moon is always being lit by the Sun (just like half the Earth is always being lit by the Sun) but because the Moon orbits the Earth, we don't always see the entire lit side of the Moon. Sometimes, the lit side is turned away from us.

It takes the Moon $27^1/_3$ days to complete one orbit and as it does, the angle that the Sun, Earth and Moon make with each other is constantly changing. The phase cycle starts with 'new moon' which happens when the Sun, Earth and Moon are in a straight line with the Moon on the same side of the Earth as the Sun. As a result, the entire lit side of the Moon is turned away from the Earth and no moon is visible in the sky. A few days after new moon, the Moon has moved far enough along in its orbit so that a tiny sliver of the lit side is now visible from Earth. This is called the 'waxing crescent'. The term 'waxing' is used to indicate that the Moon appears to be getting larger. Seven days after the new moon, the Moon has now moved about one quarter of the way around the Earth in its orbit. The Sun, Moon and Earth now make a right angle and from Earth it looks like half the Moon is visible in the sky. This phase is called 'first quarter'. 'Waxing gibbous' happens just after first quarter and it's the phase where the Moon looks like an oval. Finally, fourteen days into the phase cycle the Moon has moved about half-way around the Earth in its orbit and it rises opposite the Sun in the sky. From Earth we can see the entire lit side of the Moon. This is 'full moon'. As the Moon continues in its orbit, we see less and less of the lit side. The phases now reverse themselves as the Moon goes through the 'waning' part of the cycle. There is waning gibbous, last quarter, waning crescent and finally new moon when the cycle begins again.

Pre-Visit Activities

Moon Phase Flip Book

Most students realize that the Moon doesn't always appear to be the same shape in the sky even if they don't know why lunar phases happen. A good way to introduce the idea of phases is for them to make there own flip book showing one complete phase cycle. Each student will need nine blank index cards (3x5 works best), a pencil and a quarter. Before you begin the activity, discuss the fact that the Moon appears to change its shape on a regular basis. Ask student volunteers to come forward and draw pictures showing some of the different ways the Moon can appear on the chalkboard. Make sure that they include a crescent, quarter and gibbous phase along with a full moon. At this point, you may also want to introduce the names of the different phases and the terms 'waxing' and 'waning'.

Pass out the materials and have them begin by numbering the cards 1–9. Tell them to trace the quarter on each card so that they have nine identical circles. Make sure that they draw each circle at the same location on each card. On card number 1, they should simply leave the circle blank. This is new moon. On card number 2, they should fill in the right side of the circle so that it looks like the crescent moon. On card number 3 they should shade in the right half of the circle so they have the quarter moon. On card number 4 they should draw the waxing gibbous moon by shading in about 3/4 of the circle leaving only the left side of the circle blank. On card 5, they should shade in the entire circle. This is full moon. On cards 6, 7 and 8 they should follow the same procedure as with cards 4,3 and 2 only in reverse so that 6 is the waning gibbous, 7 is the last quarter moon and 8 is the waning crescent. Remind them that on these last three cards, the left side of the cards should be shaded in and the right side should be blank. Card 9 should look like card 1 since it is the new moon. Have them assemble the cards in a stack with 1 on the top and 9 on the bottom and hold tightly to one end of the stack. By flipping through the cards, they will be able to view one complete phase cycle. Please note that in this activity, the lit part of the Moon is the part that is shaded in!

After completing the activity, explain that they will be going to a special place called a planetarium where they will not only see the Moon go through its phases, but discover why these changes happen in the first place.

Moon Phases and Cultural Events

Many people don't realize it but there is an important connection between moon phases and the timing of different religious and cultural events. Rosh Hashanah, the Jewish New Year, starts on the first new moon following the autumnal equinox. Easter Sunday is the first Sunday following the first full moon after the vernal equinox and Ramadan begins with the sighting of first crescent moon following the first new moon after the autumnal equinox. A good way to introduce the idea of moon phases is to discuss how the lunar cycle is used as a time keeper (the word 'month' comes from moon) and how it impacts on our everyday life.

The Digital Lesson: Going Through a Phase

The *Going Through a Phase* lesson is designed to introduce students to the concept of Moon phases and cyclic change. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning / afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at Earth's nearest neighbor in space . . . the Moon.

Here we are looking at a typical nighttime sky.

Can anyone find the Moon? Everyone point to it.

> **Give students a moment to locate the Moon and have them all point to it.**

The Moon is easy to find because there's nothing else that looks like it in the sky. Take a look at the Moon in the sky. I've made it a little larger here then it really is so we can see it better. Here it looks like we can see only half the Moon. The white stripe across the sky that is next to the Moon is called the Milky Way.

Does the Moon always look this way? Let's take a look and see.

2. Moon Appearance

Everyone hold onto your seats — we're going for a little ride. If the motion bothers you, just close your eyes.

> **Action**
>
> *Click on the button and stop when the date gets to Oct 17, 2005 at about 8:00 PM.*
>
> **As time passes ask the following:**

Each day that goes by, you'll see that the Moon moves a little farther away from the Milky Way. What else is happening to it?

[The Moon appears to be getting bigger.]

Okay, now I'm going to stop time. It's now a week later than when we first looked at the Moon.

How does the Moon look now?

[The Moon looks like a complete circle.]

Does anyone know what we call this type of Moon?

[A full Moon.]

Now let's move forward in time again. Can anyone predict what will happen to the Moon?

[The Moon will appear to get smaller.]

Action

Click on the button and stop when the date gets to Oct 23, 2005 at about 4:00 AM.

As time passes ask the following:

Each night that goes by, the Moon moves a little farther to the east in the sky.

What else is happening to it?

[The Moon appears to be getting smaller again.]

Okay, now I'm going to stop time again. It's now a week later than when we last looked at the Moon.

How does the Moon look now?

[The Moon looks like half of a Moon again but this time the opposite side of the Moon is lit.]

When the Moon changes shapes like this, scientists say that it's going through ***phases.*** *Each month, the Moon goes through a complete set of phases. Let's take a closer look at these phases and what makes them happen.*

3. New Moon

Here we are looking at the Moon in space. Right now, time is moving really fast. As time moves on, you will see that the Moon keeps changing its phase. Over the course of one month, the Moon will go through one full cycle of phases. A cycle means that it will return to the place it started. The Moon goes through this phase cycle because the Moon ***orbits*** *or goes around the Earth. Let's take a look at each of the Moon's phases and see what causes them.*

Allow the Moon to go through one full month of phases before moving on.

Action

Click on the words 'Click here' to set the sky for March 30, 2006 at about 21:00 hours.

Here we are looking at the ***new moon*** *phase. New moon is when you really can't see the Moon in the sky. Each new phase cycle starts with a new moon.*

How does the Moon appear in the new moon phase?

[The Moon looks completely dark.]

The reason the new moon looks dark has to do with where the Moon gets its light. The Moon gets its light the same way that the Earth does.

What lights up the Earth?

[Earth is lit by the Sun.]

What lights up the Moon?

[The Moon also gets its light from the Sun.]

If you look next to the Moon in the distance, you can see the Sun. It looks like a big bright star because it is! When the sunlight hits the Moon, half of the Moon gets lit. Just like when the Sun shines on Earth, half of the Earth is lit. The part that is lit is daytime and the part that is dark is night.

Based on what I just said, can anyone explain why the new moon looks dark?

[The new moon looks dark because we are looking at the side that is not being lit by the Sun. In other words, the lit side of the Moon is pointing away from the Earth.]

Let's move a little forward in time and see what happens.

4. Waxing Moon

Action

Click on the button to advance the date to April 2, 2006 at about 21:00 hours.

Here we are about 2 days later. You can see that the Moon has moved so that now the Sun is not behind it anymore, but off to the side.

How does the face of the Moon appear now?

[A small sliver of the right side of the Moon is now lit.]

*Scientists call this phase the **waxing crescent moon**. The crescent part is easy to understand because it looks like a crescent shape. The waxing part means that the Moon appears to be getting bigger.*

Based on what we said before, can anyone explain why we now see the crescent Moon?

[The Moon has moved in orbit around the Earth so that now we can see a small part of the lit side of the Moon.]

Okay, so what do you think will happen if we keep moving forward in time?

[The lit part of the Moon should get bigger.]

Here we go . . .

Action

Click on the button to advance the date to April 6, 2006 at about 21:00 hours.

5. First Quarter Moon

Here we are four days later at what scientists call first quarter moon.

How does the Moon look now?

[It looks like half the Moon is lit and the other half is dark.]

The name first quarter is a little confusing because it looks like we're really seeing half the Moon. The truth is, we're seeing only half of the half of the Moon that is lit. The reason it's called a quarter Moon is because the Moon is now ¼ of its way around the Earth in its orbit. Another name for first quarter would be ***waxing quarter.***

6. Waxing Gibbous Moon

Okay, shall we continue in our journey? The new phase we'll encounter is called ***waxing gibbous moon.***

Can anyone guess what the Moon will look like in this phase?

[The side that is lit should get bigger still so it will look ¾ full.]

Let's move forward in time three more days and see what happens.

Action

Click on the button to advance the date to April 8, 2006 at about 21:00 hours.

Here we are at waxing gibbous. In this phase, we're seeing almost the entire lit side of the Moon. Only a tiny little sliver is still dark.

If we continue in time a few more days, what phase do you think we will we reach?

[Full moon.]

Let's try it and see.

7. Full Moon

Action

Click on the button to advance the date to April 13, 2006 at about 21:00 hours.

Here's the ***full moon.*** *Now we're seeing the entire lit side of the Moon.*

In order for this to be happening, where does the Sun have to be in the sky?

[The Sun is behind us.]

During the full moon phase, the Sun and Moon are directly opposite from each other in the sky with the Earth in between.

Why don't we see any of the dark side of the Moon during a full moon?

[The side of the Moon that is in darkness is facing away from the Earth.]

We have now completed one half of the Moon's phase cycle.

Can anyone guess what will start happening to the Moon once we get past full moon?

[The lit side of the Moon will get smaller again.]

Let's give it a try and find out if you're correct!

8. Waning Moon

Action

Click on the button to advance the date to April 17, 2006 at about 21:00 hours.

Okay, can anyone tell me what we call this phase when the Moon appears ¾ full?

[Gibbous.]

*This is the **waning gibbous** phase. It looks similar to the waxing gibbous phase but this time, the Moon is getting smaller. That is what the word waning means.*

There is something else that is different about this phase when compared to the waxing gibbous. Can anyone see it?

[During the waxing gibbous, the right side of the Moon is lit. During the waning gibbous, the left side is lit.]

Okay, so if we keep going, the lit part of the Moon should keep getting smaller. This will produce the last two phases.

*During the **last quarter moon** we'll see only half the lit side again then the final phase is the **waning crescent.***

How do you think it will look?

[We should see a thin sliver of the lit side only this time, the lit side will be on the left side of the Moon.]

Let's move forward in time and check it out.

Action

Click on the button to advance the date to April 24, 2006 at about 21:00 hours.

Excellent, here we are at the waning crescent phase. Can anyone tell me what the bright object is to the left?

[The Sun.]

9. Phase Cycles

We have almost completed one full phase cycle. What has to happen to finish it?

[The Moon has to move so that it's directly in front of the Sun again so that we are only seeing the dark side. We have to reach new moon.]

Let's finish it up. I'm going to step time forward again and everyone yell 'stop' when you think the phase cycle ends.

Action

Click on the button to advance the date to April 28, 2006 at about 21:00 hours.

Here we are, back to where we started. Now can anyone tell me how long in real time it takes for the Moon to complete one phase cycle?

[The exact amount of time is 29.5 days or about 1 month.]

Yes, the lunar phase cycle lasts about a month. In fact, can anyone guess what word they took the word 'month' from?

[Moon.]

So now that we've seen what the Moon phases look like from here on Earth, let's move a little farther out into space and see what's happening with the Moon's orbit.

10. Phase Cycles from Space

Action

Click on the button to put the Moon in motion around the Earth.

Here you can see what the Moon looks like as it orbits the Earth. You're seeing what it would look like if you were millions of miles above the Earth looking down. Note that in this image, the Moon has been made much larger than the Earth so you can see the way the sunlight hits it.

As the Moon orbits the Earth, about how much of it is lit by the Sun?

[Half of the Moon is being lit by the Sun at all times.]

Action

Click on the word 'here' to put the Moon back in its starting position.

Here we see the Moon in the new moon phase. Everyone point to the Sun. Let's zoom out to see if you are correct.

Action

Click and hold the button until the Sun appears in the sky.

11. Predictions

During the new moon, which side of the Earth is the Moon on? The same side as the Sun or the opposite side of the Sun?

[The same side as the Sun.]

Since the Moon is in between the Earth and the Sun, which side of the Moon is facing the Earth, the lit side or the dark side?

[During the new moon, the dark side of the Moon is facing the Earth.]

Now let's take a look at full moon.

Action

Click on button and run the Moon forward until date says April 24, 2005 at 6:00 PM.

Compared to new moon, where is the Moon in its orbit during full moon?

[The Moon is now on the opposite side of the Earth.]

During a full moon, which side of the Moon is facing the Earth, the lit side or the dark side?

[During the full moon, the entire lit side of the Moon is facing the Earth.]

Based on what we have just seen, can anyone predict where the Moon would be in its orbit during either of the quarter phases?

[During the quarter phase, the Sun, Moon and Earth make a right angle.]

Lets take a look at last quarter moon.

Action

Click on the button to run the Moon forward until the date says April 30, 2005 at 11:00 PM.

When the Moon is in the last quarter phase, its ¾ of the way around in its orbit. From Earth, we are seeing half of the lit side and half of the dark side. That is why it looks like only half the Moon is there.

If we were to continue on and look at the crescent and gibbous phases, you would see that the two things that create the Moon phases are where the Moon is in its orbit, and how much of its lit side we see.

This wraps up our little Moon phase adventure. Next time you see the Moon up in the sky, see if you can figure out what phase it's in and where the Sun would be.

Have students recap their observations and present their ideas. The main concepts that they should be able to relate are: 1) The Moon goes through a phase cycle that lasts about a month. 2) Half of the Moon is always being lit by the Sun but from our view on Earth, we don't always see the lit side of the Moon. 3) As the Moon orbits the Earth, we see differing amounts of the lit side.

Starry Night High School Link

Students who have access to the Starry Night High School computer program should refer to Lesson A4 — Phases of the Moon.

Extending the Lesson

Moon Phase Model

One of the best follow-up activities to the planetarium experience is for students to create their own three-dimensional model showing how moon phases work. To conduct the activity you will need a dark room along with a point source of light like an overhead projector or a desk lamp with the shade removed. You can also do this activity in the planetarium with the lights turned off. Students can work in teams or individually but each student should try the activity for him/herself. For the model, the light represents the Sun, the student's head represents the Earth and a small white ball (softball, white tennis ball, or Styrofoam ornament ball) represents the Moon.

Students should start by facing the light and holding the ball out in one hand at arm's length so that it is directly in front of their face. (The ball should not be blocking the light however, because it will create a solar eclipse!) In this position, the side of the ball that is being lit by the light is facing away from the student's head. Since their head represents the Earth, in this position, the ball represents a 'new moon'. Now have them slowly rotate their bodies to the left while observing the ball. They should start to see a thin crescent of the lit side of the ball appear followed by half the lit side and finally ¾ of the lit side. Have them stop rotating when their backs are to the light. Now they should be able to see the entire lit side of the ball. (Make sure that they hold the ball up high enough so that it's not in the shadow of their heads. Otherwise they would have a lunar eclipse!) After observing the 'full moon', they should continue rotating so that they can see the waning gibbous, last quarter and waning crescent phases finally returning to the starting position and new moon again.

Moon Calendar

Most people think of the Moon as being a nighttime object but the truth is the Moon is visible during daylight hours just as often as during the night. The only difference is that it's harder to see in the day because the sky is so bright. If you know what phase the Moon is in, you can easily predict when it will be visible in the sky because certain phases are visible only during certain times of the day or night. For example, when the Moon is in the waxing part of the cycle, it is visible in the afternoon before sunset. (First quarter moon rises at noon and sets at midnight.) When it is in the waning part of the cycle, the Moon is visible in the morning after sunrise. (Last quarter moon rises at midnight and sets at noon.) In fact, the only time that the Moon is visible from sunset to sunrise is during the full moon. Students can easily discover this relationship for themselves by charting the Moon for a month, recording when it is visible in the sky and what phase it is in. To get them started, they can look at a local newspaper which usually has the moon phases for the month listed on the weather page.

Lesson 3 — Finding Your Way Around the Sky

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- Most objects in the solar system are in regular and predictable motion.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Science influences society through its knowledge and world view.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

Long before people had GPS systems or even compasses, they were able to navigate around the Earth by using the position of the stars in the sky. If you go out and look at the sky night after night, you'll notice that the stars appear to be fixed in their positions relative to each other moving as a group as the Earth turns. For people living in the Northern Hemisphere, one star in particular stood out. The star **Polaris** was different because unlike the other stars which appeared to rise and set, it never moved. It always stayed directly north in the sky so they named it the North Star. People also discovered that the stars are not evenly distributed across the sky. Instead, they make groups that resemble familiar patterns. Some make shapes like triangles and squares. Others look like letters and some, like the big and little dipper, resemble kitchen utensils. Astronomers call these simple patterns **asterisms** and people used them to find other objects in the sky. Asterisms are different from constellations because they often cross constellation boundaries or make up only a small piece of a larger constellation.

As people traveled north and south on the Earth, they noticed that the positions of the asterisms, and in particular the star, Polaris, changed. Most people didn't know it at the time but this is due to the fact that the Earth is a sphere so if you change your latitude, you change the angle at which you are seeing the stars. To help keep track of these changes, they measured the positions of the stars using two important references points; the **horizon** and the **zenith.** The horizon is the point where the sky and the ground meet. In cities where there are tall buildings and in mountainous areas, it's often hard to see the full horizon, but out on the ocean it's very clear. The zenith is the point that is straight over your head. The horizon and the zenith are at right angles to each other.

As people traveled north, Polaris would get higher in the sky, closer to the zenith. As they traveled south, it would move closer to the northern horizon. Whenever they crossed the equator, Polaris would disappear from view. The reason this happens is because Polaris is located directly above Earth's north rotation pole. In other words, if you went to the North Pole, it would be at the zenith. Once you get below the equator, Polaris is no longer visible because the Earth itself is blocking the view. As a result, people traveling in the Southern Hemisphere have to rely on a different set of stars to guide them.

Pre-Visit Activities

Dot Puzzles

The idea of using the stars to create pictures in the sky is really nothing more than connecting dots. While many of the celestial asterisms known today are well known, people in the past probably used these same stars to create very different patterns. A simple way of showing this is to make up a master sheet of paper with 20–30 widely scattered dots on it. The dots should not be evenly distributed. Instead they should be clumped into different groups. Make a copy for each student and then using a pencil, have them create several different patterns from the dots. After they have finished, have the students compare their patterns to see any similarities and differences. Chances are that you will get a few repeating patterns but many more will be different.

Longitude and Latitude

Prior to conducting the planetarium workshop with the class, it would be helpful to introduce or refresh student understanding of longitude and latitude. The best way of doing this is to use a globe rather than a flat map. In this way, the class will be able to see that the Earth itself is spherical. Have them try to locate several different cities by their coordinates and then actually point them out on the globe.

Angular Measurement

Another important concept to help students understand the lesson is to introduce the idea of angular measurement. A simple way of doing this is to give each student a protractor and a piece of paper. Have them draw a circle and then use the protractor to measure a 30, 60 and 90 degree angle.

Using an Astrolabe

These days, navigators have a whole host of high tech electronic gear to help them find their way around the Earth, but any good navigator knows how to measure his/her position using some basic instruments such as a sextant and an astrolabe. Astrolabes have been around since the middle-ages and basically, they are really nothing more than a sight with a protractor that helps to accurately measure the angle that an object makes with the horizon. Students can research different types of astrolabes and they can even build a simple one by taping a drinking straw to the flat edge of a protractor and then hanging a weight (like a metal washer or nut) from a string tied through the small center hole in the protractor. Use the straw as a sight to look at a star or the Moon. Because of gravity, the weight will always hang straight down pulling the string across the curved part of the protractor. The angle that the string marks on the protractor is the angle that the star is above the local horizon.

For an inexpensive, easy-to-assemble Astrolabe Kit, contact Learning Technologies, at 800 537-8703 or log onto www.starlab.com for pricing and ordering information.

The Digital Lesson: Finding Your Way Around the Sky

The *Finding Your Way Around the Sky* lesson is designed to introduce students to the basic reference points in the night sky and how to use the stars to find a location on Earth. In addition, they will discover how to locate different celestial objects by 'star hopping' from one constellation to another. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

You will also have to set the Auto Identify Options for stick figures only. To do this, select the options pane, scroll down to 'Constellations' and click on 'Auto Identify Options' to bring up the box. Ensure that only 'stick figure' is selected, then un-check the Auto Identify check box on top to turn it off. Then click OK to close the box.

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to discover how the stars can be used to help us find our location here on Earth. By using patterns of stars and by hopping from one star to another, you'll also see how easy it is to find your way around the night sky.

Before we begin our little adventure, I need to introduce you to two very important astronomical terms. One is 'horizon' and the other is 'zenith'.

Does anyone know what the word 'horizon' means?

[The horizon is the place where the sky meets the ground.]

The horizon goes all around your head in a circle. Everyone take your hand and point to the horizon. As long as you're pointing to the place where the sky and ground meet, you are correct.

> **Have students point to the horizon and move their hand around in the circle so that they see that the horizon goes all around them.**

Now everyone point straight up over your head. This is the 'zenith'.

> **Have students point straight up to the zenith.**

The zenith is the highest point in the sky, straight up over your head. In a way, we all have our own personal zenith because in theory, there's only one point directly over your head. Of course, if you happen to be standing near someone, you're basically sharing your zenith with them!

Okay, now that we've got that out of the way, let's move on.

Long before people had television, computer games or even read books, they had the stars. Spending night after night outside, they came to realize that not all stars looked the same. They also discovered that by memorizing certain patterns of stars, they could use the stars to tell time, seasons and where they were on Earth. Let's take a look at some of the things they saw . . .

2. Forming Star Patterns

Here we are looking at a typical night sky in the middle of New York City. We can see the Moon and we can lots of stars. On a typical night if you're not near any street lights or buildings, you can see several thousand stars.

Do all the stars look the same?

[No.]

What are some of the ways that the stars look different from each other?

[Some appear bigger, some appear brighter, and some have different colors.]

People of the past noticed these differences too and they noticed one other important fact . . . the stars were not spread evenly across the sky. Stars appeared to form groups. By taking the brightest stars and connecting them together, they made patterns. Today we have a special name for these patterns. They're called 'asterisms'. Let me show you a few asterisms.

If you look toward the zenith in the western part of the sky, you'll see three bright stars named Altair, Vega and Deneb.

Action

Click on the word 'here' to label the three stars.

Now I need a volunteer to do some pointing.

Ask a student to take one of the hand-held pointers and move from one labeled star to the next.

If we were to connect these three stars together with lines, what shape would we get?

[A triangle.]

Action

Click to on the word 'show' to draw in the Summer Triangle.

This particular asterism is called the 'Summer Triangle'. Even though it is visible well into the fall, it's called the Summer Triangle because it first appears in the summer sky.

3. Asterisms

Now let's shift our view over to the south a little higher in the sky so we're closer to the zenith. Here we have four stars that are not quite as bright as the last three we just viewed. Their names are Algenib, Markab, Scheat, and Alpheratz.

Action

Click on the word 'here' to label the four stars.

Let's have another volunteer to do some more pointing.

Ask another student to take one of the hand-held pointers and move from one labeled star to the next.

If we connect up these four stars with lines, what shape do we get this time?

[A square or diamond.]

This asterism is called 'The Great Square'.

Action

Click on the word 'show' to draw in the Square of Pegasus.

Now watch what happens when we start the Earth rotating. To make it easier to see, we'll allow it to spin about 300 times faster then it normally goes.

Action

Click on the button and stop when it reaches 7:00 PM.

What did you see happen?

[The stars appeared to move. Some stars set near the western horizon and a new group of stars rose near the eastern horizon.]

4. Unchanging Star Patterns

Even though the stars appeared to move across the sky, did the patterns of stars change?

[No.]

Once people discovered that the patterns that the stars made always stayed the same, they didn't have to worry about remembering individual stars. All they had to do was look up at the sky and search for a few special patterns that could help them tell direction. Let me show you what I mean. Let's take a look at the sky around midnight.

Action

Click on the word 'here' to go to 12:00 AM.

Now everyone look to the north, right down near the horizon. If you look carefully, you should be able to see seven relatively bright stars that make up one of the most famous asterisms in the night sky. Here, let me draw the lines in for you.

Action

Click on the word 'Highlight' to highlight the Big Dipper.

Does anyone know what we call this asterism?

[The Big Dipper.]

5. Circumpolar Stars

Now watch what happens when I start the Earth rotating again. This time we'll go a little faster than before.

Can anyone predict what will happen to the Big Dipper?

[The Big Dipper will change position.]

Action

Click on the button and when it reaches 5:00 AM.

How was the motion of the Big Dipper different from the motion of either the Summer Triangle or the Great Square that we viewed before?

[Instead of moving across the sky, the Big Dipper went around in a circle.]

From our present viewing location on Earth, the Big Dipper never appears to set. It simply pinwheels around the sky. Because of this, we say that this asterism is 'circum-polar' in nature. It appears to move around the star 'Polaris.'

Let me show you Polaris. It's really easy to find once you have found the Big Dipper because the Big Dipper points the way.

The Big Dipper has two parts to it. There are three stars that make up the handle and four stars that make the bowl or scooper part. The end two stars in the bowl are called the pointer stars. If you follow the line that they make, it points straight to Polaris.

6. Polaris

Action

Click on the word 'highlight' to label Polaris.

Look at Polaris. Does it look very special?

[Not really.]

Is it the biggest star?

[No.]

Is it the brightest star?

[No, not even close.]

Is it a colorful star?

[No.]

So does anyone know what makes Polaris stand out from all the rest of the stars in the sky? I'll give you a hint . . . watch Polaris and I'm going to set the Earth rotating again. This time I'll run the Earth backwards!

Action

Click on the Button and stop when it reaches 2:00 AM.

Did anyone catch it? What was different about Polaris?

[It didn't appear to move.]

Of all the stars that we have in the night sky, Polaris is the only one that appears to stay fixed in the same spot all night long every night of the year. You can always find it directly north in the sky. Because of this, Polaris has a much more common name.

Can anyone guess what it is?

[The North Star.]

Now here's the really big question . . .

Why is Polaris the only star that never moves? I'll give you a hint . . . Since it's really the Earth that is moving and not the stars, where does Polaris have to be in the sky in order for it to stay in the same place when the Earth rotates?

[Polaris is almost directly centered over the Earth's North Rotational Pole.]

To see how this works, we're going to have to take a little trip. I hope you packed your warm clothes and mittens because we're heading to the North Pole!

7. Stars from the North Pole

Okay, so here we are at the North Pole. Can anyone find the Big Dipper?

> **Ask a student to take one of the hand-held pointers and point out the seven stars in the Big Dipper.**

Now use the Big Dipper to find Polaris. Does everyone see Polaris? Where is it in the sky?

[It's right at the zenith, directly overhead.]

Just in case you missed it, let me show them to you.

> **Action**
>
> *Click on the word 'highlight' to label Polaris and the Big Dipper.*

Now it's time to go for a little ride. Let me start the Earth rotating again. Watch the Big Dipper and Polaris this time.

> **Action**
>
> *Click on the button. Stop when it reaches 6:00 PM on Dec 11, 2005.*

Believe it or not, we've just gone 24 hours forward in time. What did you notice about the Big Dipper and Polaris this time?

[Polaris stayed fixed at the center and the Big Dipper just went around it in a complete circle.]

The reason the North Star never moves is because it just happens to be in space directly over Earth's North Pole. It's sort of like you standing under a light in a room and spinning around as you look up. The light will appear to stay in the same place but the walls will look like they're turning.

The truth is, we're lucky to have Polaris in such a special place. Not only can the North Star tell you which direction you're looking in, but navigators on ships discovered that they could use it to tell where they were on Earth.

What happened to the position of Polaris in the sky when we traveled from New York to the North Pole?

[It got higher in the sky.]

8. Changing Latitude — Northern Hemisphere

Whenever we travel north or south on Earth the position of the stars change too. That is because the Earth is a sphere. As we change our latitude, we're looking at the same stars, but at a different angle. Watch what happens when we return to New York again.

> **Action**
>
> *Click on the word 'here' to change the setting for New York.*

Here we are back in New York. Everyone look north and point to Polaris. At the North Pole, Polaris was right at the zenith. Here in New York it's about half way between the zenith and the northern horizon. That is because New York is about half way between the North Pole and the Equator. It turns out that the farther south we go, the lower Polaris is in the sky.

Let me label them so you can see it better.

Action

Click on the word 'highlight' to label Polaris and the Big Dipper.

Now it's time to put your navigational skills to work.

Where do you think Polaris will be in the sky if we head all the way down south to Colombia, a country that is right on the equator?

[Polaris will be right on the northern horizon.]

Let's see if you're correct. It's time to put on your sandals and shorts because we're heading to the tropics!

9. The Equator

Here we are in Colombia. We're right on the equator, the line that divides the Earth's Northern Hemisphere from the Southern Hemisphere.

Can anyone find the North Star now?

[It's right on the northern horizon.]

As you can see, when we're on the equator, the North Star is as low as it can go in the sky. From this point, you can't even see the Big Dipper because it is actually below the horizon. If we start the Earth rotating again, you'll see the Big Dipper rise. Here we go . . . everyone say 'stop' when you see the Big Dipper rise.

Action

Click on the button and stop when it reaches 4:00 AM on Dec 11, 2005.

Does everyone see the Big Dipper? Point to it. Let me label it for you.

Action

Click on the word 'highlight' to highlight the Big Dipper.

Did anyone notice anything different about how the stars appeared to move at the equator?

[Instead of going around in circles, the stars just rise straight up in the east and go straight down in the west.]

Depending on where you are on Earth, you get a totally different motion in the stars. Before we leave Colombia I have one last navigational question. Suppose you're on a boat out in the middle of the Atlantic Ocean and you're sailing south. Each night Polaris appears to get a little lower in the sky, then one night, it suddenly disappears!

Where have you gone?

[You've sailed across the equator and now you're in the Southern Hemisphere.]

10. Changing Latitude — Southern Hemisphere

Once you have left the Northern Hemisphere, the North Star is no longer visible in the sky. Let's take another trip, this time to Peru.

Action

Click on the word 'here' to change the setting for Peru.

Here we are in Peru, a country that is just south of the equator. If we look to the north, you'll see that the North Star is nowhere in site. Watch what happens when we start the Earth rotating again.

Action

Click on the button and stop when it reaches 4:00 AM on Dec 11, 2005.

Does anyone recognize anything familiar on the northern horizon?

[The Big Dipper is visible pointing down toward the ground.]

Action

Click on the word 'here' to highlight the Big Dipper.

If we follow the pointer stars of the Big Dipper, you'll see that they point to the horizon. So where would Polaris be?

[It's below the horizon.]

The reason we can't see Polaris from the Southern Hemisphere is that the Earth itself gets in the way. If the Earth were made out of clear glass then maybe we could!

Now I know what some of you are probably wondering. . . . If there's a North Star, is there also a 'South Star'? Rather than having me give you the answer, how about if you tell me.

Based on what we've learned so far, where would we have to go to see a South Star straight up at the zenith? I'll give a hint. In what location did we see the North Star at the zenith?

[We saw the North Star at the zenith at the North Pole so if there was a South Star we would see it at the zenith at the South Pole.]

Here we go for one more trip. We're off to Antarctica — home of penguins and wingless flies!

11. The South Pole

Here we are at McMurdo Station, directly on the South Pole. We've had to make a slight adjustment to the planetarium projector. I've turned off the sunshine because in the middle of summer in the Southern Hemisphere, we have 24 hours of daylight at the South Pole. If I didn't do this, we wouldn't be able to see any stars except for the Sun!

Everyone look straight up at the zenith. Anyone see a star up there?

[Not really.]

Watch what happens when I start Earth rotating again.

Action

Click on the Button and stop when it reaches 8:00 PM on Dec 11, 2005.

Does anyone see a star that does not move?

[No, at the South Pole, all the stars appear to rotate.]

So is there a South Star?

[No.]

Because there is no South Star, people who live in the Southern Hemisphere have a much harder time navigating. If you were watching carefully, you may have noticed an asterism that is near the zenith at the South Pole. It's made of four stars in the form of a cross. It's called the 'Southern Cross'. Let me show it to you.

Action

Click on the word 'highlight' to highlight the Southern Cross.

Even though the Southern Cross is not directly over the South Pole, it is close enough that people can use it to get a sense of direction. This makes it one of the most important asterisms in the Southern Hemisphere.

Okay, we've spent enough time globetrotting. Now it's time to get back home to do a little 'star hopping'.

12. Star Hopping

Instructor's Note

This would be a natural break point to stop the lesson and continue at a later time.

Here we are back in the Northern Hemisphere. Instead of New York we've moved a little farther north. We're in Toronto, Canada but instead of winter, it is the middle of July. Here you can see the Big Dipper and Polaris is labeled. We also have a few other asterisms drawn in.

Can anyone guess what we call the asterism that has Polaris in it? I'll give you a hint. Since we have a Big Dipper then we should also have a what?

[Little Dipper.]

If you look just below the Little Dipper closer to the horizon you see something that looks like a bent 'W'. This one is also easy . . . it's called 'the W'.

If we start Earth rotating again, you'll see that the Big Dipper isn't the only circumpolar asterism. I'm going to turn daylight off again so you can see the stars for 24 hours.

Action

Click on the Button and stop when it reaches 10:00 PM on July 22, 2005.

Which other asterisms are circumpolar?

[Both the 'W' and the Little Dipper never set.]

We already saw how the stars of the Big Dipper could be used to find the North Star. The process where you use one star to get you to another is called 'star hopping'. Let's try it another way. This time instead of using the pointer stars on the bowl of the Big Dipper, let's use the handle. If we follow the curve of the handle to the west, we come to a bright star on the edge of an object that looks like a big kite. This is the star Arcturus.

Action

Click on the word 'highlight' to label Arcturus.

If we continue following the same curved path, we come to another bright star at the bottom of the kite. This is the star Spica.

Action

Click on the word 'highlight' to label Spica.

A good way to remember this is to think of the curved path as an arc. From the handle of the Big Dipper you arc to Arcturus and speed on to Spica.

13. Reasons for Navigating with Stars

Star hopping isn't only useful for finding bright objects. Astronomers use this technique all the time to locate very faint objects in the sky with their telescopes. By moving from stars that are easy to spot, they can get close to the target area that they want to look at.

This brings us to the end of our little journey through the night sky. As you can see, by learning only a few simple patterns in the stars, you too can be navigating around in no time!

Have students recap their observations. The main concepts are: 1) The sky has two different reference points called the horizon and zenith. 2) As you change your location on Earth, the position of the stars change with respect to the horizon and zenith. 3) Using specific stars and the asterisms in which they are located, it is possible to 'star hop' to locate other celestial objects and tell direction and location on Earth.

Starry Night High School Link

Students who have access to the Starry Night High School computer program should refer to Lesson E1 — Finding Your Way Around the Sky.

Extending the Lesson

Making a Dipper Finder

One of the easiest asterisms to find in the skies of the Northern Hemisphere is the Big Dipper. Because the stars of the dipper are located near Polaris (North Star) in the sky, they are generally visible all year long. Instead of rising and setting, the Big Dipper moves in a pinwheel fashion with the two 'pointer stars' of the bowl aligned with Polaris. As a result of this arrangement, the Big Dipper can actually be used as a 'star clock'. To see how this works, students can build a simple 'Dipper Finder' using the template on the next page. After constructing the device, they can use it to locate the Big Dipper in the sky for different days of the year and for different times of the night by following the instructions of the template. The Dipper Finder can be used either in a planetarium or in the real sky.

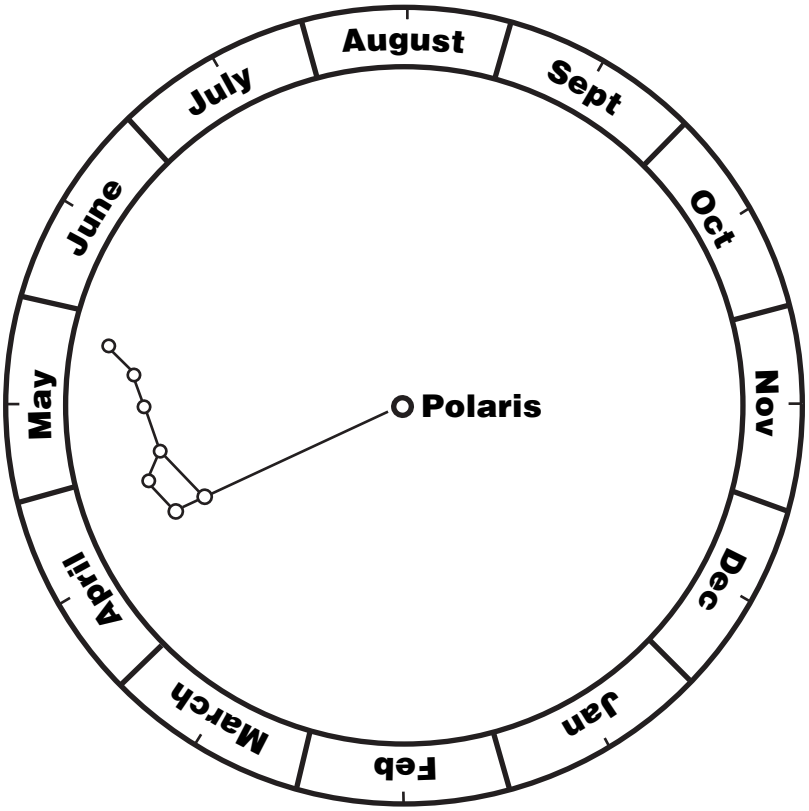
Dipper Finder Pattern and Instructions

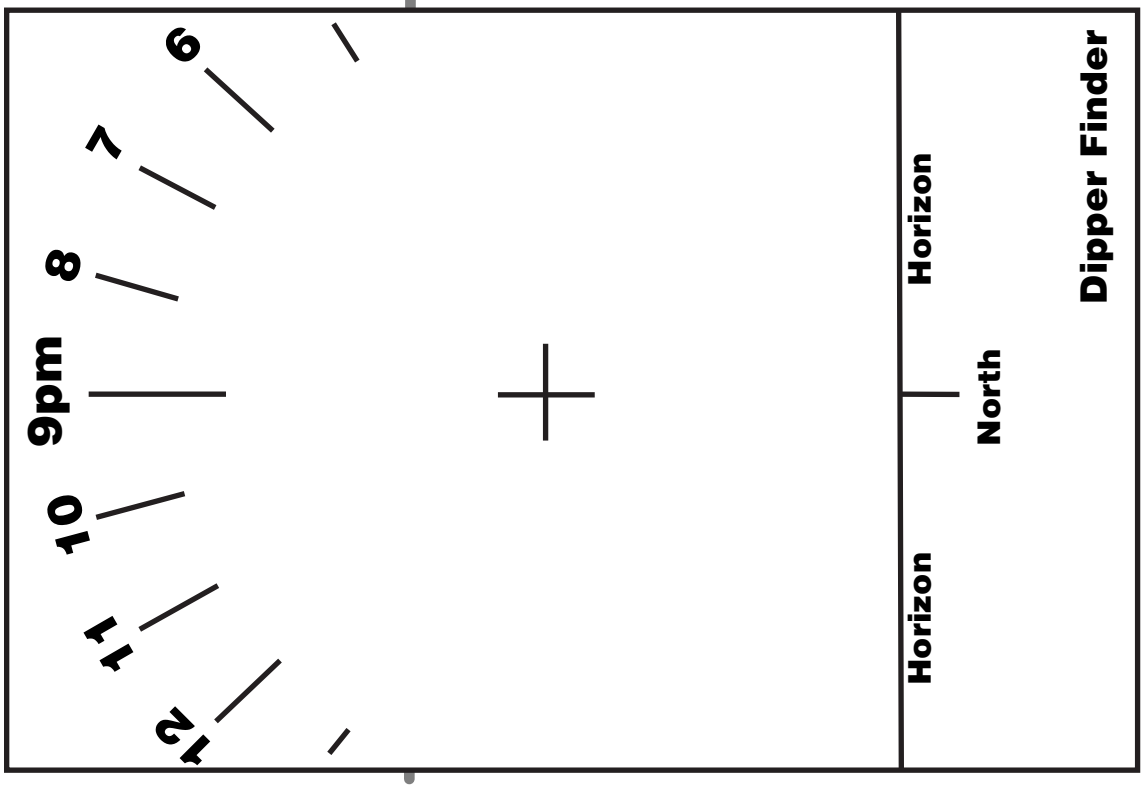
Construction

1. Cut out the circle and rectangle and glue-stick both onto tag board. Trim tag board to exact size of circle and square.
2. Fasten circle to rectangle by putting paper fastener through Polaris.

Use

1. Line up the date of observation with the time of observation. For example, if it is 10 p.m. on April 11, turn the month wheel until a point about a third of the way into the space marked "April" is aligned with 10 p.m. on the square card.
2. Hold the card up so that the north horizon on the card corresponds with the north horizon in the planetarium or real sky.





Using Star Maps

A natural extension to this lesson would be to introduce students to the use of star maps. These can be used either in the planetarium or outdoors with the real sky at night. Star maps look like a large circle with the location of stars, constellations and asterisms plotted in the center. The circle of the star map represents the horizon with the four cardinal directions plotted along the outer edge. The center of the star map represents the zenith. The closer a star is to the horizon, the closer it will plot to the circle. The higher a star is in the sky, the closer it will plot to the center of the map. The easiest way to use a star map is to flip it up over your head so you are looking straight up at it. Turn the map so that the northern horizon is facing north and the other three directions should line up. For most star maps, bright stars are plotted with large dots and dim stars have small dots. Start by trying to locate some of the circumpolar asterisms like the Big Dipper and the 'W' of Cassiopeia in the Northern Hemisphere or the Southern Cross in the Southern Hemisphere.

Star maps can be downloaded from a variety of different Web sites and purchased from publications like *Sky and Telescope* or *Astronomy* magazine. Often newspapers will print weekly star maps. Since star maps are plotted to represent the sky from specific location for a specific time of the year it is important to get a star map that matches your location and date you want. You can even view and print custom star maps using the Starry Night software. Simply follow the instructions under the help menu found on the main program screen.

Lesson 4 — Constellations and Star Lore

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- Most objects in the solar system are in regular and predictable motion.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Science influences society through its knowledge and world view.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

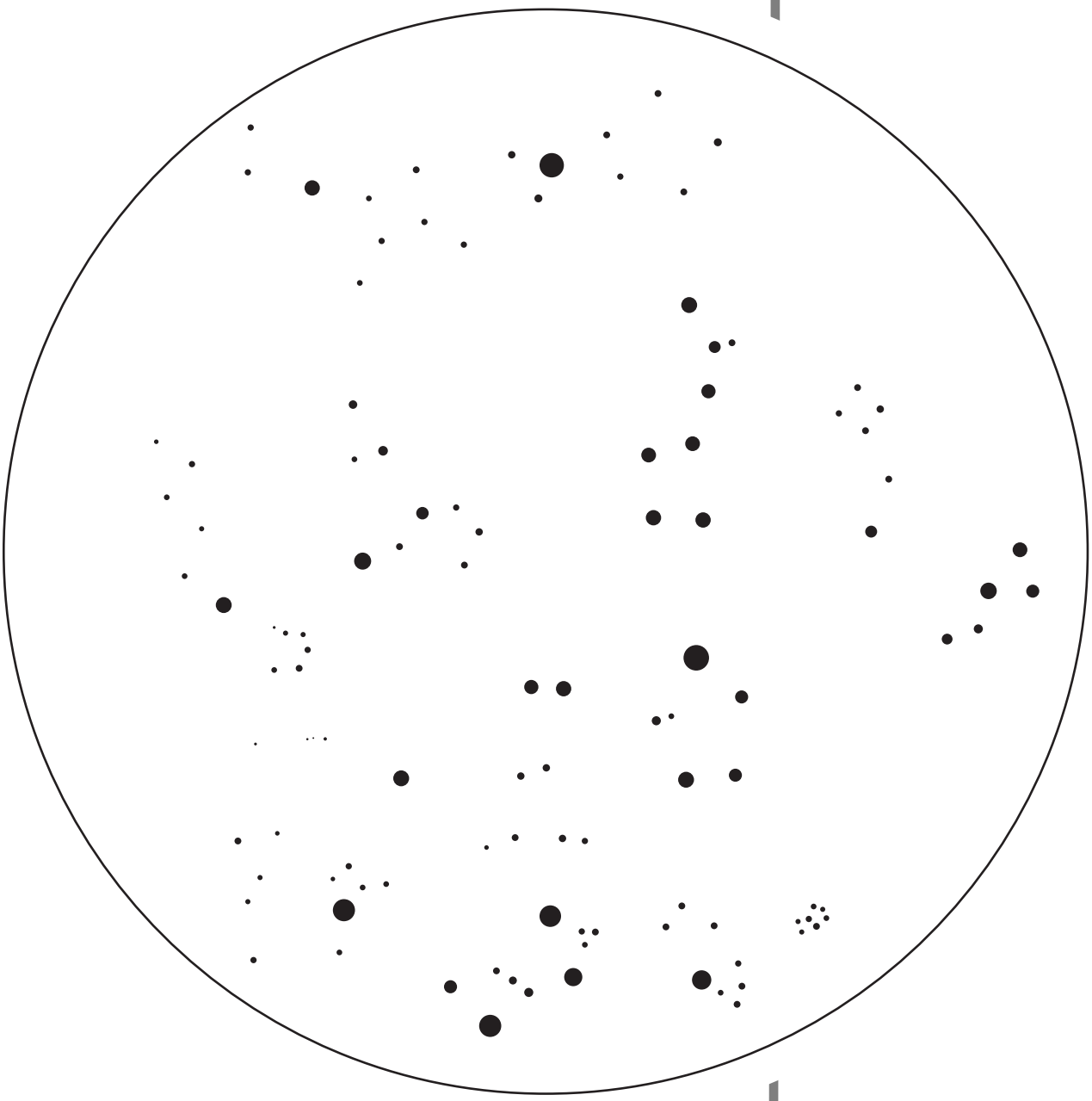
When most people hear the word constellation, the first thing that usually comes to mind is fantastic pictures made from the stars portraying great heroes and beasts from classic Greek and Roman mythology. While students may be familiar with Orion the Hunter, Taurus the Bull, and Leo the Lion, the idea that constellations are simply pictures in the sky used to tell stories is really an over simplification of what they represent. People of the past also had a practical reason to make up constellations. In ancient times few people used a written language and most information was passed along through stories. Creating images and building stories around them made it easier for people to remember where and when a particular group of stars would appear it the sky.

While it is true that some of the constellations do look similar to the objects that they are supposed to represent, many more were simply named for important people and creatures as a way of honoring them. With the original constellations there were really no set boundaries and quite often, a single star could belong to more than one. These days, astronomers have a much stricter definition of how constellations fit together in the sky. Modern astronomers recognize 88 official constellations, each one with very specific boundaries. You can think of these modern constellations as being an 'address in the sky' and as in the past, they are still used to help astronomers locate different celestial objects. Roughly half of the constellations have their origins in ancient times. Because ancient astronomers often ignored large sections of the sky where there were few bright stars, and since people in ancient Greece could not see the skies of the Southern Hemisphere, there were many gaps where no constellations existed. As a result when modern astronomers began to re-draw the star charts for the entire sky, they added over 40 new constellations with modern names like Microscopium, the microscope and Telescopium, the telescope.

Pre-Visit Activity

Constellation Creations

A simple activity that will help get students thinking about how and why people of the past developed constellations is for students to create their own constellations. Make copies of the blank star map below for each student and then ask them to see if they can come up with their own images. A good place for them to start would be for them to try and find pictures of modern day devices like cell phones or cars. Another approach would be to have them look for famous cartoon characters (the stars of Auriga make a great Patrick the Starfish). After creating their images, ask them to make up a story that links the images together. After students have presented their creations and stories, invite them to visit the planetarium where they will learn about some of the classic myths of ancient Greece.



The Digital Lesson: Constellations and Star Lore

The *Constellations and Star Lore* lesson is designed to introduce students to some of the more famous Greek constellations and the myths that go with them. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to discover some of the myths and legends about the stars that were popular in ancient Greece more than 2000 years ago.

Long before there was television, video games or even books, people used to spend many hours outside at night, looking up at the sky. Using the brighter stars as guides, they imagined pictures of great heroes, wild beasts and beautiful princesses. Often, they made up stories to go along with the pictures and over the years, these stories were repeated from parents to their children. Today we call these stories myths, and they go hand in hand with the constellations we can see in the night sky.

Can anyone explain what a 'constellation' is?

[A constellation is a group of stars that makes a picture in the sky.]

While many of the constellations started out as simple pictures made from stars, today these patterns in the sky have taken on a new meaning. The main use of the constellations by modern astronomers is for locating objects in space. Today, the entire sky has been divided into 88 'official' constellations. Each constellation has its own boundary and none of them overlap. Let me show you what I mean.

2. Sky Pictures

You can think of a modern constellation in the sky in the same way as a country on a map. Let's say you wanted to locate a particular place, like Mt. Fuji. First, you would begin by looking up what country it was in. After you found that it was located in Japan, then you would find a world map, find Japan and go from there. It works the same way with constellations. If an astronomer wanted to look at the Andromeda galaxy with his or her telescope, they would start by looking it up in a star atlas. Then they would look at the night sky within the boundaries of the constellation Andromeda, and use the map in the atlas to find it.

Action

Click on the word 'here' to label the Andromeda galaxy.

Long before they became 'addresses in space', constellations captured the imaginations of countless generations of people. The myths and legends that grew around them not only entertained people, but they helped people remember important events in their own lives. Adults used these stories to teach their children about right and wrong, and even today, many of these stories occur in books, on television and in movies.

Can anyone think of any classic Greek myths that have become movies?

[Hercules, Clash of the Titans, etc.]

So let's take a trip back in time to the days of ancient Greece and look at some of the more famous constellations and the stories that they tell!

3. Connecting the Dots

Here we are looking at a typical winter sky in the Northern Hemisphere. As you look around, you can see many different stars. Some are brighter, some are colorful. The origins of modern constellations probably started with a scene just like this.

How many of you have ever played a game of 'connect the dots'?

This is when you have a sheet of paper with lots of dots on it and you follow the numbers with a pencil until you make a picture. Well back in ancient times, people didn't use paper and pencils, they used stars. Concentrating on the brightest stars first, they created images that reminded them of things in their lives. Let's connect some dots and see what we get . . .

Action

Click on the word 'here' to show the constellation stick figures.

Here we have some of the real simple shapes created from the stars. Let's play a little game.

Do any of these shapes remind you of anything?

Let's see how good your imaginations are. I'm going to give you all a chance to be a planetarium director and do some pointing.

I have my hand-held pointer here and we're going to pass it around the room. What I'd like you to do is pick any object you see up in the sky, and tell the group what it reminds you of. Don't worry this is not a test! There are no right or wrong answers.

Who wants to start?

At this point, you can either have every student in the dome try or just select a few. It's all up to you and how much time you have available. After you have finished this part of the exercise, continue with the narrative.

4. The Greek Sky

As you can see, by simply 'connecting the dots' we get images that are very open to interpretation. This is what happened in the past too. Different people saw different things. Some of the images did stand out really well however, and those became the ones upon which many of the ancient Greek myths were based. The people of ancient Greece actually identified 43 different constellations and using some creativity, they came up with pictures that looked like this.

Action

Click on the word 'here' to show the constellation illustrations.

As you probably guessed, those people in ancient Greece had some pretty active imaginations! While some of the constellations actually look like the objects they are supposed to represent, some of the constellations are 'honorary constellations'. What this means is that they were named for things that people were looking to honor or remember, and they didn't necessarily look like what they were named for.

A good example is the constellation Aries the ram. Can anyone find a picture of a sheep?

Pass the pointer to a student volunteer to point to Aries. It's in the southwest sky about half way between the horizon and zenith.

5. Aries the Ram

Here we have a pretty picture of a ram complete with horns and fluffy tail. Let's take a look at what the actual stars of Aries look like.

Ask the student to hold the pointer still right over the picture of Aries while you turn off the illustrations.

Action

Click on the word 'here' to turn off the constellation illustrations so that the stars show.

Does anyone see a ram now?

[Not really.]

The truth is Aries has only two bright stars in it so there is really no way to draw it to look like a sheep but to the ancient Greeks, Aries was an important symbol so rather than have an empty place in space, they put the symbol up as a constellation.

There are quite a few constellations that do look similar to the objects that they are supposed to represent, and they are fairly easy to spot once you get the hang of it. Naturally we don't have time to go over every constellation and myth, so how about if we pick out a few real stand outs.

6. Orion the Hunter

Let's start with Orion the hunter. Can anyone spot Orion?

He's not far from Aries. The trick is to look for three stars in a row. These make up Orion's belt!

Pass the pointer to a student volunteer to point to Orion. It's directly south about 1/3 of the way up between the horizon and zenith. You may also want to use a second pointer to help guide the student into the right spot. Ask the student to use his or her pointer to point to the stars as you describe the following stars:

Orion is one of the easiest constellations to spot in the winter sky. Not only does he have a few stars that are 'stand outs', but he actually looks a little like what he's supposed to be, a big guy in the sky. The first thing that you will probably notice about Orion is his belt . . . three stars in a row that make a straight line across his mid-section.

Next we have a bright red star in his shoulder. This is the star Betelgeuse, (pronounced bettle-jouz) a red supergiant star. While it sounds like the name of a movie ghost, Betelgeuse is actually an old Arabic word that means 'armpit'.

Can you guess why they called it that?

[It's in the position of Orion's armpit.]

If you move down to the corner of the constellation diagonally opposite Betelgeuse, you come to Rigel, a blue star whose name means 'foot'.

Action

Click on the word 'here' to label Betelgeuse and Rigel.

Finally, if you look in Orion's right hand, you can see several stars in a row that make up his club and in the left hand there is a curved line of stars that make up his shield. If you really concentrate, you should be able to get the full picture even with the lines off. Let's try.

Action

Click on the word 'here' to show the constellation stick figure of Orion.

Can you see him now? I thought that would help!

7. The Myth of Orion

Okay, I promised you folks a story so here goes — an abbreviated version of the myth of Orion.

According to the ancient legend, there once was a man named Hyrieus who was a poor farmer. Even though he was poor, he was always kind to those around him and shared what little he had. One day, he helped three strangers who were actually the gods Zeus, Hermes and Poseidon traveling in disguise. In return for his kindness, he was granted one wish. Hyrieus asked for a son and Orion was born.

As Orion grew up, he became a skillful hunter, however, the more famous he became, the more insensitive he became about killing animals. Instead of hunting just for food, Orion began killing animals just for fun. This got Artemis, the goddess of hunting very upset. To teach Orion a lesson she sent down Scorpius, a giant scorpion from Mt. Olympus. The scorpion stung Orion on the foot and he became very ill and was about to die when Ophiuchus, (pronounced oh-fee-YOO-kis) the healer gave Orion an antidote that saved his life.

Orion was grateful to be saved and realized that he was wrong about killing the animals. He asked for forgiveness and as a reward he was placed into the stars in the sky. So that he wouldn't forget the lesson he learned, the scorpion was also placed opposite him in the sky as a reminder of his bad deeds. Does anyone want to see the scorpion? Let's see if we can find him. First we'll have to change the sky a little because Scorpius is best seen in the summer.

8. Scorpius the Scorpion

If we look south just above the horizon, we can see the constellation Scorpius. Like Orion, Scorpius is a constellation in which the stars actually form an image that is close to what it's suppose to be. To find the scorpion, look for another bright red star. This isn't Belegeuse, it's called Antares and it's the heart of the scorpion. Let me show it to you.

Action

Click on the word 'here' to label the star Antares.

Can you see the Scorpion now? I'll give you a hint, the scorpion has a body that is shaped like the letter S with a long tail that looks like a fish hook. At the tip of the tail there is a stinger. Who wants to give it a try?

Ask a student volunteer to use the hand-held pointer to try and point out the Scorpion. After a few tries, turn on the constellation illustrations.

Excellent job! Let's see what the whole picture is supposed to look like.

Action

Click on the word 'here' to turn on the constellation illustrations again.

Here you can see Scorpius in all his glory. Directly above him we have Ophiuchus, the man with the snake. He is known as the healer and he was the one who gave Orion the antidote to save him from the scorpion's sting.

9. Sagittarius the Centaur

Does anyone know the name of the constellation directly behind the scorpion to the east? It's the one who is half man and half horse.

[Sagittarius.]

According to the legend, Sagittarius was put up in the sky to keep watch over the scorpion. If the scorpion gets out of line, Sagittarius will shoot him with his bow and arrow. Sagittarius is known as a Centaur. Centaurs were mythological creatures who supposedly roamed the forests of the past. Some of you may know about centaurs from some modern day mythology.

Can anyone think of a book or movie that had centaurs in them?

[They are often mentioned in Harry Potter books.]

It turns out that author J.K. Rowlings uses many names and characters from ancient Greek mythology for the plots in her books. Would you like to see another one? If everyone turns and looks north, you'll see the constellation Draco. Draco is a dragon and is also the name of one of the evil characters in the Harry Potter books.

[Draco Malfoy, one of Harry's classmates.]

Ask a student volunteer to use the hand-held pointer to try and point out Draco.

10. Draco the Dragon

Let me tell you the myth of Draco the dragon.

A long time ago, there was a group of people called the Chaldeans who lived in the area of the Tigris and Euphrates rivers, where modern day Iraq is. These people believed that there was a monstrous dragon that brought chaos, darkness and evil. At first, the dragon conquered all who came in his way and it seemed that evil and darkness was always going to win over good. Finally, a brave god of light named Marduk challenged the dragon and using all the magical powers, Marduk finally beat him. Draco the dragon was placed in the sky as a reminder to all that with enough strength and perseverance, goodness will always conquer evil. Because this was such an important lesson, Draco is one of the few constellations that never appears to set in the sky. Watch.

Action

Click on the button to put the stars in motion.

11. Northern Circumpolar Constellations

Did anyone notice which other constellations never set?

[Ursa Major, Ursa Minor, Cassiopeia, Cepheus and Camelopardalis.]

These are all called 'northern circumpolar constellations' because they all revolve around the star Polaris which is in the tail of Ursa Minor, the Little Bear. With the exception of Camelopardalis, all of these constellations were first viewed by the people in ancient Greece. Camelopardalis is actually one of 45 constellations that were added to the sky much later on to 'fill in the blank spots'.

Well this just about brings us to the end of our story time. If you are interested in Greek mythology, there are plenty of great books that tell the other Greek myths and legends. In addition, it's important to remember that the folks in ancient Greece weren't the only people looking up at the night sky and seeing constellations. Just about every group of people who looked at the sky made up constellations and myths. There are constellations from China, India, Africa, and even North and South America. As you might expect, the images that these other people saw and the stories that they told were quite different from those that were told by the people in ancient Greece. It's not that one group was right and another group was wrong . . . they were just different because they had different beliefs and cultures. The only reason that the Greek constellations are so well known is because those were written down in books. Many of the other cultures only told their stories so over time the information was lost or changed.

Of course, you don't have to be from Ancient Greece, China or Babylon to make up constellations. You can do it right now in the comfort of your own backyard. All you need is a dark sky, some stars and an active imagination!

> **Have students recap their observations and present their ideas. The main concepts that they should be able to relate are: 1) Stars remain fixed in their position in the sky relative to each other. 2) Stars can be grouped into patterns called constellations. 3) Different people from around the world made up different constellations and in many cases the images they saw were quite different from each other. 4) Myths are stories that people made up to remember the different constellations and when and where they were visible in the night sky.**

Starry Night High School Link

Students who have access to the Starry Night High School computer program should refer to Lesson E2 — Constellations and Star Lore.

Extending the Lesson

Constellations Around the World

While the classic myths of ancient Greece and Rome are the best known, it is important for students to realize that people all over the world were looking at the stars, creating constellations and making up myths to go with them. There is extensive star lore from China, India, Africa and even North and South America. Have students research constellations from other cultures and see how they compare with those of ancient Greece. Have them look for similarities and differences for specific groups of stars and compare how the star patterns were related to each other.

Myths and Morality

In addition to helping people remember where and when different star patterns were

visible in the sky, the myths and legends associated with different constellations were often used to teach important lessons to the 'younger generation.' Most of the classic myths had some sort of moral involving things like right and wrong, good and evil, jealousy and vanity. Ask students to pick one of the classic myths and dissect the moral aspects of it. Also, you can have them see if any modern stories use any of the same basic ideas.

Modern Day Myths

As noted in the narrative for this program, some of the classic myths (and their characters) have been 'borrowed' by modern day authors and movie producers. While some movies like *Clash of the Titans* have stayed true to the original myth, others like the animated *Hercules* have changed the plot lines considerably. A great way to introduce classic mythology is to have students compare some of these modern creations with the original myths and see where the deviate. Students can even vote on which version of the story they like better!

Lesson 5 — Seasonal Change

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- The Sun is the major source of energy for phenomena on the Earth's surface.
- Objects in the sky have patterns of movement. The Sun appears to move across the sky in the same way every day but its path changes slowly over the seasons.
- Seasons result from variations in the amount of the Sun's energy hitting the surface, due to the tilt of the Earth's axis of rotation and the length of the day.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

Understanding why we have seasons on Earth is a difficult concept for both children and adults. Many people are under the false impression that the seasons here on Earth are controlled by a change in distance between our planet and the Sun as we move in our orbit. While it is true that Earth's orbit is an ellipse (oval-shaped) and the distance to the Sun varies throughout the year, the change in distance is so small that it has almost no impact on the amount of heat we receive. In fact, Earth is closest to the Sun in early January, right in the middle of the northern winter.

The real reason we have seasons on Earth has to do with the fact that when we orbit the Sun, our axis of rotation is tilted to the plane of our orbit. (That is why globes always have the Earth sitting at an angle.) Because of the tilt, during the year the radiation we receive from the Sun is not equally distributed around the planet. During the northern summer, the Northern Hemisphere is pointed toward the Sun. As a result, most of the direct solar radiation falls north of the equator. What this means here on Earth is that the Sun appears to be higher in the sky (the angle of insolation is greater) and it is visible for a longer period of time during the day (the duration of insolation is greater). During the northern winter, the Southern Hemisphere is pointed toward the Sun and most of the direct solar radiation falls south of the equator. As a result the angle and duration of insolation for those people in the Northern Hemisphere is lower and the people in the Southern Hemisphere have summer. The only time the two hemispheres get exactly the same amount of sunlight is on the vernal and autumnal equinoxes when the direct radiation falls exactly on Earth's equator.

Pre-Visit Activities

My Favorite Season

Everyone has a favorite season. Some people like winter sports and snowball fights while others like summer fun in the sun. A good way to introduce the concept of seasonal change is to have students draw or write about their favorite seasonal scene paying particular attention to the weather conditions controlled by the Sun.

Sun Angle and Radiation

Anyone who has ever spent time in the tropics knows that when the Sun is directly overhead, the radiation is much more intense. Not only does the Sun feel hotter, but if you're not careful, your skin can burn in a matter of minutes. A simple way to quantify the intensity of direct radiation is to conduct the following demonstration. You'll need a flashlight, two identical pieces of graph paper, a pencil, some masking tape and a ruler. Tape the two pieces of graph paper next to each other on the chalkboard and make the room as dark as possible. Ask a student volunteer to hold the flashlight exactly 12 inches in front of the first piece of graph paper. Make sure that the light shines straight onto the paper and that it's not angled in any way. The spot of light should be almost a perfect circle. Have another student volunteer use the pencil to trace the spot of light.

Repeat the procedure with the second piece of paper only this time hold the light at an angle so that the spot is now oval. Have the students count the number of boxes in each spot and compare the area that is lit. The one with the direct radiation should have fewer boxes than the one that is at an angle. Since the same amount of light energy is spread over a bigger area, the light that comes in at an angle must be less intense.

Tracking Hours of Daylight

While the angle of the Sun helps to explain some of the differences between summer and winter temperatures, the number of hours of sunlight is also important. Most students realize that it gets darker earlier in the winter months than in the summer, but to really see the change, it's best to quantify it. Have students record the sunrise and sunset times for two weeks straight. They can get the information from a local newspaper. After recording the times, they should calculate the total amount of daylight by subtracting the two times from each other. Depending on whether it's the fall or the spring, they should see the hours of daylight either decrease or increase respectively.

The Digital Lesson: A Change of Season

The *Change of Season* lesson is designed to introduce students to the observational evidence that explains the true reason that we have seasons here on Earth. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

To enhance this lesson, photocopy and distribute the master data chart found at the end of this narrative. By recording their observational data, students will be able to make easy comparisons of the Sun's position in the summer and winter sky.

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at why we have seasons here on Earth.

Before we get started, do any of you have any ideas about why the seasons change?

> **Accept all student responses without passing judgment or expressing an opinion. Typical answers involve the size and shape of Earth's orbit, the distance from the Sun, the length of the day and the tilt of the Earth.**

2. Earth's Orbit

Here we are looking at a view of our Earth as it orbits the Sun in space. How long does it take for the Earth to complete one orbit around the Sun?

[One year or 365 days.]

As you probably figured out, Earth is moving much faster here . . . over 800,000 times faster in fact!

Does anyone have an idea of what the other two white dots moving around the Sun are?

[The planets Venus and Mercury.]

Does anyone know what we call the shape of Earth's orbit?

[The orbit is an ellipse.]

An ellipse looks like an oval and the Sun is not quite in the center.

This means that at certain times of the year, the Earth is closer to the Sun and at other times it is farther away. Because of this, many people mistakenly believe that it is the shape of the orbit that produces seasons here on Earth.

Look closely at the shape of the Earth's orbit that is shown here. What shape does it appear to be? Does the Earth ever appear to be closer to the Sun?

[In this plot, the orbit appears to be circular and the distance stays fairly constant.]

The truth is, even though our Earth orbits the Sun in an ellipse, the shape of the ellipse is really close to being a circle. As a result, the distance between the Earth and the Sun only changes a tiny bit during the year. Because of this, the shape of Earth's orbit has almost no effect on the seasons. Let's see if we can figure out what's really going on.

3. Predicting Sunrise and Sunset in Winter

Let's move back to the Earth and take a look at the Sun's position in the sky for a few different days of the year.

Instructor's Note

To enhance this part of the lesson, please photocopy the black line master data chart found at the end of this narrative. Give each student his or her own copy so that they can record their observational data and make easy comparisons of the Sun's position in the summer and winter skies.

Action

Click on the word 'here' to change the setting to see the Sun in the winter sky in the Northern Hemisphere.

Here we are looking at the sky right after sunrise on Dec 21. The time is about 8:00 AM. I've made the sky darker than normal so that you are better able to see the Sun. The line going across the sky with the numbers on it is called the meridian. I'll explain what that is in a few minutes.

Does anyone know what is special about this date?

[Dec 21st is the Winter Solstice, and it is the official start of winter in the Northern Hemisphere.]

4. Understanding Horizon, Zenith and Meridian

Before we go any further, we must define three words that astronomers use . . . horizon, zenith and meridian.

Does anyone know what these terms mean?

[The horizon is the point that the sky and ground meet. The Sun rises and sets on the horizon. The zenith is the highest point in the sky straight over your head. It is 90 degrees above the horizon. The meridian is a line that runs from the southern horizon, through the zenith and back down to the northern horizon.]

In what direction is the Sun rising on the horizon?

[The Sun rises in the southeast.]

Now I'm going to put the Earth in motion. Time is going to move very quickly. Watch the path of the Sun as it moves across the sky. I'm going to stop time when the Sun is on the meridian. When this happens, it will be local noon. Local noon is the

time of the day when the Sun appears to be at its highest point in the sky above the horizon.

Explain that the terms AM and PM actually are measured by where the Sun appears to be in the sky. When it's in the morning, the Sun is in front of the meridian (Anti Meridian) when it's in the afternoon, the Sun is past the meridian (Post Meridian).

Action

Click on the button to put the Earth in motion. Stop when the Sun is directly on the meridian.

The numbers on the meridian show how many degrees above the horizon an object is in the sky. When something is straight overhead it's at the zenith. It is 90 degrees above the horizon.

About how high is the Sun in the sky when it crosses the meridian on the winter solstice?

[Approximately 25 degrees above the horizon.]

Let's put the Earth in motion again and see where the Sun will set. Does anyone have a guess what direction it will be?

Have a few students offer their ideas by using the hand-held pointer to show where they think the Sun will set.

[The Sun will set in the southwest.]

Action

Click on the button to put the Earth in motion. Stop when the Sun reaches the horizon.

Here we see the Sun setting in the southwest. The time is about 4:00 PM. About how many hours of daylight did we have?

[If the Sun rose at 8:00 AM and sets at 4:00 PM, the total amount of daylight is 8 hours.]

5. Predicting Sunrise and Sunset in Summer

Now let's take a look at the path of the Sun for the Summer Solstice. Does anyone know what day of the year that is?

[The summer solstice is usually June 21 or 22.]

Action

Click on the word 'here' to change the setting to see the Sun in the summer sky in the Northern Hemisphere.

Here we are on looking at the sky on June 21st, the Summer Solstice. It's about 5:00 AM and the Sun is starting to rise.

What direction is the Sun rising on the horizon?

[The Sun rises in the east-northeast.]

Let's put the Earth in motion again and see how high the Sun will be in the sky when it crosses the meridian this time.

Do you think it will be in the same place, higher or lower in the sky?

[It will cross higher in the sky.]

Action

Click on the button to put the Earth in motion. Stop when the Sun is directly on the meridian.

About how high in the sky is the Sun as it crosses the meridian on the Summer Solstice?

[About 73 degrees.]

Let's put the Earth in motion again and see where the Sun will set. Does anyone have a guess what direction it will be?

Have a few students offer their ideas by using the hand-held pointer to show where they think the Sun will set.

[The Sun will set in the northwest.]

Action

Click on the button to put the Earth in motion. Stop when the Sun reaches the horizon.

Here we see the Sun setting in the northwest. The time is about 7:00 PM.

About how many hours of daylight did we have?

[If the Sun rose at 5:00 AM and sets at 7:00 PM, the total amount of daylight is 14 hours.]

6. Sun's Path Comparisons

Now let's compare what we just observed about the path of the Sun for both the winter and summer solstices.

During which season was the Sun higher above the horizon at noon?

[Summer — about 73 degrees as compared to about 25 degrees for winter.]

During which season were there more hours of daylight?

[Summer — about 14 hours as compared to about 8 hours for winter.]

*As you can see, during the summer months, not only is the Sun visible for a longer period of time (something scientists call the **duration of insolation**) but it's at a much higher angle in the sky. The closer the Sun is to the zenith, the greater its **angle of insolation.** A high angle of insolation means that the surface of the Earth is getting more direct radiation from the Sun. The more direct the Sun's rays are, the more intense the radiation and the greater the heating.*

The reason it's warmer in the summer is because the Sun is both higher in the sky and shining for a longer period of time. In other words, both the angle of insolation and the duration of insolation are high. The question is, what controls how high and how long the Sun is in the sky? To understand this, we have to take a short trip into space!

Action

Click on the word 'here' to change the setting to see the Earth and Sun from space.

7. Earth's Axis

Here we are looking at the Earth as it orbits the Sun in space. To help you get a better view of things, the Earth has been greatly magnified. The red line going around the Earth is the equator, the line that separates the Northern and Southern Hemispheres. The two lines sticking out of the North and South Pole show the axis of the planet. The axis is the imaginary line around which the Earth rotates.

As you can see from this drawing, when the Earth orbits the Sun, it does not do so straight up and down. The axis of our planet is tilted about 23.5 degrees.

Right now, we're looking at the way the Earth would appear on June 21st, the first day of summer in the Northern Hemisphere.

Based on your observations, which hemisphere is getting more sunlight?

[The Northern Hemisphere.]

Now let's put the Earth in motion and see what happens as we orbit the Sun .

Action

Click on the button to put the Earth in motion. Stop when the date reaches December 21st.

8. Axis and Sunlight

Now we are looking at the way the Earth would appear on December 21st, the first day of winter in the Northern Hemisphere.

Based on your observations, which hemisphere is getting more sunlight now?

[The Southern Hemisphere.]

How do these observations from space fit with the observations we made before when we were following the path of the Sun across the sky for different days of the year?

[On the Summer Solstice, from Earth the Sun appears to be higher in the sky and from space the Sun appears to be shining more on the Northern Hemisphere. On the Winter Solstice, from Earth the Sun appears to be lower in the sky, and from space, the Sun appears to be shining more on the Southern Hemisphere.]

Because of the tilt of the Earth's axis, sunlight is directed on different parts of the Earth during different times of the year. During winter months in the Northern Hemisphere, the direct rays from the Sun are shining south of the equator. During the summer months in the Northern Hemisphere, the direct rays from the Sun are shining north of the equator. This is why the seasons are reversed in the Northern and Southern Hemispheres.

So far, we've only looked at the position of the Sun in the sky for winter and summer. Does anyone have an idea of where the Sun will be in the sky during the spring and fall? Let's take a look.

9. Sun Position in Autumn

Action

Click on the word 'here' to set time to September 21st.

We're now looking at the Earth in its orbit on September 21st. This day is usually the first official day of autumn, a day we call the ***autumnal equinox****. The term 'equinox' means equal night. It's the day of the year when the number of hours of daylight and night are equal.*

Where on the Earth does most of the sunlight appear to be focused on this day?

[On the equinox the Sun shines directly on the Earth's equator.]

If we were standing on Earth watching the Sun as it appeared to move through the sky on the equinox, we would find that the path it takes would be midway between the path for the winter and summer solstice. There are actually two equinoxes: one in the spring and one in the fall. Only on those two days does the Sun appear to rise exactly in the east and set directly in the west.

Before we wrap up our discussion of the seasons, there's one last point to consider. Since the Sun appears to take different paths across the sky in the different seasons, this means that each day, the position of the Sun at noon on the meridian will be a little different from the day before. We don't really notice this change on a day to day basis because the change is rather small but if we were to plot the position of the Sun at noon each day, it would give us a very interesting picture. Let's see what it would look like.

10. The Sun at Noon

Here we see the Sun in the sky at noon on July 14th from Toronto, Canada which is located about half way between the equator and the North Pole. I have the sky darker than normal like we did before so that we can see the Sun better. I'm going to speed up time and move us forward about a month. As each day passes, you'll see the position of the Sun marked in the sky at noon.

Based on what we've observed so far, should the Sun get closer to the horizon or closer to the zenith?

[Since July 14th is past the summer solstice in the Northern Hemisphere, the Sun should appear to move closer to the horizon with each successive day.]

Action

Click on the button to step forward in time. Stop when the date reaches September 21st .

As you can see, each day, the Sun appears to move a little closer to the horizon. This makes sense because we are going from summer to autumn and the days are getting shorter.

Based on what we've observed so far, on which day should the Sun appear to be closest to the horizon at noon in the Northern Hemisphere?

[The Sun should be at its lowest point on or about Dec 21st which is the winter solstice.]

Let's put the Earth in motion again and see if you're correct.

Action

Click on the button to step forward in time. Stop when the date reaches December 21st.

As you can see, on the winter solstice, the Sun is very close to the horizon.

What should happen to the position of the Sun if we continue to move forward in time? On what day of the year will it be at its highest point above the horizon in the Northern Hemisphere?

[As we move forward in time from the winter solstice, the Sun will appear to get higher in the sky each day until we reach the summer solstice again, which is on or about June 21st.]

Let's put the Earth in motion again and see what happens . . .

Action

Click on the button to step forward in time. Stop when the date reaches June 21st.

11. Analemma

Here we are on June 21st. Since this is the date of the summer solstice in the Northern Hemisphere, the Sun is at its highest point above the horizon. Almost a full year has gone by since we first started plotting the Sun's position.

What is the shape of the path made by the Sun?

[The pathway looks like a figure 8.]

Scientists call this graph the ***analemma*** *and you can frequently find it on globes and other maps. It's used to show the position of the Sun in the sky for different days of the year relative to different positions on Earth.*

Based on the plot of the analemma, you can see that at noon, the Sun is in a different position in the sky on almost every day of the year. The only exception is where the figure 8 crosses. As it turns out, on two days of the year the Sun can be found to travel on the exact same path.

Can anyone guess which days these are? Here's a hint . . . these days happen exactly 3 months after a solstice.

[The point at which the analemma crosses are the two equinoxes.]

This wraps up our little seasonal adventure. Now you know the true reason for the seasons!

Have students recap their observations and present their ideas. The main concepts that they should be able to relate are: 1) The Sun appears to rise and set at different locations during the different seasons of the year. 2) The number of hours of daylight change as the seasons of the year change. 3) The Sun is at its highest point during the day when it is on the meridian. This point defines solar noon. 4) The tilt of the Earth is responsible for the change in the seasons.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson A2 — The Year and Seasons.

Change of Seasons Data Chart for Use in the Planetarium

Winter Solstice — Dec 21st

Sunrise Direction: _____

Sunrise Time: _____

Angle of Sun on Meridian at Noon: _____

Sunset Direction: _____

Sunset Time: _____

Hours of Sun Light: _____

Summer Solstice — June 21st

Sunrise Direction: _____

Sunrise Time: _____

Angle of Sun on Meridian at Noon: _____

Sunset Direction: _____

Sunset Time: _____

Hours of Sun Light: _____

Autumnal Equinox — Sept. 21st

Sunrise Direction: _____

Sunrise Time: _____

Angle of Sun on Meridian at Noon: _____

Sunset Direction: _____

Sunset Time: _____

Hours of Sun Light: _____

Extending the Lesson

Sunshine Model

After completing the lesson in the planetarium, a good way to reinforce the concept that axial tilt is what really causes the change of season is to show the students a concrete model using a flashlight and a globe. Get the room as dark as possible and place a globe (with tilted axis) on a desk near the front of the room where the entire class can see. Ask a student volunteer to come forward to be the Sun. Have the volunteer hold the flashlight so that it is pointed level to the globe from about two feet away. Turn the globe so that the Northern Hemisphere is tilted in the direction of the student. The class should see that most of the light strikes the globe north of the equator. Ask the class: Based on the position of the globe and what we learned in the planetarium, what season is it in the Northern Hemisphere? [Since most of the light is concentrated north of the equator, it would be summer in the north and winter in the Southern Hemisphere.] Next, have the student volunteer walk around the desk and point the light at the opposite side of the globe. Now the Southern Hemisphere should be receiving the bulk of the light. Ask: What season is it in the Northern Hemisphere now? [Winter.] Finally, ask if anyone in the class can explain where the light would have to shine in order for it to be either spring or fall in the Northern Hemisphere. [The light would have to be directed right at the equator, ¼ of the way around the globe from either the winter or summer positions.]

The Analemma

While you have the globe out, take a look and see if you can find a figure 8-shaped object. (It's usually found in the Pacific Ocean.) This feature is called the 'analemma' and as discussed during the lesson, it is drawn based on the position of the Sun in the sky at noon for different days of the year. These days, the analemma is not used all that often but in the past, it was used by navigators to adjust their positions based on the position of the Sun in the sky. From it, you can calculate the declination of the Sun (its angle above the horizon) for different locations on Earth. Also, it allows you to set a clock based on when solar noon is (when the Sun is on the local meridian).

Lesson 6 — Solar and Lunar Eclipses

NSES Connections

- The Sun, Moon and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movement. The Moon moves across the sky on a daily basis much like the Sun. The observable shape of the Moon changes from day to day in a cycle that lasts about a month.
- Most objects in the solar system are in regular and predictable motion. Those motions explain phases of the Moon and solar and lunar eclipses.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

In the past, eclipses of the Sun and Moon were considered to be ominous events, spreading fear throughout the masses. Today, we know that an eclipse is actually a very regular, predictable phenomenon and while they are no longer feared, they are followed with great interest round the world. There are two different types of eclipses and both are caused by the motion of the Moon. A solar eclipse happens when the Moon passes between the Earth and the Sun, casting a small shadow on the face of the Earth. Solar eclipses can only happen during a new moon phase and because the Moon's shadow is relatively small, in order to see the entire Sun blocked out, you must be lucky enough to be within the path of totality which is generally less than 300 kilometers wide. Once you are outside this zone, you either see either a partial eclipse or no eclipse at all. Because the Moon's shadow moves quickly over the Earth, a total solar eclipse usually lasts less than four minutes.

A lunar eclipse happens when the Moon crosses behind the Earth and into the shadow of our planet. Because the shadow of the Earth is so much bigger than that of the Moon, the duration of a lunar eclipse is several hours long and it is visible from a much larger area on the Earth's surface. Lunar eclipses can only happen during a full moon phase and unlike a total solar eclipse where the Sun is completely blocked out, the Moon is still visible. Instead of going black, the Moon often takes on a deep red color illuminated by light that is refracted by Earth's atmosphere.

Eclipses follow a natural cycle based on the geometry of the orbits of the Earth and Moon and generally occur once each year. The reason we don't have eclipses during each new and full moon is due to the fact that the plane of the Moon's orbit around the Earth is tilted about five degrees to the plane of the Earth's orbit around the Sun. As a result, an eclipse can only occur when the Moon, Earth and Sun are on the same plane and in a straight line.

Pre-Visit Activity

Umbral and Penumbral Shadows

When spherical objects (like the Moon and Earth) cast a shadow, they actually cast two shadows, one on the inside and one on the outside. The inner, darker shadow is called the umbra and it narrows to a point behind the object. The outer shadow, called the penumbra, is lighter and spreads out from behind the object. When eclipses happen, they begin with the penumbral shadow, move through the umbral shadow and conclude with the penumbral shadow again. It is easy to demonstrate how these two types of shadows interact by using a simple model.

Set up an overhead projector or bright desk lamp with the shade removed near the middle of a darkened room. Place a projection screen or large sheet of white paper about ten feet from the light. Use a Styrofoam ornament ball with a pencil stuck into it to simulate the eclipsing celestial object. Hold the ball about two feet in front of the light source by the pencil so that it casts a shadow on the screen. Make sure you stand off to the side so that you don't block any student's view. On the screen you should see two shadows, a darker inner shadow (umbra) and a lighter outer shadow (penumbra). By moving the ball closer to and farther from the screen, you can change the relative size of the two shadows. Ask students to predict what would happen if they were standing on the Earth when a shadow from the Moon passed over them. After they have expressed their ideas, invite them to visit the planetarium where they will see firsthand what the results of these shadows would look like.

The Digital Lesson: Solar and Lunar Eclipses

The *Solar and Lunar Eclipses* lesson is designed to introduce students to the concept of why and when we see eclipses from Earth. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Eclipses

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at what causes eclipses of the Sun and Moon. These are called solar and lunar eclipses.

Before we get started, can anyone explain what we mean by the term 'eclipse'?

[An eclipse is when the shadow of one celestial object temporarily covers another object. A solar eclipse happens when the Moon blocks the Sun from reaching Earth and a lunar eclipse happens when Earth blocks the Sun from reaching the Moon.]

In the past, people were frightened when eclipses occurred. They thought that they were bad omens and that they would bring bad luck. This is easy to understand because very few people actually understood what was happening to cause an eclipse. These days, eclipses are easy to understand and easy to predict. Even so, seeing one in the sky is a fantastic event and some people travel great distances to experience one.

2. Solar Eclipse

Let's start with a solar eclipse. Here we are looking at the Sun in the sky from a point on Earth. The sky appears darker then it really is so that we can see the Sun better. In the sky next to the Sun, you see a label for the Moon. From Earth, we can't see the Moon because the entire lit side is facing away from the Earth.

Can anyone tell me what Moon phase this would be?

[New moon.]

A solar eclipse can only occur during a new moon. During a new moon, the Sun and Moon are both in the sky during the daytime. During a real solar eclipse, you should never view the Sun directly. The intense light can cause severe damage to your eyes! Here in the planetarium, however, we're safe!

Now let's speed up time a little and watch what happens to the Sun.

Action

Click on the button to put the Earth and Moon in motion. Stop when the edge of the Sun starts to get blocked by the Moon — about 10:14 AM on the time counter.

Even though we can't see the Moon, we can see the disc of the Moon beginning to move in front of the Sun. It looks like there is a small curved bite taken out of the Sun. The point when the Moon just begins to cover the Sun is called 'first contact'.

Now let's continue watching the eclipse. Can anyone predict what will happen as the Moon continues to move in front of Sun?

[As the Moon moves, more of the Sun will be covered.]

Action

Click on the button to put the Moon in motion again. Stop when the disc of the Moon completely covers the Sun — about 11:25 AM on the time counter.

3. Solar Eclipse Totality

Here we are at a point that scientists call 'totality'. As the name suggests, it's when the disc of the Moon totally covers the Sun.

Besides the darkened sky, what else can you see?

[A halo appears around the Sun.]

The bright halo that you see around the Sun is called the 'corona'. It means 'crown' and it's the outermost layer of the Sun. The only time that the Sun's corona is visible from Earth is during a total solar eclipse. Most of the time, the glare from the Sun is so bright that it keeps us from seeing the corona. During totality of an actual eclipse, it not only gets dark enough to see the corona of the Sun, but the stars in the daytime.

The period of totality is very short. In most cases, it lasts less than four minutes. Let's put the Moon in motion again so we can see the end of the eclipse.

Action

Click on the button to put the Moon in motion again. Stop when the disc of the Moon completely leaves the Sun — about 12:50 PM on the time counter.

Now the eclipse is complete. The point at which the disc of the Moon leaves the Sun is called 'last contact'. The length of time between the first and last contact is usually about 2 ½ hours.

Not every solar eclipse is a 'total eclipse' however. Let's take a look at the same eclipse we just saw from a different place on Earth.

4. Partial Eclipse

Here we see the Sun and like before, the Moon is not visible. This time, it's not labeled. I'll put the Moon in motion and let's see if you can spot it. Say 'stop' when you think you know where the Moon is.

Action

Click on the button to put the Moon in motion. Stop when the disc of the Moon begins to cover the Sun — about 9:55 AM on the time counter.

Here we are at the first contact of the eclipse. I'm going to put the Moon in motion again. Let's see how this eclipse compares with the one we just watched.

Action

Click on the button to put the Moon in motion again. Stop when the disc of the Moon leaves the Sun — about 11:25 AM on the time counter.

Can anyone explain some of the differences between the two eclipses?

[During the second eclipse, there was never any totality. Instead of moving directly across the face of the Sun, the Moon only covered a part of the Sun. The second eclipse took much less time to happen.]

The second eclipse is called a 'partial eclipse'. As the name suggests, only a part of the Sun was covered. As a result, you could not see the corona at all. As it turns out, partial solar eclipses are much more common than total solar eclipses. The reason has to do with the way the shadow caused by the Moon crosses the Earth. The best way of seeing this is to take a quick trip into space.

5. Demonstrating a Partial Eclipse from Space

Here we are about 6.4 million kilometers from Earth. We're looking at both the Earth and the Moon.

Since we can see them both lit, where must the Sun be?

[The Sun would have to be directly behind us.]

On the surface of the Earth you can see two circles. These represent the shadow cast by the Moon. The Moon's shadow has two parts. The inner darker part of the shadow is called the 'umbra'. The outer lighter part of the shadow is called the 'penumbra'. The only places on Earth that will experience a total solar eclipse are those over which the umbral shadow passes. People who are in the penumbral shadow will see only a partial solar eclipse. In this view the smaller circle at the center represents the umbral shadow and the larger circle is the penumbral shadow. Let's see what happens as the Moon crosses between the Sun and the Earth.

Action

Click on the button to put the Moon in motion. Stop when the disc of the smaller circle is centered in the middle of Africa — about 10:00 UT on the time counter.

Based on what we just learned, where would people be seeing a total solar eclipse?

[The only place is within the smaller circle, right in the middle of Africa.]

Where would people be seeing a partial eclipse?

[Anywhere within the larger circle.]

Let's continue with the eclipse. As we do, think about this . . . is there any place on Earth that people won't be seeing an eclipse?

Action

Click on the button to put the Moon in motion again. Stop when the shadow circles completely leave the Earth — about 13:00 UT on the time counter.

So, who missed the eclipse?

[Everyone who is not in either circle including South Africa, Australia, Antarctica as well as the people in North and South America.]

Even though solar eclipses occur almost every year, can anyone explain why most people on Earth never get a chance to see them?

[Unless people are in the path that the umbral shadow follows, known as the path of totality, they won't see a total solar eclipse. Many people also miss the partial eclipse too because even though the penumbral shadow is bigger, it still won't cover the entire Earth.]

6. Lunar Eclipse

Solar eclipses aren't the only type of eclipses that we experience here on Earth. We also have 'lunar eclipses'.

Can anyone explain what a lunar eclipse is?

[A lunar eclipse happens when the Moon passes behind the Earth and our planet blocks the Sun from reaching it. Basically, it's when the shadow of the Earth falls on the Moon.]

Let's take a look at a lunar eclipse in action . . .

Action

Click on the word 'here' to change the setting to see the Moon in space.

Here we are looking at the Moon in the sky from Earth. What phase is it in?

[Full moon.]

Lunar eclipses can only occur during a full moon phase.

Action

Click on the button to put the Moon in motion. Stop when the shadow of the Earth just starts to cover the Moon — about 4:30 PM on the time counter.

It's about 4:30 PM. Here we are at first contact again only this time instead of the shadow of the Moon covering the Earth, we have the shadow of the Earth covering the Moon.

Where would the Sun have to be in space for this to be happening?

Have the class point in the direction where they think the Sun is.

[Directly opposite the Moon from the Earth.]

Let's continue with the eclipse.

Action

Click on the button to put the Moon in motion again. Stop when the shadow completely covers the Earth — about 5:30 PM on the time counter.

Here we see the Moon completely covered by Earth's shadow, but the Moon still looks fairly bright. The reason for this is due to the fact that just like the Moon's shadow has two parts, so does the shadow of the Earth. Right now, the Moon is being covered by the Earth's 'penumbral' shadow. This is the lighter, outer part of the shadow. I'm

going to put the Moon in motion again and I'll stop when we've entered the 'umbra' of Earth's shadow.

Action

Click on the button to put the Moon in motion again. Stop when the dark shadow begins to cover the Moon — 5:45 PM on the time counter.

7. Lunar Eclipse Totality

When the Moon enters the umbra of Earth's shadow, you can see a big change in its brightness. Let's continue until we get to totality.

Action

Click on the button to put the Moon in motion again. Stop when the umbral shadow completely covers the Moon — about 6:45 PM on the time counter.

Okay, it's 6:45 PM and we've reached the point of totality.

How is a total lunar eclipse different from a total solar eclipse?

[During a total lunar eclipse, you can still see the Moon only it turns a dark reddish color.]

Let's put the Moon in motion again so we can see how long a total lunar eclipse lasts.

Action

Click on the button to put the Moon in motion again. Stop when the dark umbral shadow begins to leave the Moon — 8:00 PM on the time counter.

Okay, it's now 8:00 PM. How much time has elapsed since the total part of the lunar eclipse started?

[About an hour and 15 minutes.]

How does this compare with the length of time that a total solar eclipse takes?

[It's much longer. Totality for a solar eclipse rarely lasts more than 4 minutes.]

8. A Solar vs. Lunar Eclipse

I'm going to put the Moon in motion one more time so that we can watch the end of the eclipse. As we do, I want you to think about this . . . Why does a lunar eclipse last so much longer than a solar eclipse?

Action

Click on the button to put the Moon in motion again. Stop when the penumbral shadow completely leaves the Moon — about 10:25 PM on the counter.

Now it's about 10:25 PM and the lunar eclipse is finally over. The entire eclipse from first contact to last contact has taken over 6 hours.

Does anyone have a guess as to why lunar eclipses last so much longer than solar eclipses?

[Because the Earth is much bigger than the Moon, about 4 times the diameter, the shadow cast by the Earth is also much bigger. It takes the Moon much longer to move through it.]

And now for a bonus question . . . which do you think is more common to view from Earth, a lunar eclipse or a solar eclipse and, most importantly, why?

[Lunar eclipses are far more common for the same reason that they last longer. Usually, when the Moon enters the Earth's shadow everyone on Earth who can see the Moon can see the eclipse. Because the Moon's shadow is much smaller, to see even a partial solar eclipse, you have to be in the right spot at the right time. The truth is, both eclipses happen with just about the same frequency. It's only the number of people who can see them that differs!]

This wraps up our little eclipse adventure. Now, your next assignment is to find out when the next eclipse is going to happen in the real sky and check it out for yourself!

Have students recap their observations. The main concepts are: 1) A solar eclipse is caused by the Moon blocking the Sun and casting a shadow on the Earth. 2) A lunar eclipse is caused by the Moon moving through the Earth's shadow. 3) Solar eclipses can only happen during a new moon. 4) Lunar eclipses can only happen during a full moon. 5) Both lunar and solar eclipses can be either total or partial events.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson A5 — Eclipses.

Extending the Lesson

Eclipse Models

After conducting the planetarium lesson, a good way to reinforce the mechanics of an eclipse is to have students create their own simple model using a flashlight to represent the Sun, a globe to represent the Earth and a small ball to represent the Moon. Allow students to test their knowledge by first drawing the alignment for both solar and lunar eclipses on a piece of paper and then experimenting with the hands-on materials.

Web Search for Future Eclipses

When will the next eclipse be visible from your location? Since eclipses occur on a regular basis, they can be predicted well in advance. Have students conduct a Web search to find out when the next solar and lunar eclipses will occur for your location. For the solar eclipse, have them plot the path of totality on a map or globe. For the next lunar eclipse, have them determine if it will be a partial or total eclipse and when will be the best time for viewing.

Eclipses of the Past

People have been observing eclipses for a great many years and there are many stories of how they affected people of the past. Some were reported to have stopped battles and others caused the downfall of important leaders. Have students research some of the connections between eclipses and history to see the different ways these celestial events many have impacted societies of the past.

Eclipse Photos

As long as there have been cameras, people have been photographing eclipses. Have students search out pictures of past eclipses in order to create an eclipse collage. In addition, they can report on how the technology has changed over the past century and what new techniques may be on the horizon.

Lesson 7 — Overview of the Solar System

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements.
- Most objects in the solar system are in regular and predictable motion.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

You can think of our solar system as our local neighborhood in space bound together by the force of the Sun's gravity. In addition to a central star (the Sun), the solar system also contains a variety of other objects including planets, moons, asteroids and comets. Each of these celestial objects has its own unique set of properties and as new information became available, the definitions of each of these objects have been revised. Take the word planet for instance . . . it's based on the ancient Greek term that means 'wanderer' because early on, these objects were seen to wander back and forth across the sky. In ancient times there were only five known planets, but after the invention of the telescope, this number was increased to nine including our Earth and the Pluto, which was originally classified as a planet when it was discovered back in 1930.

As technology advanced and more discoveries were made, astronomers began to identify even more 'wandering objects'. Moons were like planets except instead of orbiting a star directly, they orbited a planet. Originally there was only one moon, but today there are well over 100 known moons. Objects with highly elliptical orbits that produced long glowing tails when they approached the Sun were called comets. Rocky objects that orbit the Sun directly that are too small to be planets are called asteroids.

Recent discoveries of a number of large objects orbiting the Sun past Pluto have forced scientists to go back and refine the definition of the word 'planet'. As a result of this recent decision, there are now eight official planets in the solar system. Pluto, along with several other large objects orbiting the Sun beyond Neptune, is now classified as a 'dwarf planet'. Undoubtedly new discoveries will be made that may require astronomers to change some of these definitions again. That is the way science is supposed to work however, which is an important lesson in itself.

Pre-Visit Activity

Road Map of the Solar System

Before taking a long trip in a car, most people will consult a road map to get a sense of just how far they are going to travel. In order to give students a tangible sense of just how far the planets are away from each other, you can have them construct a 'roadmap of the solar system' using a roll of adding machine tape as the base. Have the students begin by first measuring the exact length of the tape in meters. Most often the rolls are between 40 and 50 meters long. In order to get the appropriate scale, divide the length of tape by 30 astronomical units (A.U.) which is the average distance between the Sun and Neptune, the last official planet. (1 A.U. equals the average distance between the Sun and Earth, about 150,000,000 kilometers.) In this way, you will be certain to have enough tape to plot all the way to the last planet.

Using the chart below and the calculated scale, calculate the scale distance between each planet and the Sun in meters. Label one end of the tape with the word SUN and then using the scale distances and a meter stick, plot each of the planets in order. Not only will this give students a better sense of the true size of the solar system, but it will help them hone their mapping and mathematical skills.

Example: If the adding machine tape is 50 meters long, divide it by 30. This means that 1 AU is equal to 1.67 meters. To plot Mercury, you would multiply its distance (0.4 AU) by 1.67 meters so that the distance from the Sun on the map would be 0.67 meters.

Planet Name	Average Distance From Sun (AU)
Mercury	0.40
Venus	0.75
Earth	1.00
Mars	1.50
Jupiter	5.00
Saturn	10.00
Uranus	20.00
Neptune	30.00

The Digital Lesson: An Overview of the Solar System

This lesson is designed to introduce students to some of the characteristics of the known planets in the solar system. Because it is a long lesson, you may want to split it into two parts. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at our local neighborhood in space . . . a place we call the solar system.

Does anyone have an idea where the term 'solar system' comes from?

[The Latin word for Sun is 'Sol'. A solar system includes all of the objects that are in orbit around the Sun.]

Our solar system is a busy place. In addition to Earth, there are seven other 'officially recognized' planets. The reason I say 'officially recognized' is because recently, astronomers have agreed that Pluto, which up until August of 2006 was the ninth planet in the solar system, should no longer be classified as a planet. I'm getting a little head of myself however. We'll come back to this planet question again later and see why this change with Pluto was made.

Besides planets, what other objects can be found in the solar system?

[Moons, meteoroids, asteroids, comets.]

Now here's a tough question . . . how many stars are there in our solar system?

[Only one star . . . the Sun. All the rest of the stars that we see at night are way outside our solar system.]

Let's take a look at the sky and see how these things fit together.

2. Our Solar System

Let's start with a view of our solar system. Here we are looking at the Sun from about 500 million miles away. It's as if we are hovering in a spaceship looking down at the

solar system. If you look closely, you can see four planets orbiting the Sun plus five additional colored lines. These colored lines represent the orbits of the other planets and Pluto. It turns out that our solar system is so big that at this scale, we can't see the full orbits of all the planets at once. If we wait a while, we'll see the other planets come into view.

Which planet is closest to the Sun?

[Mercury.]

Which one is farthest away?

[Even though we can't see it here, Neptune is.]

Moving out from the Sun, the order of the eight planets is Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

3. The Sun

Today, we realize that the Sun is the center of the solar system and everything else orbits around it. This wasn't always the case, however. Less than 500 years ago, most astronomers believed that the Earth was at the center. This was known as the geocentric (meaning Earth-centered) system and it was based on the work of a Greek astronomer named Ptolemy. The problem was that when astronomers tried to use the geocentric model to predict where the planets should be in the sky, their predictions were often wrong. A Polish astronomer named Nicholas Copernicus began looking for another, simpler system. In 1543 he wrote a book that presented a heliocentric (meaning Sun-centered) model of the solar system. It took over 100 years for his ideas to catch on, but eventually, his model proved to be correct.

4. Planetary Motion

Let's look at the motion of the planets. Are they all moving the same way around the Sun?

[The planets are all moving in the same direction but not at the same speed.]

Which planet is moving the fastest? Why do you think this is?

[Mercury moves the fastest. The reason is because of the size of the orbit. The smaller the orbit, the faster a planet moves around the Sun.]

In this view, the orbits of the planets have been sped up quite a bit. Under real conditions, how long would it take Earth to make one orbit around the Sun?

[One year.]

Watch the motion of Earth and Mars. About how much longer does it take Mars to orbit the Sun than Earth?

[Mars's orbital period is about twice that of Earth's.]

The farther a planet is from the Sun, the longer it takes for it to complete one orbit. This makes sense because as the distance from the Sun increases, so does the length of the orbit. Back in the early 1600s, another astronomer named Johannes Kepler discovered this fact. He also discovered something interesting about the shape of the orbits of the planets.

5. Planetary Orbit

What shape do the orbits of the planets appear?

[Oval.]

Kepler discovered that the shape of the orbits are really ellipses. An ellipse is like an

oval. The truth is that the orbit of most planets is close to being a circle.

Planets aren't the only objects that orbit the Sun, however. If you look closely you'll see hundreds of small white dots.

Can anyone guess what these objects might be?

[Asteroids.]

6. Asteroids

Originally called the 'minor planets', asteroids were first discovered in the early 1800s. Recent space probes have shown that asteroids are made mostly out of rock and range in size from a grain of sand, to over 900 kilometers across.

Where do most of the asteroids appear to be moving?

[Between Mars and Jupiter.]

Many asteroids are in a stable orbit around the Sun between Mars and Jupiter in an area called the 'asteroid belt'. If you watch closely, however, some asteroids do cross the orbit of planets including our Earth. While it doesn't happen too often, scientists believe that Earth has been hit by asteroids many times in the past.

Now let's move a little farther out in space so we can get a better view of the entire solar system.

7. Planetary Orbits from Space

Here we are almost nine billion kilometers from the Sun. Now you can see the full orbit of the last four planets in the solar system.

Why can't we see the orbits of the rest of the inner planets from here?

[At this scale, the orbits of Earth, Venus, Mars and Mercury are too small to see.]

Why do you think that Pluto is moving so much more slowly than Jupiter?

[Since Pluto has a much larger orbit, it moves more slowly.]

Astronomers have long considered Pluto to be a different type of planet based on the shape of its orbit. Take a close look at the orbit of Pluto.

How is its orbit different from that of the other planets we've looked at so far?

[Pluto's orbit is much more stretched out. In addition, even though it doesn't look like it here, Pluto actually crosses the orbit of Neptune.]

Not only is the orbit of Pluto much more elliptical than that of the other planets, but if we look at the solar system edge on, it has another big difference. Let's take a look.

Action

Click on the word 'here' to change the location for viewing the solar system edge on.

Here we are a little farther out in space. Instead of looking down on the solar system we are looking at it from the side. As in the last two views, the lines represent the orbits of some of the planets.

Which planets are represented here?

[Venus, Earth, Saturn, Uranus and Neptune plus Pluto.]

As you can see, our solar system is really quite flat when viewed edge on. Take a look at the orbit of Pluto though. It's colored with a green line to make it stand out.

How is Pluto's orbit different from those of the planets shown?

[Pluto's orbit is much more tilted than the orbits of the planets.]

8. The Ecliptic and Kuiper Belt

All of the planets in the solar system orbit the Sun in nearly the same plane. Astronomers call this plane 'the ecliptic'. Pluto's orbit is tilted 17 degrees to the plane of the ecliptic. Because of these orbital differences and the fact that Pluto is made mostly of ice, astronomers concluded that Pluto should be reclassified. Instead of calling it a 'planet', Pluto, along with several other large icy bodies farther out in the solar system is now known as a 'dwarf planet'. These orbiting bodies are often called 'Kuiper Belt Objects' or 'KBOs'. The Kuiper Belt, named for astronomer Gerard Kuiper who first proposed it, starts at about the orbit of Neptune and extends out well beyond the orbit of Pluto. The Kuiper Belt also contains millions of smaller icy objects called 'comets'. Every so often, a comet will drift into the inner part of the solar system and we can see it in the sky. It is important to remember that as new discoveries are made, astronomers have to keep changing their ideas about our neighborhood in space.

This would be a natural break point to stop the lesson and continue at a later time. If time permits, you can continue with the inventory of the solar system.

9. The Planet Mercury

Now that we've seen the big picture of how our solar system is put together, it's time to take a close-up view of each planet. Thanks to a series of unmanned space probes, astronomers have been able to obtain a wealth of data on every planet in the solar system. Let's see what they've found out.

First we'll visit Mercury, named for the messenger of the gods.

Action

Click on the word 'here' to view Mercury close up.

Up close, Mercury looks a lot like Earth's Moon because it's covered with craters. Mercury is the smallest planet in the solar system. It takes only 88 days for Mercury to orbit the Sun but it rotates very slowly. One day on Mercury lasts 58 Earth days. With almost no atmosphere to trap heat, Mercury has the biggest temperature range of any planet. On the lit side it can reach over 430 degrees Celsius but when it's dark, the temperature drops to – 273 degrees Celsius.

10. The Planet Venus

Now let's move on to Venus, named for the Roman goddess of love.

Action

Click on the word 'here' to view Venus close up.

For many years astronomers considered Venus to be a 'twin' of Earth. It's about the same size and mass as our world and with a telescope you can see that it's covered with clouds. In fact, at one point they thought that Venus could have living things on it until they discovered that the planet is really a 'toxic twin'. Instead of being made of water vapor like the clouds here on Earth, the atmosphere of Venus is composed of carbon dioxide and sulfuric acid! Because carbon dioxide is a greenhouse gas, it traps heat giving Venus a surface temperature of almost 500 degrees Celsius making it hotter than Mercury. If that isn't bad enough, all that carbon dioxide means the atmospheric pressure of the planet is hundreds of times greater than Earth. If the heat and toxic gases didn't get you, you'd literally be crushed to death by the weight of the air!

Like Earth, the surface of Venus has mountains and valleys. At one time, water may have existed on the surface but since the temperature is so far above its boiling point, any water would have turned to vapor long ago. It takes Venus 225 days to orbit the Sun and its rotation is even slower than that of Mercury. One day on Venus would equal 243 Earth days. Back in 1965, astronomers discovered that Venus has a 'retrograde rotation' meaning that it rotates in the opposite direction of most other planets in the solar system. On Earth, we see the Sun rise in the eastern part of the sky and set toward the west. For an observer on Venus, the Sun would rise in the west and set in the east!

11. The Planet Mars

Let's continue our journey. Next stop Mars, named for the Roman god of war.

Action

Click on the word 'here' to view Mars close up.

Mars is often called the 'red planet' and as you can see from this close-up view, the name is well deserved. Over the years, scientists here on Earth have sent a number of space probes to Mars, several of which have actually landed on the planet. What they discovered is that Mars is covered with a fine red dust. While its atmosphere is thinner than here on Earth, Mars does have periodic wind storms.

Mars is about half the size of Earth but it rotates at just about the same speed . . . once every 24 1/2 hours. One year on Mars lasts 687 Earth days which means it takes Mars about twice as long as Earth to orbit the Sun. While we have yet to find any running water on the surface of the planet, Mars almost certainly has some water frozen beneath the surface. As you can see in this photo, Mars also has a distinctive polar ice cap. However, instead of being made of frozen water like the icecaps here on Earth, the polar caps on Mars are thought to be made of frozen carbon dioxide which is similar to 'dry ice'.

Most scientists are convinced that at some point in its past, Mars did have running water on the surface and may have even had an ocean or two. Close up photos show what look like dried up river channels and at least one 'grand canyon'.

Action

Click on the word 'here' to view Valles Marineris.

Here we're looking at the grand canyon of Mars. Known as Valles Marineris, it stretches over 4000 kilometers and averages six kilometers deep making it much larger than Earth's biggest canyon. Mars also has some rather large volcanoes, including Olympic Mons, the largest volcano discovered in the solar system to date. Rising to a height of 25 kilometers, 'Mt. Olympus' is almost three times taller than Mauna Loa, the biggest volcano on Earth. Unlike the volcanoes here on Earth, all of the Martian volcanoes have long since stopped erupting lava but when they were active, they certainly would have had a major impact on the Martian climate.

12. The Planet Jupiter

Now it's time to leave the 'inner solar system', cross the asteroid belt and move on to Jupiter, the king of the planets!

Action

Click on the word 'here' to view Jupiter close up.

Here we're looking at Jupiter, the largest planet in the solar system and the first of the so-called 'outer planets'. Named for the king of the Roman gods, Jupiter is not a rocky world like the first four planets. Instead, Jupiter is made primarily of condensed hy-

drogen and helium, two substances that would be gases here on Earth. Most scientists believe that deep under the surface, Jupiter probably has a dense rocky or metallic core. Jupiter is truly a massive planet. Its diameter is more than eleven times greater than Earth and it is 317 times more massive. While it takes Jupiter almost twelve years to complete one orbit around the Sun, its day is surprisingly short . . . only about ten hours — faster than any other planet.

Looking at Jupiter through a telescope is a real joy. The first things you see are the multicolored bands of clouds stretching across the planet. On this image, you can also see the famed 'Great Red Spot'. First discovered over 300 years ago, scientists think that it's a giant storm that could swallow the entire Earth. Through a telescope, you can also see some of Jupiter's moons.

13. Moons of Jupiter

Here we are looking at a view of Jupiter that is probably very similar to the one that Galileo had back in 1609. Using a simple telescope, Galileo was the first one we know of who actually used the device to look at objects in the night sky. In addition to craters of the Moon and the phases of Venus, Galileo discovered four 'starlets', as he called them, orbiting Jupiter. Today we know these starlets were really four big moons. These discoveries not only helped to convince Galileo that Copernicus was correct about the Sun being at the center of the solar system, but they showed astronomers that there was much more to the night sky than they ever imagined.

Today astronomers have identified more than 60 natural satellites orbiting Jupiter but the four largest are still called the Galilean Moons in honor of their discoverer. You can see them pictured here moving in a regular pattern that can easily be tracked from Earth.

14. The Planet Saturn

Our next stop is Saturn, the ringed wonder!

Action

Click on the word 'here' to view Saturn close up.

There is probably nothing as spectacular as viewing Saturn for the first time through a telescope. While astronomers now know that all of the outer planets have some type of ring structure, the rings of Saturn are by far the best developed and the most spectacular. Named for the Roman god of the harvest because of its golden wheat color, Saturn is the second largest of the planets. It's about 9 ½ times wider than Earth but 95 times more massive. In fact, the mean density of Saturn is less than that of liquid water so, if you had a big enough bathtub, Saturn could float in it! The reason for the planet's low density is due to the fact that like Jupiter, Saturn is composed of mostly hydrogen and helium with a much smaller core.

It takes Saturn almost 29 ½ years to complete one orbit around the Sun but like Jupiter, it spins really fast with a day that is only 10 hours and 14 minutes long. Like Jupiter, Saturn also has a large family of moons to go along with its rings. In fact, some scientists believe that these moons not only keep the rings in place, but provide the raw material to make the rings. Based on information from the Cassini space probe, we know that the rings are made of mostly ice and dust and it's quite possible that they formed when one or more of Saturn's moons got smashed or ripped to pieces.

The story behind Saturn's rings is far from complete but astronomers are getting new information every day which will help them put the pieces together. Now it's on to our next destination . . . Uranus.

15. The Planet Uranus

Unlike all of the planets that we have looked at so far, nothing was known about Uranus before 1781. That is when it was first discovered by the astronomer William Herschel using a homemade telescope. Because it is more than a billion and a half kilometers from the Sun, Uranus is not visible to the naked eye. At this great distance, it takes a little more than 84 years to make one complete orbit of the Sun yet like the other outer planets, it rotates quickly. A day on Uranus lasts 17 ¼ hours but unlike all the other planets, Uranus spins in a unique direction.

Action

Click on the word 'here' to view Uranus rotating.

It appears that sometime in the past, something crashed into the planet knocking it over on its side, as a result, the axis of rotation for the planet is tilted almost 90 degrees.

While Uranus does have a small set of rings, they are not nearly as well developed as Saturn's. Uranus is also smaller than either Saturn or Jupiter, roughly four times larger than our Earth. To go along with the rings, Uranus has at least 15 moons but as new images of the planet become available, this number will almost certainly increase.

16. The Planet Neptune

Next stop Neptune, the last planet of the solar system.

Action

Click on the word 'here' to view Neptune close up.

Neptune wasn't officially discovered until 1846 but that doesn't mean that people didn't know it was there. Because of a wobble in the orbit of Uranus, astronomers felt that there had to be another planet whose gravity was tugging on it. After many painstaking calculations, the position of this mystery planet was predicted and sure enough, when astronomers trained their telescopes on that part of the sky, they discovered the planet. In truth, it appears that Galileo had been the first one to actually see Neptune over 200 years earlier, but he just thought it was another star.

Neptune is the smallest of the four 'gas' planets being a little smaller than Uranus. Rotating once every 16 hours, Neptune has some of the fastest winds ever recorded. Like Jupiter, Neptune has a large storm moving around the planet. Known as the great dark spot, you can clearly see it here on this image taken by the Voyager 2 space probe. It takes Neptune almost 165 years to make one complete orbit of the Sun and because it's so far away, the planet actually generates more heat from the inside than it gets from the Sun. As with the other outer planets that we've looked at so far, Neptune has more than a dozen moons and is composed mostly of hydrogen.

17. Pluto

And now onto our final destination . . . Pluto.

Action

Click on the word 'here' to view Pluto close up.

Even though Pluto is no longer classified as a planet, it's worth taking a look at because it represents the first of a whole new class of objects found at the outer edge of our solar system. Named for the Roman god of the underworld because it is in perpetual darkness, Pluto is so far out in the solar system that the Sun would appear to be nothing more than a bright star. It takes Pluto 248 years to complete one orbit of the Sun. Discovered in 1930, Pluto is only about 1/5 the size of Earth.

Almost since its discovery, astronomers had questions about whether Pluto was really a planet. Unlike the inner planets it's not made of rock and unlike the outer planets it's not made of gas. Instead, Pluto appears to be made mostly of ice. This fact plus it's highly elliptical orbit and orbital tilt had some astronomers thinking that Pluto should be reclassified. With the discoveries of other large orbiting objects even farther from the Sun than Pluto, the decision was made to create a new class of objects called 'dwarf planets'.

Pluto has three known moons, the largest of which is called Charon and is visible in this view. Even though it's now considered to be a dwarf planet, Pluto is still a big part of our solar system's story because trapped within its icy body may be some of the original matter that our solar system was made from!

Well, that brings us to the end of our tour of the solar system. I hope you enjoyed the ride and remember to stay tuned to the latest breaking news about our neighborhood in space.

Have students recap their observations. The main concepts are: 1) The Sun is the only star found in our solar system. 2) The solar system contains a variety of different celestial objects including planets, moons, asteroids and comets. 3) Planets orbit the Sun at different distances. 4) Each planet has a different size, location and set of physical properties. 5) The Sun is the largest object found in the solar system forming a central mass around which the planets orbit.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson B1 — Overview of the Solar System.

Extending the Lesson

Planetary Travel Brochures

An excellent way of having students conduct independent research on the solar system and enhance their creative writing skills is to have them create their own travel brochures for each of the planets or moons. Have each student select a different celestial object and using books, magazines and Web sites, research some of its physical properties. Interesting facts would be things like distance from the Sun, length of the day and year, surface temperature and composition. Once they have collected their 'facts', they should write it up in the form of a travel brochure similar to those available at travel agents for exotic places here on Earth. They can even decorate their brochures with pictures and if time permits, make an oral presentation to the rest of the class where they can 'pitch their planet'.

How Did the Planets Get Their Names?

With the exception of Earth, all of the names of the planets are taken from the names of characters in Roman mythology. As it turns out, these names weren't given by chance. Each planet was identified with a particular mythological character because of properties that the two shared. An ideal research project that also leads into the study of Greek and Roman mythology is to have students select a planet and compare its properties to that of the character and see if they can make the connection.

The Great Planet Debate

As you might expect, many people including astronomers were not happy with the decision of the International Astronomical Union that reclassified Pluto as a dwarf planet. Some people believed that Pluto should be called a planet for sentimental

reasons and others felt that instead of 'demoting' Pluto, the newly discovered Kuiper Belt Objects should be classified as planets too. Whatever your opinion is, the truth of the matter is that this is a great lesson on how science works. Over the years, scientists have had to change much of what they originally thought was correct as new information was discovered. Many examples from other scientific disciplines can be found . . . for instance mushrooms were once classified as plants because they grew in the ground, but now they are in their own kingdom because they don't use sunlight to make food. In a similar manner bats were grouped with birds and whales with fish because one had wings and the other swam in the ocean. Now they are both known to be mammals. Have your students research the IAU classification process and see if they agree with it. You can even hold your own in-class Pluto/planet debate. In the end, they still might not all agree with the outcome, but they will have a better appreciation of how real science works.

Lesson 8 — The Motion of the Planets

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements.
- Most objects in the solar system are in regular and predictable motion.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

Recently, our solar system has undergone a serious makeover due in large part to the motion of the planets. For almost 80 years, astronomers had recognized nine different planets. In August of 2006 Pluto, along with several newly discovered objects on the outer reaches of the solar system, was placed in a new category and is now officially known as a 'dwarf planet'. This decision was based primarily on the fact that Pluto crosses the orbit of the planet Neptune, something no other planet does.

This isn't the first time that astronomers have changed their ideas about how planets move. In 140 AD, a Greek philosopher named Claudius Ptolemaeus, most often called Ptolemy, proposed a model to explain how planets moved. Based on what was observed from Earth, Ptolemy concluded that the Earth was the center of the universe and the rest of the planets, along with the Moon, Sun and stars revolved around us. The reasons for suggesting this geocentric or Earth-centered model were obvious. If you watch the Sun, Moon, stars and planets, they do appear to go around us. Since we don't feel the Earth moving, it's much harder to accept that their apparent motion is caused by our planet rotating. One of the big flaws in the geocentric model is the fact that from Earth, Mars, Jupiter and Saturn all appear to 'back up' for a short time as they move past the stars.

The problem caused by this 'retrograde motion' was solved by a Polish astronomer named Nicolaus Copernicus. In a book published in 1543, Copernicus suggested a heliocentric (Sun-centered) model for the solar system with the Sun in the center and the Earth and other planets going around it. To explain the motion of the Sun, Moon and stars across the sky, Copernicus said that Earth also rotated once each day. While the heliocentric system did solve the riddle of retrograde, it still had some problems. This was because Copernicus said that the planets went around the Sun in circular orbits. Later in the early 1600s, a German astronomer named Johannes Kepler calculated that the orbits were really elliptical or oval in shape. With this change, the modern system of planetary motion was finally established.

Pre-Visit Activity

Observing Planets

Students can get a better appreciation of what astronomers had to do in order to come up with a working model of planetary motions by actually observing the planets in the night sky over the course of a few weeks. Start by getting a copy of the current star map for your location. These are available from many Web sites or they can be printed out on your computer using the Starry Night software. For people living in the continental United States, an excellent source of star maps is the Abrams Planetarium located at Michigan State University in East Lansing, MI. Have the students use the maps to locate the position of one or more planets visible in the evening sky. Ask them to plot the position of the planet relative to the stars that can be seen behind it for a period of two weeks. The best way to do this is to have them actually sketch the way the sky looks around the planet making sure that they put the date and time on each drawing. After making the observations, ask them to analyze the drawings to see which way the planet (or planets) move.

If you have a desk top version of the Starry Night software, students can do the same exercise in less than an hour. Start by looking at the sky for a particular night and use the 'find' option on the toolbar to locate a planet that is visible at night. Next, use the advance time button to run time forward for a period of two weeks observing where the planet is relative to the starfield. Since the Starry Night™ software is designed to reproduce the actual night sky, students will be able to make the same observations and record the same data as if they went out at night.

The Digital Lesson: Moving Out — The Motion of the Planets

This lesson is designed to introduce students to the motion of the planets in the solar system as they appear from Earth. In addition, it traces the development of both the geocentric and heliocentric models of the solar system. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at how the different planets appear to move across the sky when viewed from Earth.

Before we get started, do any of you speak ancient Greek?

[Probably not.]

That is too bad because I was wondering if anyone knows what the word 'planet' really means? You see, it's based on the word 'planetes' which is an ancient Greek term meaning wanderers. Now why do you think that they would give the planets such an unusual name? Let's take a look and find out.

2. Wanderers

Here we are looking at a typical night sky. The planet Mars is labeled to make it easier to recognize. What else do you see in the sky?

[The first quarter Moon and lots of stars.]

Okay, now we're going to move forward two weeks moving one day at time. We'll keep our view fixed on the same area in space.

What do you think will happen?

[The Moon will appear to move to the east and change phase, Mars will also shift its position slightly but the stars will remain fixed in their positions relative to each other.]

Action

Click on the *button 14 times in a row and stop when the date is Dec. 22nd.*

Did anyone see any changes? What didn't change?

[Mars shifted ever so slightly but the stars remained fixed in their positions relative to each other.]

Back in ancient times, people were very keen observers of the night sky. They noticed that almost all of the stars stayed in the same patterns night after night. Only five stars appeared to shift positions. They called these special stars 'planets' which meant 'wanderers'. They called them wanderers because unlike the other stars, these seemed to wander back and forth across the sky.

They used some of the visible properties of these 'wanderers' to give them each a name tied to a Roman god. Mercury moved the fastest across the sky so it was named for the fleet-footed messenger. Venus glowed with a beautiful bright white light so it was named for the goddess of love. Blood red Mars was named for the god of war. Jupiter, being the largest, was named for the king of the gods. Saturn, with its golden wheat-like color was named for the god of the harvest.

Today, we know that there are really eight planets. Why do you think they only came up with five?

[In order to see Uranus and Neptune you need a telescope, which wasn't invented until the early 1600s. Because they were standing on the Earth, it wasn't considered to be a planet in the sky.]

3. The Power of Prediction/Geocentric Earth

After watching the motion of the Sun, Moon and planets in the sky, ancient Greek philosophers began creating models for what they thought was going on. They felt that if they had a good working model, then they would be able to predict where the different objects would be in the sky before they got there. This 'power of prediction' is something that modern day scientists look for in models and theories too.

Since everything appeared to be going around the Earth, they naturally assumed that the Earth was the center of the universe. In their model, they put the Earth at the center and had everything else revolve around it in circular orbits. The Moon was placed in the first circle because it seemed to move the fastest. Mercury went in the second circle. It was followed by Venus, the Sun, Mars, Jupiter and Saturn. The final circle was the fixed sphere of stars. Astronomers call this the geocentric model because the Earth (geo) was in the center.

At first, this model worked fairly well for predicting when and where the planets would be in the sky. As time progressed, however, the predictions based on the model became more and more inaccurate. If we watch and plot the motions of the planets with the Earth in the center, you'll see what the problem is.

Action

Click on the word 'here' to show the geocentric model.

Does this look like a simple model?

[No.]

Not wanting to give up on an Earth-centered model, other scientists tried to fix the model by adding small circles inside the large circles to explain the little loops. Finally in 140 AD, an astronomer named Ptolemy came up with the final version of the geocentric model. It was a very complex model which not only had the planets moving in circular orbits around the Earth, but had them moving on little wheels called 'epicycles'. Astronomers used his model for well over 1000 years but by the mid 1500s it was so inaccurate that people began looking for a simpler explanation.

The biggest problem with the geocentric model was what astronomers call 'retrograde motion'. This happens with the planets Mars, Saturn and Jupiter. Let's take a look at what it's all about.

4. Retrograde Motion

The large bright object in the middle is the Sun but I've turned off the daylight. If I didn't would we be able to see Mars?

[Probably not.]

Watch what happens when we speed up time.

Action

Click on the button and stop when you get to about June 12th.

The green line traced out the path that Mars made through the sky. What direction did Mars appear to move?

[First it moved one way, then it stopped, then it moved the other way a little, then it stopped again and continued moving in the original direction.]

The loop you see in the motion of Mars is called the 'retrograde loop'. It happens whenever a planet appears to go backwards through the sky. Do you think that Mars is the only planet that has a retrograde loop? Let's take a look at Jupiter and Saturn and see how they move.

5. Demonstrating Retrograde Motion

Here we are looking at the planets Jupiter and Saturn. The bright object near the western horizon is the setting Sun. As before, I've switched off the daylight so we can actually see the planets in the sky during the day. I'm going to speed up time again. Say stop if you see either Jupiter or Saturn begin to move in a retrograde loop.

Action

Click on the button and stop when the students say to. Saturn should begin to show retrograde motion when the date says November 5. If the students don't see it, stop when the date says November 15.

Okay, so here we are about 5 months later and Saturn is starting to 'back up'. Let's keep going.

Do you think Jupiter will do the same?

Action

Click on the button and stop when you get to about January 15th. Jupiter starts its retrograde loop about January 7th.

6. The Heliocentric Model

Mars, Jupiter and Saturn all appear to move backwards at some time in their orbit. So the big question is, why? This was the same question that had most astronomers confused until 1543. In that year, a Polish astronomer named Nicolaus Copernicus published a book that totally changed the way people looked at the solar system. Instead of going with the geocentric model, Copernicus introduced a 'heliocentric model'. 'Helios' is the Latin word for 'sun'.

Can anyone guess what the heliocentric model looked like?

[Instead of having Earth in the center, the heliocentric model has the Sun in the center. Earth is simply another planet that goes around the Sun.]

The model that Copernicus offered solved many of the problems created by the geocentric model. In addition to having the Earth orbit the Sun, he said that Earth rotated once a day. This explained why the Sun and the Stars appeared to move across the sky. His model still had the Moon going around the Earth but all the other planets moved around the Sun.

His model looked like this . . .

Action

Click on the word 'here' to see the orbits of the inner planets of the solar system.

7. Planetary Speed

This is what we would see if we left the Earth and headed out into space over a billion kilometers from the Sun. You can see the first four planets of the solar system all orbiting the Sun.

They are all traveling in the same direction, but are they all traveling at the same speed?

[No – Mercury is traveling the fastest and Mars is traveling the slowest.]

The fact that the planets travel at different speeds in their orbit explains the riddle of retrograde. Based on this piece of information, can anyone figure out why Mars, Jupiter and Saturn sometimes appear to back up when viewed from Earth? Here's a hint . . .

Have you ever been riding in a car and passed another car going in the same direction? If you didn't know that you were passing the other car, how would it appear to be moving?

[Backwards.]

Here's how the retrograde loop works. Because Earth is orbiting the Sun faster than Mars, Jupiter and Saturn, every year we catch up to and pass these planets. When we're far from the other planet, we see it move across the sky in an easterly direction. As we begin to pull even with the other planet, however, it looks like the other planet comes to a stop. As we pass the other planet it seems to drift backwards but it's really Earth that is moving forward. Finally, once we move far enough along in our orbit and begin to turn around the Sun, the other planet appears to move forward again.

While it may sound complicated, the heliocentric model provided a much simpler explanation of retrograde motion than the geocentric model. Even so, it took almost 100 years for astronomers to accept this new idea. Part of the problem was that in his theory, Copernicus still had the planets moving in circular orbits. Because of this, his model still produced errors when people tried to predict where and when the planets would be visible in the sky.

8. Elliptical Orbit

As it turns out, the planets orbit the Sun in ellipses, not circles. This fact was discovered by a German astronomer named Johannes Kepler in the early 1600s and once he made the corrections, the model worked perfectly.

Figuring out the true nature of planetary motions was one of the most important discoveries in astronomy. Even though it took almost 2000 years to get it correct, the fact is that it is great example of the scientific method in action. By making observations, creating a hypothesis, testing the hypothesis and revising the theory, scientists today are working out even more complex problems!

This wraps up our adventure into planetary motions. Now it's your turn to go out at night and watch the planets as they do their little dance!

Have students recap their observations. The main concepts are: 1) Even though it appears that the planets move around Earth, they orbit the Sun. 2) The original model of the solar system was a geocentric model that had Earth at the center. The geocentric model was complicated and was not very accurate when it was used to predict the position of the planets in the sky. 3) Copernicus introduced the heliocentric model that had the Sun at the center of the solar system. 4) Planets orbit the Sun at different speeds which explains why Mars, Jupiter and Saturn appear to move backwards in a retrograde loop when viewed from Earth.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson C2 — The Motion of the Planets.

Extending the Lesson

Retrograde Motion Model

You can create a simple model of retrograde motion right in the classroom. Start by clearing out a large open space in the classroom or if the weather is nice, you can go out in the school yard. Make up a sign that has the word 'Mars' written on it. Draw a picture of a large star on another piece of paper and make four copies so that you have five 'star signs'. Ask five students to be the stars and have them stand in a line about three feet apart. Ask another student to be Mars. Give this student the Mars sign and have him/her stand about ten feet in front of the first line of students. Mars should be directly in front of the center star. Explain to the rest of the class that they will be the Earth. Have each student slowly walk in the straight line directly past the planet Mars about six feet in front of the student with the Mars sign. As they pass, students should look at where Mars is relative to the stars behind it. They should keep looking at Mars even after they pass it. As they walk past Mars, they should see that it appears to 'back up' relative to the position of the stars behind it.

To make the model even more realistic, you can repeat the procedure but instead of having the students stand in a line, you can have them make a large circle of stars. Have the student who is holding the Mars sign walk slowly around in front of the star circle and have the students who are simulating the Earth walk about twice as fast in the inner part of the circle. Then they will not only see Mars back up, but move forward again too!

Research Kepler, Copernicus, and Galileo

In order to get a better understanding of just how important the work of Copernicus and Kepler was, you can have students research their lives and then discuss the impact of their discoveries. Both of these men faced many challenges as did Galileo, who was the chief defender of Copernicus and paid for it by being imprisoned.

Lesson 9 — Meteors, Asteroids and Comets

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements.
- Most objects in the solar system are in regular and predictable motion.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

In addition to the major planets and their respective moons, our solar system is also home to many billions of smaller objects that also orbit the Sun. On occasion, these objects will cross the orbit of the Earth, our Moon and the other planets and when they do, they often make a big impact. Most astronomers agree that meteoroids, asteroids and comets are all 'leftovers' from when the larger bodies of the solar system first formed. Asteroids were first discovered back in the early 1800s and today we know that they are made primarily out of rock and iron. Most asteroids can be found orbiting the Sun in the space between Mars and Jupiter in the so-called 'asteroid belt' although a group of asteroids known as 'Apollo asteroids' orbit much closer to Earth and actually cross our orbit. Asteroids range in size from more than 900 kilometers across to only a few meters but even a small asteroid can have an enormous impact on the Earth if it strikes in the wrong place. In addition to leaving a massive crater, asteroids can explode in the atmosphere or crash into the ocean triggering killer shock waves and tsunamis. Many scientists believe that it was an asteroid that hit the Earth some 65,000,000 years ago causing one of the largest extinction incidents in our planet's history virtually wiping out the dinosaurs.

Unlike asteroids, comets are made primarily of ice and dust and while they do travel into the inner solar system, they start much farther away. Many comets come from the Kuiper Belt which extends from the orbit of Neptune out past Pluto. As they approach the Sun, comets begin to heat up and some of their ice vaporizes. Energized by cosmic rays streaming from the Sun, the gas starts to glow and along with the dust particles, forms a long tail. Originally, people thought that comets would just appear randomly in the sky but back in the 1700s, Edmund Halley determined that many actually have a regular orbit around the Sun. Unlike planets, however, the orbit of a comet is extremely elliptical.

Each time a comet makes a pass around the Sun it loses some of its mass and in the process, leaves a trail of debris behind it. As the Earth passes through the trail of a comet's tail, we are hit by millions of tiny meteoroids (sand-grain-sized) which burn up when they enter our atmosphere. The streaks of light that these particles produce are called meteors and sometimes, they can produce a spectacular meteor shower.

Pre-Visit Activity

Moon Maps

A great way of introducing students to the damage potential from an extra-terrestrial impact is to have them examine a close-up picture of the Moon. The lunar surface is covered with literally millions of impact craters and by studying their pattern and distribution, students can learn to distinguish old craters from new ones. The first step is for them to make a model of the lunar surface in the classroom.

Fill a large dishpan or baking dish with a layer of baking flour about one inch deep and then sprinkle a thin layer of cocoa powder on top of the flour. Spread a few sheets of newspaper on the floor and place the pan in the center which will prevent you from having 'meteor ejects' all over the floor. Using marbles or small pebbles to simulate the meteoroids, have the students take turns dropping them onto the surface and then looking at the crater that is made. If possible, use a few different-sized meteoroids so that students can compare the craters that they make. After they have dropped a dozen or so, have them compare the surface of the pan with the photo of the Moon. Based on their observations see if they can tell which craters happened first.

Craters on Earth

While they don't stand out as well as the craters on the Moon, there are plenty of impact craters right here on Earth if you know where to look for them. As a preview to going into the planetarium, have students conduct a Web search to see how many different craters they can find. They can even download and print out pictures to compare.

Asteroids and Comets

While students are searching for craters, another fun activity is for them to search out photos of famous asteroids and comets. Nothing beats a firsthand view of one of these objects through a telescope.

The Digital Lesson: Meteors, Asteroids and Comets

This lesson is designed to introduce students to the composition, location and motion of meteors, asteroids and comets as they appear in the night sky. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at some of the small objects that have a big impact in our solar system: the 'big MACs' of the solar system. No, we're not talking about McDonald's® hamburgers here. What I'm referring to are Meteors, Asteroids and Comets.

Before we get started, we're going to have to define a few terms.

Can anyone tell me what a meteor is?

[A meteor is the streak of light produced as a meteoroid travels through Earth's atmosphere and burns up.]

2. Defining Meteors, Asteroids and Comets

People often call meteors 'shooting stars' but they're not stars at all. They are the result of rocks from space hitting our atmosphere at high speed and burning up. There is some confusion about the word 'meteor' however. The actual rock that falls from the sky is not called a meteor, it's called a meteoroid. The thing you find lying on the ground after you see the streak moving across the sky is not a meteor either. That is a meteorite! The meteor is simply the streak of light moving across the sky. You see, a meteoroid, meteor and meteorite can all be the same object only at different times.

Next we have asteroids. What's an asteroid?

[Asteroids are chunks of rock or metal in orbit around the Sun.]

While the largest asteroids are hundreds of kilometers across, many more are smaller than a car. Many meteoroids are actually small asteroids that have broken out of orbit eventually hitting Earth, the Moon and other planets.

Finally we have comets. The word comet comes from the Greek word 'kometes' which

means 'hairy star'. Comets are not really made out of hair, but they are different from asteroids and meteoroids.

Does anyone know what a comet is made from?

[Most astronomers believe that comets are frozen balls of ice, rock and gas. The common analogy is that they are 'dirty snowballs'.]

Okay, so now that we know some of the vocabulary, let's take a look at what some of these big and not so big MACs look like in the sky. We'll go in alphabetical order starting with asteroids.

3. Finding An Asteroid

Here we are looking at the evening sky through a telescope. Do you see any asteroids?

[Probably not . . . everything looks like stars.]

Don't feel bad if you think you just see stars, after all the word asteroid actually means 'star-like object'. They are very hard to see unless you notice their motion. Like planets, asteroids appear to 'wander' across the sky. In fact, in the past, asteroids were often called 'minor planets'. The first asteroid was discovered on Jan 1, 1801 by Giuseppe Piazzi. After viewing the same part of the sky over several nights with his telescope, he noticed that one 'star' appeared to move. At first, Piazzi thought he had discovered a new comet or even a small planet between the orbits of Mars and Jupiter, but what he really discovered was the largest asteroid that we now call Ceres.

Let's take a look at what he saw.

Action

Click on the button to start the motion.

Now we have speeded up time so that it's running about 3000 times faster than normal.

Do you see the asteroid now? Point to it if you think you see it.

[The asteroid is the object that appears to stay still while the stars slowly drift across the sky.]

Action

Click on the button to stop the motion when the time says May 8, 2004 ,12:00 UT.

While Ceres was the first asteroid discovered, it was certainly not the last! Within a few years, other astronomers discovered hundreds more orbiting the Sun. Let's see where they hang out.

4. Asteroid Belt

Here is a plot showing most of the known asteroids larger than 100 kilometers across. Let's see how they move.

In what part of the solar system do most of the asteroids appear to be moving?

[Most large asteroids orbit the Sun in between the planets Mars and Jupiter.]

This area of the solar system is called the main asteroid belt. Early on, astronomers thought that asteroids were debris left over from a planet that got smashed to bits, but these days, most agree that they are actually leftover remnants of material that never

actually pulled together to form a planet. One of the reasons that they stay in this orbit is due to the interaction between the gravity of the Sun and Jupiter. It's almost like a gravitational tug of war with the asteroids stuck in the middle.

5. Toutatis

If you watch closely, you'll see that a few of the asteroids do cross the orbits of the inner planets of the solar system and a few even cross the orbit of Earth. These special asteroids are called 'Apollo Asteroids'. One Apollo asteroid is called Toutatis. Let's take a look at its orbit.

Action

Click on the word 'here' to view the orbit of Toutatis.

Look at the orbit of Toutatis compared to the orbit of Earth. As you can see, Toutatis actually crosses Earth's orbit in two places.

Based on how fast Earth is going around the Sun, about how long do you think it takes Toutatis to orbit the Sun?

[Earth makes five orbits for every one that Toutatis makes so the orbital period of Toutatis is about five years.]

Can you think of any reason that astronomers may be keeping a watchful eye on Toutatis?

[Since it crosses Earth's orbit, it has the potential to actually strike the Earth.]

As it turns out, astronomers believe that our Earth has been struck with Apollo asteroids many times in the past. Often these collisions have resulted in some major changes on our planet. In fact many scientists believe that 65,000,000 years ago, a large Apollo Asteroid struck the Earth in the Gulf of Mexico leading to one of the biggest extinction events in Earth's history. Asteroids aren't the only things that have the potential to interact with our planet. Let's see how comets fit into the picture.

6. Comets

Here we are out in space about 250 million kilometers from the Sun. You can see the Sun in the distance along with the planets Mercury and Venus. The comet that we're looking at is named Comet Hale-Bopp. As we said before, comets are made primarily of ice and dust and can be thought of as being 'dirty snowballs'. Most astronomers believe that they are leftover remnants of the 'stuff' that actually formed our solar system 4.5 billion years ago.

How do comets look different from asteroids?

[They often have a long tail.]

The tail of a comet is made of gas, dust and plasma, which is a super heated gas that glows. A comet's tail is the result of the icy head of the comet being hit with high energy particles from the Sun. Known as the 'solar wind' these particles literally blast material off the comet's surface. While the actual core of a comet (called the nucleus) may only be a few kilometers in diameter, a comet's tail can stretch millions of kilometers into space.

Let's see what happens to the tail of a comet as it approaches the Sun.

7. Comet Hale-Bopp

Comet Hale–Bopp was discovered by two astronomers named Alan Hale and Thomas Bopp. It made a spectacular pass near Earth back in 1997. Watch the comet as we speed up time.

Action

Click on button to start the motion and stop when the date reaches May 15th.

What happened to the tail of the comet as it moved around the Sun?

[The tail changed direction.]

Since the tail of a comet is being pushed by the 'solar wind', a comet's tail will always face away from the Sun. Sometimes, a comet will even ride into its own tail as it moves away from the Sun. Now let's keep watching as Comet Hale–Bopp moves back into space.

Can anyone predict what might happen to the tail?

[The tail of the comet will shrink in size.]

Action

Click on the button to start the motion and stop when the date reaches September 1st.

As you can see, when a comet is far from the Sun, the tail disappears. That is because the amount of energy hitting it is much smaller.

So where do comets come from anyhow? Any ideas?

[Most comets start in the outer reaches of the solar system.]

Let's take a look at one of the most famous comets. It's named for one of the greatest astronomers that ever lived. Any idea who we're talking about?

[Edmond Halley — Halley's Comet.]

8. Halley's Comet

Despite what many people have heard, Halley's Comet was not discovered by Edmond Halley. It's named for him because he was the first person to understand that some comets move around the Sun in a regular orbit, just like planets do. As you can see from the graphic, Halley's Comet begins its journey way out in the solar system past the orbit of Neptune. This is an area known as the 'Kuiper Belt'. Named after astronomer Gerard Kuiper who first suggested it was there, it's thought to contain billions of comets. If we go even farther out into the solar system there is the Oort Cloud. This is another place where comets are thought to be 'stored'.

Scientists think that every so often, gravity from the outer planets or a distant passing star causes some of these comets to 'fall' into the inner solar system where the Sun's gravity holds them in orbit. Not all comets have a stable orbit, however. Some enter the inner solar system, whip around the Sun and head out into space never to be seen again. Others actually collide with the Sun where they are instantly vaporized.

Look at the shape of the orbit of Halley's Comet. How is it different from the orbit of most planets or asteroids?

[The comet's orbit is very elliptical and crosses the orbit of several planets.]

9. The Orbit of Comets

Now let's put the comet in motion and see what else we can observe about its orbit.

Action

Click on the button to start the motion and stop when the date reaches 2001.

Did you notice anything interesting about the speed of the orbiting comet?

[As the comet got closer to the Sun, it sped up and then as it moved back out into the outer solar system it slowed down.]

Comets follow the same laws of motion that planets do. They move slower when they are far from the Sun and faster when they are close. Because their orbits are very elliptical, the speed change is much more noticeable with comets than with planets.

While seeing a comet in the sky is a spectacular event, it is also possible to see the 'ghosts' of past comets every few months. Each time a comet makes a pass around the Sun, it shrinks a little in size. This is because the energy from the Sun causes some of the ice to evaporate. After many passes, some of the dust and rocks that were in the comet stay trapped in the orbit leaving a trail where the comet had been. If the Earth moves through this trail, some of these tiny particles fall toward the planet. This is where meteor showers come from. Let me show you what I mean.

Action

Click on the word 'here' to view a close-up of the orbit of Halley's Comet.

Here we are looking at a close-up view of Halley's Comet as it approaches the Sun.

How many times does Earth cross the trail of its orbit each year?

[Twice.]

10. Meteor Showers

On these days, our atmosphere gets hit with millions of mini-meteoroids that have come from the comet's nucleus. Most of these rocks are tiny, about the size of a grain of sand. Because of the speed at which they strike the atmosphere, however, they quickly burn up with a bright flash. From the ground, it looks like Earth is being 'showered' by shooting stars.

Here on Earth we experience about two dozen meteor showers each year. While some are spectacular events with hundreds of meteors per hour, others may just result in a few streaks. Each one of these meteor showers is tied into the orbit of a comet. Since we actually cross the orbit of Comet Halley twice each year, it is responsible for two different showers. On or about May 6th we see the Eta Aquarids shower and then around October 20th we see the Orionids shower. The names of these showers are based on the constellations from which the meteors appear to come. To view the May shower you would look toward the constellation Aquarius and in October you would look toward Orion.

Action

Click on the word 'here' to view the constellations and apparent origins of the most common meteor showers.

Here we are looking at the radiant points of about two dozen meteor showers. The radiant point is the place in the sky where the meteors appear to come from. As you can see, the radiant points appear in different constellations. The name of the constellation that the radiant point is in gives the name to the meteor shower.

Whether you are seeing a comet among the stars or simply a 'shooting star' streaking across the sky, the big MACs of our solar system are truly spectacular sites. The more we learn about these objects, the more we realize just how much of an 'impact' they've had on our planet!

That brings our big MAC adventure to a close. Remember when you're outside, keep looking up . . . you never know when a space rock may be approaching!

Have students recap their observations. The main concepts are: 1) Asteroids and comets are in orbit around the Sun 2) Asteroids and comets have hit Earth in the past and will continue to do so in the future 3) As a comet approaches the Sun, its tail grows longer. The comets tail always points away from the Sun. 4) Meteor showers are the result of Earth passing through the debris trail left by the tail of a comet and they are named for the constellation from which they appear to come from.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson D1 — Asteroids and the Main Belt, D2 — Comets and Meteors.

Extending the Lesson

Dates of Meteor Showers

If you live in an area where light pollution isn't too much of a problem, observing a meteor shower can be a truly spectacular event. Since a meteor shower is the result of the Earth crossing the trail of a comet's orbit, they occur on pretty much the same date each year. Have students conduct a Web search to find out when the next meteor shower will be. For bonus credit, see if they can identify which comet is responsible for the shower and from what constellation it will appear to radiate.

Make a Model Comet

Since a comet nucleus is really nothing more than a 'dirty snowball' with a few other things mixed in, you can easily make a model in the classroom by using the following recipe: Open a tall plastic kitchen garbage bag and place it inside a large mixing bowl. Into the bag pour about one cup of water, ½ cup dry sand a few drops of dark corn syrup to represent organic materials and a few drops of ammonia. Using gloves place a few large pieces of dry ice into another bag and using a hammer, crush it until you have about two cups. Ask a student volunteer to assist you. Give the student a second pair of gloves, some safety goggles and a large spoon. Slowly pour the crushed dry ice into the water/sand mixture while the student stirs with the spoon. Stir for about ten seconds. The water should start to freeze. Carefully lift the bag out of the bowl and squeeze the outside of the bag and compress the mass into a round, frozen ball. Using the gloves, extract the frozen mass from the bag and you'll have a model comet nucleus.

Lesson 10 — Seasonal Constellations

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

Even though we can't feel it, our Earth is in constant motion. Each day we rotate once in space. This diurnal motion causes day and night and makes the stars appear to rise and set on the horizon. In addition to rotation, our Earth also revolves around the Sun in an orbit that takes one year. Because of this second motion, each night, the stars appear to rise a few minutes earlier than the night before. As a result, our view of the stars and the constellations that they form gradually change with the seasons. Some constellations are only visible in the evening sky in winter while others are visible only during the summer. In the past, before people had written calendars, these 'seasonal constellations' were used as a calendar in the sky.

Not all constellations disappear from view as the seasons change. In the Northern Hemisphere, five constellations (Ursa Major, Ursa Minor, Cassiopeia, Cepheus and Draco) are visible every night of the year, although their positions relative to the horizon do change. These are called the northern ***circumpolar*** constellations because they are located near the star Polaris, the North Star, which is directly above Earth's north rotational pole. Instead of rising and setting, these stars simply spin in a circle as the seasons change. While there is no 'South Star', there are southern circumpolar constellations that can be viewed by people living south of the equator.

While there are dozens of seasonal constellations, thirteen stand out because of the way that the Sun appears to move through the sky. These constellations make up the ***zodiac*** and they are also used by astrologers. While most astronomers do not believe in the predictive powers of astrology, they use the zodiac constellations as important markers in the sky. If you could darken the sky during the daytime, you would find that the Sun appears to be in front of one of these zodiac constellations. As the Earth moves through its orbit, the Sun slowly shifts its position from one zodiac constellation to the next, spending about a month in each. Over the course of the year, it appears to pass through all 13 zodiac constellations with the cycle starting again the next year. While many people know their zodiac sign, they don't know how they get it. It is based on which constellation the Sun is in on your birthday. This means that you can't see your zodiac constellation on your birthday because it's up during the daytime!

Pre-Visit Activity

Rotation vs. Revolution

Two words that are often confused are 'rotation' and 'revolution'. Since our Earth goes through both of these motions and both have an impact on what we see in the sky, a good way of reinforcing the meaning of the words is to construct a model using the students themselves to simulate the motion. The activity is best conducted outdoors in a school yard or gym. If need be, you can do it in the classroom but you will have to clear a large open space in the center of the room by moving the desks off to the side. Start by having the students stand and form a large circle. Select a student volunteer to be 'the Sun' and have him or her stand in the center of the circle. First ask students to slowly walk around 'the Sun' to demonstrate that they are in orbit. Explain that this motion is called 'revolution'. Ask them how long it takes for the Earth to complete one revolution around the Sun (one year). When they get back to their starting place have them stop and then slowly spin in place. Explain that this motion is called 'rotation' and it's what gives us day and night. Ask them how long it takes for the Earth to go through one rotation (one day). Now ask them to put the two motions together by slowly spinning while they move around the Sun. (Make sure that they don't go too fast because you don't want anyone to get motion sickness!) When they have completed a full orbit, ask: In order for this to be an accurate model of the Earth's motion, how many rotations would they have to make for each revolution around the Sun? (365).

Astronomy vs. Astrology

Students (as well as adults) have questions about the validity of astrology and how it compares to astronomy. This type of discussion is very useful in comparing the differences between an actual science and a belief that has little or no supporting evidence to back it up. One way of introducing the discussion is to have students find out their zodiac sign and see what their horoscope is. Most daily newspapers carry this information. According to astrologers, each sign has certain telltale traits. By using either a book on astrology or some Web sites, have students look up the traits that their sign is supposed to carry and compare it to their actual behaviors to see if they fit the pattern. An alternative is to list the traits for the twelve zodiac signs on a handout sheet but do not give the name of the sign that each set of traits represent. Make sure that you make a key so you know which set of traits matches each. Have the students read them over and select the set of traits that they think fits their own personality. After they have selected the traits, reveal which sign fits each set of traits and then have the students see if they picked their own sign. Most often, the match will be much less than 50%.

The Digital Lesson: A Calendar in the Stars — Seasonal Constellations

This lesson is designed to introduce students to the zodiac and how the constellations can be used to predict the change of season. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to discover how the stars can be used like a calendar in the sky.

Long before there was television, video games or even books, people used to spend many hours outside at night, looking up at the sky. Using the brighter stars as guides, they imagined pictures of great heroes, wild beasts and beautiful princesses.

Does anyone know what word we use to describe these pictures made out of stars?

[Constellations.]

2. Ancient Constellations

While just about every group of people who have looked at the sky over time have made up their own constellations, it's the constellations of the people of ancient Greece that are the most famous. The truth of the matter is that the Greek people weren't the first ones to see many of these images. Many of the Greek constellations were 'borrowed' from the ancient Egyptians. If we go back even further in time, we find that some of the Egyptian constellations were based on the images first described by the people living in ancient Babylon and some of their constellations can be traced back to even earlier groups of people living over 5000 years ago!

Let's take a look at what they saw . . .

3. Constellations in Motion

Here we are looking at a typical winter night sky from the Northern Hemisphere with the pictures of the constellations drawn in as people imagined them long ago. To make things move a little quicker, we've sped up the rotation of our Earth so it's now moving about 100 times faster than normal.

Does anyone recognize any of these constellations?

Pass the hand-held pointer around and allow a few student volunteers to point out and name some of the constellations. An alternative would be to use the pointer yourself and ask students to name the constellations that you point to.

As the Earth turns, what do you notice happening to the constellations?

[The constellations are moving across the sky.]

In which direction do the constellations appear to rise? Where do they set?

[The constellations are rising near the east and setting toward the west.]

How long do you think it would take for a constellation to come back to the exact spot it started from?

[Since it takes one day for Earth to make one rotation, it should take about a day for each constellation to return to its starting point.]

Let's try it and see. First let me return to our starting point.

4. Orion

Here we are, back at our starting point. To make things a little easier to find, I've also put the labels on each of the constellations.

I want everyone to find the constellation Orion. Point to it. Where is it in the sky?

[Orion is right on the eastern horizon.]

Instead of allowing the Earth to rotate smoothly, I'm going to jump us forward exactly one day in time. That means we're going to move one full rotation.

Where would you expect to find Orion tomorrow at this time?

[Based on the first set of observations, it should be in the exact same place it is right now.]

Okay, here we go . . .

Action

Click on the button once. The date should change from Dec 1st to Dec 2nd but the time should remain at 8:00 PM.

Did anyone notice anything change?

[Everything shifted a little to the west.]

Let's try it again. I'm going to move us another day forward.

Action

Click on the button once. The date should change from Dec 2nd to Dec 3rd but the time should remain at 8:00 PM.

Did you see the same shift?

[Yes.]

Okay, let's try it for five days in a row. What do you think will happen?

[The constellations will continue to shift in the same direction.]

Action

Click on the button five times in succession. The date should change from Dec 3rd to Dec 8th but the time should remain at 8:00 PM.

We've now moved one full week in time from when we first were looking at the sky. If you look at the constellation Orion, it appears quite a bit higher in the sky than it did a week ago.

Can anyone explain why it's not in the same place each night at the same time? I'll give you a hint . . . Is rotation the only motion that the Earth is going through?

[No, Earth is also revolving around the Sun.]

5. As the Earth Turns

While Earth's rotation explains why we have day and night, we have to remember that Earth is also orbiting the Sun.

How long does it take for us to complete one orbit?

[365 days or one year.]

As each day passes, we move a little bit farther along in our orbit. This means that each night, we are looking at the same stars from a slightly different location. This is what gives us the apparent shift in the constellations. Each night the shift is tiny. What do you think will happen if we move a month further in time? Let's take a look.

How many days are in an average month?

[About 30.]

Count with me as I skip 30 days forward in time.

Action

Click on the button 30 times in succession. The date should change from Dec 8th to January 7th but the time should remain at 8:00 PM.

Here we are, 30 days later in time. Do you see anything different about the sky now?

[In addition to all the constellations moving across the sky, some of the constellations that we were seeing before have set in the west and some new constellations that were not there before are now visible in the east.]

6. Seasonal Constellations

It didn't take long for the astronomers of the past to notice these shifts in the sky too. They realized that certain constellations were only visible during certain months of the year and as a result, they started using the constellations as sort of a calendar in the sky. Since they didn't have written calendars and personal electronic devices like we have today, watching the change in constellations was a convenient way to know when the seasons were going to change. Let's see how this works. We'll start with the winter sky . . .

7. Winter

Before doing this part of the activity, it's a good idea for you to familiarize yourself with the names of the prominent constellations for each season.

Here we are looking at the mid-winter sky about 8:00 PM. It's about one month later than we were looking before. Let's take a look at some of the constellations that are visible.

Let's see if you can name the constellations that I point out.

> **Use the hand-held pointer to point out the major constellations including all the constellations of the zodiac that are present. Have the class name the constellations as you point them out.**

Let's start with our friend Orion again. What part of the sky is he in?

[Orion is in the south.]

Orion is in the south along with Taurus and Aries and Pisces.

If we continue to the west we have Pegasus and Cygnus and in the North we have Draco the dragon, Ursa Major, Ursa Minor (the big and little bear) and Cassiopeia.

Finally, in the east we have Cancer and Gemini, and Canis Major.

Let's move forward 3 months and see what the spring brings!

> **Action**
>
> *Click on the button 3 times in succession. The date should change from Feb 1st to May 2nd but the time should remain at 8:00 PM*

8. Spring

Here we are in spring. It's May 2nd and the flowers are in bloom and the birds are beginning to sing!

Let's look for Orion again. Where is he now?

[Orion is in the west near the horizon.]

Also in the west we see Taurus and Aries is just starting to set. In the North we still have Draco, Ursa Major, Ursa Minor and Cassiopeia. In the west, we have a few new constellations that were not there before. There's Virgo and Leo the Lion and Cancer. Gemini and Canis Major have all moved to the south.

So what happened to Pegasus?

[Pegasus has set for the year.]

What did the other constellations appear to do?

[All the other constellations appeared to shift to the west.]

Can anyone predict what will happen when we move forward in time another three months?

[Most of the constellations will shift to the west again. Those currently in the west will set and a few new ones will appear in the east.]

Let's give it a try . . .

> **Action**
>
> *Click on the button 3 times in succession. The date should change from May 2nd to July 31st but the time should remain at 8:00 PM.*

9. Summer

Now we're looking at the mid-summer sky. Does anyone see Orion now?

[No, Orion has set for the summer.]

Orion, Taurus and Gemini are all considered to be winter constellations They are only visible in the evening sky during the winter and early spring. Once summer rolls around, they are gone. The truth is they're not really gone. We just can't see them.

What time do you think Orion and Taurus would be in the sky during the summer?

[They are up in the daytime in the summer.]

If we look to the west and south you'll see that Virgo and Leo have shifted their positions and in the south we have the constellations of Libra, Scorpius and Sagittarius.

If you turn to the north, you'll see that our old friends Draco, Ursa Major, Ursa Minor and Cassiopeia are still there, but they're upside down compared to where they were in the winter.

10. Circumpolar Constellations

It turns out that the constellations in the north never completely rise and set. They simply spin around with the seasons. We call these the 'northern circumpolar' constellations. The reason they don't set is because they are all located around Polaris, the North Star. Polaris is located in space directly above Earth's North Pole so as we rotate, it never appears to move. The closer a constellation is to Polaris, the less likely it is to set if we are located in the Northern Hemisphere.

By now, you've probably noticed a trend in the way the rest of the constellations shift with the seasons. Some of you also probably realize that most of the constellations that we've named so far all belong to a special group.

What do the constellations Leo, Libra, Pisces, Cancer, Scorpius and Taurus all have in common?

[They are all part of the zodiac. They are all 'birthday constellations'.]

11. The Zodiac

The zodiac is made up of twelve special constellations that change with the seasons. It's like a calendar in the sky. Each month, one zodiac constellation rises and a different one sets. Now depending on what time of the year you were born, you are assigned one of these zodiac constellations. What many people don't realize is that you won't see your zodiac sign in the evening sky on your birthday. You'll have to wait until six months after your birthday to see it. The reason for this is that your zodiac sign is your 'sun sign'. Let me show you what I mean.

12. Sun Sign

Here we are, a little before noon on March 21st, the vernal equinox. I've had to turn off daylight so that you can see the constellations and Sun in the sky at the same time.

Does anyone know what this day represents?

[The vernal equinox is the first 'official' day of spring.]

If you look up in the sky to the south you can see the Sun. I've left the constellation images visible even though in the real sky, it would be too bright to see any of the other stars. Now let's follow the Sun as we allow the Earth to move through its orbit.

Action

Click on the button and allow it to progress for one year until the date says March 21, 2007.

Okay, so what did you notice about the Sun's path?

[The Sun appears to move through each of the zodiac constellations.]

13. Conclusion

The zodiac is really nothing more than a band of stars across the sky through which the Sun appears to move during the course of a year. In fact, not only does the Sun follow this path, but so do most of the planets and the Moon. For this reason, the zodiac is a very important marker to astronomers.

The zodiac is also important to astrologers. Astrologers are people who claim that they can tell future events by the position of the Sun, stars, and planets in the sky. They make their predictions based on a person's birthday sign. On the day that you are born, the Sun is in front of one of these zodiac constellations. Whichever one it is, that is your sign. If you want to find out your sign, you can check out a local newspaper where it has the horoscope. A horoscope is sort of like a fortune based on the stars.

The truth is, most astronomers don't believe in horoscopes or the ability of people to make predictions about their lives based on the stars. The main thing that the zodiac is good at predicting is what season of the year it is and for that, you don't have to be an astrologer. All you have to be is a stargazer with a good memory!

> **Have students recap their observations. The main concepts are: 1) Different constellations are visible in the sky during different times of the year. 2) Circumpolar constellations are visible most nights of the year although they change their position in the sky relative to the horizon. 3) The zodiac is a band of thirteen constellations in which the Sun appears to move during the course of the year.**

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson E3 — Seasonal Constellations.

Extending the Lesson

Zodiac Model

Hopefully, most students will understand that when we see the Sun appear to move through the sky, it's really due to the motions of our own Earth. A good way to show how the Sun appears to move through the different constellations of the zodiac is to make a simple model in the classroom. Start by writing the name of each zodiac constellation on a separate piece of paper and select twelve students to represent these constellations. Have the students stand in a large circle in their proper order — Virgo, Leo, Cancer, Gemini, Taurus, Aries, Pisces, Aquarius, Capricorn, Sagittarius, Scorpius, and Libra. They each should hold their sign in front of them. Ask two other student volunteers to assist. Give one student a flashlight to represent the Sun and ask him/her to stand at the center of the circle. Give the second student a globe or large ball and ask him/her to represent the Earth. Have 'the Earth' stand in the circle in between the Sun and the constellation Virgo. Have 'the Sun' shine the flashlight directly on the Earth. Ask the student who is the Earth to look past the Sun to the other side of the circle. What constellation is the Sun in front of? (If the students are properly spaced it should be Pisces.) Now ask the Earth to move over so that he/she is in between Libra and the Sun. The Sun should slowly rotate so that the flashlight is still pointing directly at Earth while staying in the same location. Ask Earth which constellation the Sun is in front of now. (Aries.) Ask the class, did the Sun move? (No the Earth moved.) Have the Earth continue to move around the circle stopping in front

of each constellation until he/she has completed one full orbit. Based on this model, ask the class to explain why the Sun appears to move through the sky.

Origins of the Zodiac

The modern zodiac used by astronomers has gone through many changes over the past 4000 years. The word zodiac is actually based on the word 'zoo' meaning animals. Have students research the origins of the modern zodiac including who first came up with the idea and what the original constellations represented. Along the way, they should also find out why astronomers have thirteen constellations in the zodiac while astrologers only have twelve.

Star Shift

One of the best ways of seeing the change of seasonal constellations is to have students view the change with the real stars. Start by getting a set of seasonal star maps for your location. These can be printed out using the Starry Night software or you can simply go online and get them from a variety of Web sites. Have students pick one constellation and locate it on three successive monthly maps. As a follow up, ask the class to do some real time viewing by going out at the exact same time in the evening each clear night over the course of two weeks to plot the position of a bright star relative to a landmark on the ground (a tree, building, flagpole, etc.). On each plot, they should see that the star will slowly shift its position relative to the ground over time and eventually disappear from view.

Lesson 11 — Properties and Life Cycles of Stars

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- The Sun and the rest of the solar system formed from a nebular cloud of dust and gas.
- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium.
- Early in the history of the universe, matter clumped together by gravitational attraction to form trillions of stars.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

Background

Even though they are not living things, each star was born and will eventually die. All stars form from large clouds of mostly hydrogen gas, which, because of the force of gravity, slowly contract and collapse in on themselves. As the cloud collapses, it begins to heat up at the center. If there is enough mass, the center of the cloud will heat up to the point at which hydrogen atoms begin to fuse together forming helium atoms. This process, known as nuclear fusion — similar to what happens in a hydrogen bomb — releases a tremendous amount of energy. Once fusion begins, a star is born.

The more massive a star is to begin with, the faster it uses up the hydrogen gas and the hotter it becomes. As stars age and helium builds up in their cores, they become denser. Eventually the pressure becomes so great that helium begins to fuse into even heavier atoms. The more massive a star is, the greater number of heavy elements it can form.

Low mass stars, like our Sun use their nuclear fuel very economically and tend to last for a very long time. Most astronomers believe that our Sun is about five billion years old and it should have enough fuel to last for another 5 billion years. Based on observations of other stars, as our Sun reaches the end of its life, it will swell up forming a star known as a red giant. At this stage, it will become very unstable and blow off its outer layers in an event called a nova. The remaining inner part of the star will shrink down and heat up forming a small hot star called a white dwarf. From this point, the star will slowly cool down eventually burning out to become a black dwarf.

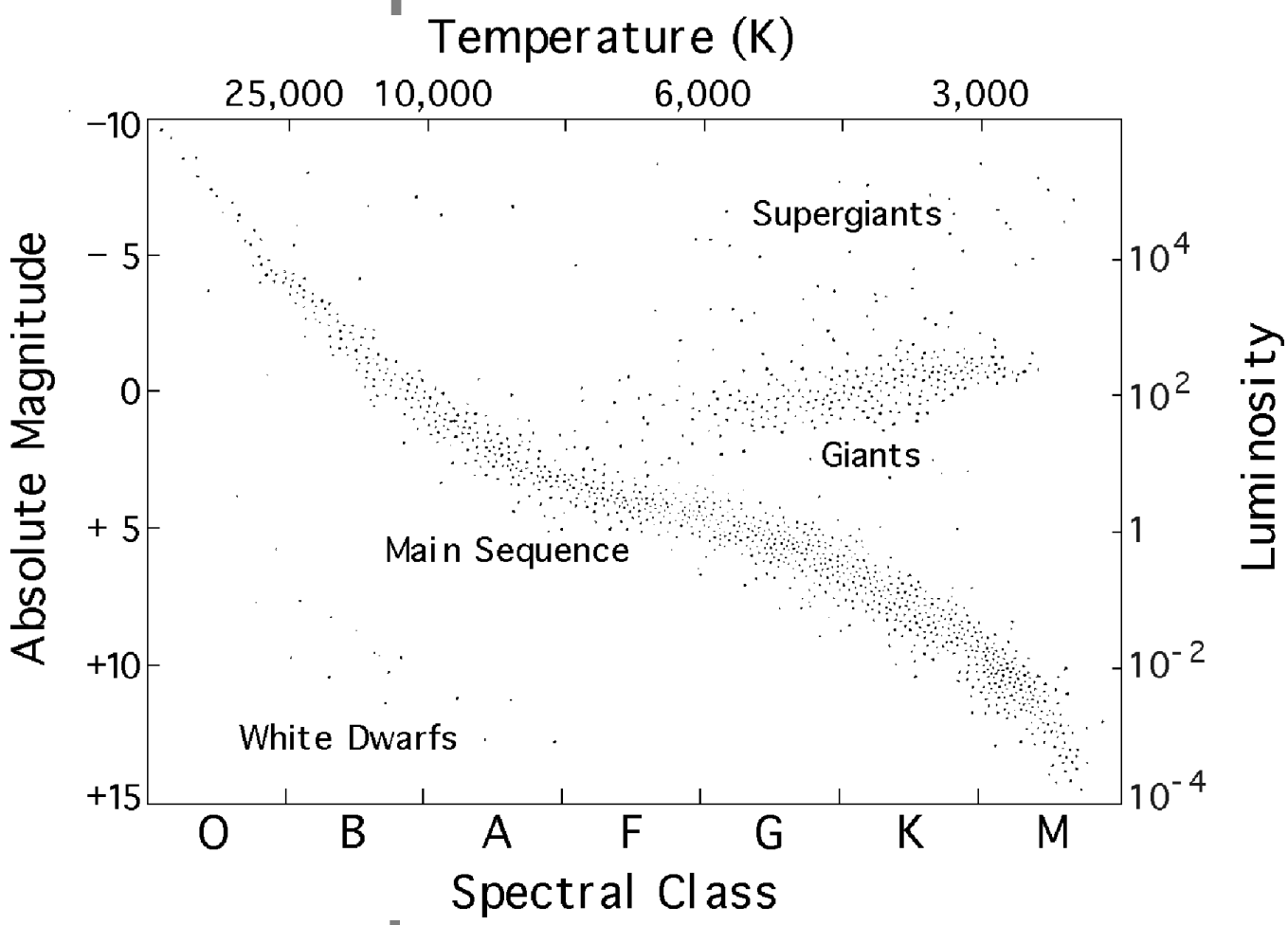
Extremely massive stars use their fuel so quickly that they burn out in only a few million years. When they eventually die, they don't go quietly. Instead, they collapse in on themselves becoming so hot that they eventually blow out their outer layers ending their existence in a colossal explosion called a supernova. After the supernova, the inner core of the star may continue to collapse into an incredibly dense compact object known as a neutron star. If the star was massive enough, the neutron star may continue to collapse forming a black hole. Contrary to popular belief, a black hole is

not a hole in space, but a small compact star that is so dense and has so much gravity that light itself is pulled back into it. That is why it looks black.

Pre-Visit Activity

Using the H-R Diagram

Pictured below is a special graph called the H-R diagram. Over the years, astronomers have classified stars into different groups known as spectral classes based on their color and brightness. By comparing the spectral classes of stars to the their true brightness (known as absolute magnitude) astronomers Ejnar Hertzsprung (the H) and Hernry Russell (the R) were able to develop this chart. This plot is one of the most important devices used by astronomers to classify stars and show where they fit in their life cycle. Prior to going into the planetarium, give each student a copy of the H-R diagram and review what the different star types refer to. Students can then use the diagram in the planetarium during the lesson as you locate different types of stars.



The Digital Lesson: Star Light, Star Bright — Properties and Life Cycles of Stars

This lesson is designed to introduce students to the properties of stars, the Hertzsprung–Russell diagram and how stars change over time. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at how astronomers classify the stars and discover how they change over time.

Before we get into some of the details, it's probably a good idea to take a step back and see what you already know. First, let's define what we mean by the word 'star'.

Can anyone give me a good definition?

[A star is a large ball of hot glowing gas. It releases a tremendous amount of energy supplied by nuclear fusion reactions deep inside the star.]

Stars are hot and they are made out of gas, but one of the big mistakes that people make is to say that they are burning. The truth is they are not on fire. The heat and light that stars give off come from nuclear fusion reactions deep within the star. These reactions are similar to what goes on in a hydrogen bomb. The most common reaction in stars is when four hydrogen atoms 'fuse' together by gravity to form one helium atom. In the process, an enormous amount of energy is released.

Based on this definition, what is the closest star to Earth?

[The Sun.]

While it looks very different from the stars we see at night, our Sun is a typical star. We'll take a close-up look at our Sun in a few minutes, but first let's take a look at some of the stars that we can see at night.

2. Star Descriptions

Here we are looking at a typical night sky during the winter in the Northern Hemi-

sphere. What I want you to do is take a few seconds and scan the sky.

Do all the stars look the same?

[No.]

First let's consider their similarities . . . what are some of the ways that all stars look the same?

[All stars give off light. They all look like little dots. They are round and do not have points.]

Despite the fact that many people draw pictures of stars with little points on them, stars are round. They are considered to be 'luminous' bodies because they give off their own light. In this way they are very different from planets or moons which get their light from a star or in the case of our solar system, the Sun. Planets and moons are 'illuminated' bodies.

What are some of the ways that stars look different from each other?

[They are different sizes, they differ in brightness, they have different colors, and they are not spread evenly across the sky.]

3. Star Brightness

Stars have many properties that enable you to tell them apart. Clearly, they don't all look the same. Let's consider some of these properties as we check out some of the stars that we see in the planetarium sky. Let's start with brightness . . .

Everyone look around and point to the star that you think is the brightest one visible right now.

> **Give students a minute or two to look around to find what they think is the brightest star. While there are several bright stars visible with this setting, the brightest is Sirius in the southeast near the horizon.**

While there are a number of bright stars visible right now, the brightest is a seriously bright one called 'Sirius'. Let's take a look at where it is . . .

> **Action**
>
> *Click on the word 'here' to label Sirius.*

4. Apparent Magnitude

When astronomers talk about the brightness of stars, the term they use is 'apparent visual magnitude'. What this means is how bright a star appears to be when viewed from Earth.

Of all the stars we see in the sky, can you name the one with the greatest apparent visual magnitude?

[The Sun.]

Okay, maybe it's a trick question but our Sun does have the greatest apparent magnitude. We'll talk about why the Sun appears so bright in a little while.

The apparent visual magnitude scale can be traced all the way back to ancient Greece when a philosopher named Hipparchus began classifying the stars based on how bright they appeared to be. He began by placing the brightest stars in class 1, the next brightest in class 2 and so on. The 6th class stars were the ones he could just barely see. His scale was a good idea but it was qualitative. This meant that all of the

classes were based strictly on his judgment and there was really no way to measure or 'quantify' the differences in brightness.

Much later on, when astronomers actually had ways of measuring the amount of light coming from stars, they attempted to 'quantify' the scale. At first this worked but they ran into a problem because some of the brighter stars that they measured were brighter than their measured values for first class stars.

So what do you think they did?

[They added a zero class for the very bright stars.]

Unfortunately, some stars were still too bright to even fit in the zero class. As a result, the magnitude measurements for the brightest stars actually have negative values. In the case of Sirius, which is the brightest star we can see in the night sky, its apparent magnitude reading is –1.46. In the case of our Sun, it has an apparent magnitude of about –27!

5. Absolute Magnitude

Stars can appear to be bright for two different reasons. First is the true brightness of the star. We call this 'absolute magnitude'.

What factors do you think might make some stars brighter than others?

[How hot the star is and how big the star is.]

The first factor that controls the absolute magnitude of a star is its temperature. Not all stars are the same temperature. Just like a fire, the hotter a star is, the brighter it usually is. This relationship between brightness (called luminosity) and temperature was first proposed by two astronomers named Hertzsprung and Russell. When they plotted all the known stars on a graph showing luminosity vs. temperature, they came up with an important discovery. In general, the hotter the star, the brighter it was. This relationship only worked for about 90% of the known stars, however. It turned out, that there were some hot dim stars and some cool bright stars.

6. Star Size

That brings us to the second factor that controls a star's brightness . . . its size. A very large star that is relatively cool can have the same brightness as a very small star that is very hot.

Today, the H-R diagram as it is called is an important tool used by astronomers to classify different types of stars. Most stars, (including our Sun) fall into the 'main sequence' with their brightness directly controlled by their temperature. Two of the star types that don't fall on the main sequence are 'dwarfs' and 'giants'. White dwarf stars are hot, dim stars. Giant stars can be either cool or hot stars. Let's see if we can find any of these stars in the sky.

As it turns out, the star Sirius is not one star, but two stars that are orbiting each other. The main Star, Sirius 'A' is a main sequence star. Sirius 'B' is a white dwarf. Let's see what Sirius would look like through a telescope . . .

Action

Click on the word 'here' to zoom in on Sirius AB image.

Here you can see the two stars that make up the Sirius system. Which one do you think is the 'white dwarf'?

[The smaller star next to the main star.]

White dwarfs are actually quite common but because they are small, they are not

that easy to spot. Astronomers believe that white dwarf stars are near the end of their lives and many are not much bigger than our Earth.

Let's go back to our naked eye view of the sky to see if we have any other unusual stars around.

7. Star Color

Take a look around. Does anyone see a star that looks a little blue?

It's really hard to spot here but if you look above Sirius a little closer to the south, you may be able to see a bright star that has a slight blue tint to it. This is the star Rigel. It makes up the foot of Orion the Hunter. Let me show you.

Action

Click on the word 'here' to label Rigel.

Even though most stars appear to be white, if you look carefully or with a telescope, you'll find that many stars have distinctive colors to them. Some stars look blue, some are orange, some are yellow and some are greenish. These different colors come from the fact that not all stars have the same surface temperature. The hotter the star is, the bluer it looks. The cooler a star, the redder it looks. Now this may sound a little backwards because here on Earth, we think of blue as a cool color and red as being hot. The best way to look at it is to think of a fire that is burning. When a fire is really burning hot, the flame looks kind of blue. As a fire starts to die down, however, the color of the flame gets yellow, then orange and finally, when all that is left is the glowing coals, they're red.

Rigel is a blue super-giant star that is much more massive than our Sun. It's also much younger than our Sun. While they are not living things, stars, like people have life cycles. They are born and they eventually die.

8. Nebula

Most stars are born from gas and dust in something called a 'nebula'. These 'stellar nurseries' usually show up in a telescope as a fuzzy patch in the sky. Let's take a look at one in the constellation Orion. In fact, it's called the 'Orion Nebula'.

Action

Click on the word 'here' to label the Orion Nebula.

The Orion Nebula is located in the sword of Orion. Let's take a close-up view.

Action

Click on the word 'here' to zoom in on the Trapezium in the Orion Nebula

Here we are looking at the Orion Nebula as it would appear in a relatively large telescope. What do you see?

[The nebula appears to have many colors of gas.]

This colorful patch of gas is where stars are born. If you look carefully you'll see some hot, bright stars in the center of the nebula. These are very young stars just starting their lives.

What force do you think is responsible for pulling a star together?

[Gravity.]

Astronomers believe that stars form from these pockets of gas as gravity starts causing the individual atoms and molecules to start clumping together. The larger clumps

have more mass, and exert a greater gravitational pull on the surrounding nebula. Eventually, all the clumps and lumps get pulled together to form a large 'protostar'. If there is enough mass in the protostar, it keeps contracting under the force of gravity and eventually, nuclear fusion reactions start happening in its core. Once these reactions start, a star is born!

9. Star Life Cycle

Depending on the mass of the star, it can either live out its life quickly or slowly. In general, the more massive a star is, the faster it uses up its fuel and the shorter its life span. Let's see if we can find some of the 'fast and furious' stars.

Take a look around and see if you can find a candidate for a 'red giant' star. Does anyone see one?

> **Allow a student volunteer to use the hand-held pointer to find a red star.**

If you look right above the Orion Nebula closer to the zenith, you can find two red stars. One is called Betelgeuse and it's in the constellation Orion. The other is called Aldebaran and it's in Taurus the Bull.

> **Action**
>
> Click on the word 'here' to label Betelgeuse and Aldebaran.

Both Aldebaran and Betelgeuse look distinctively red to the eye. Why do you think they have this color?

[Both of these stars are cooler than our Sun.]

In addition to being a cooler star, a red giant star is a star that astronomers consider to be at the tail end of its life cycle. Both of these stars are huge. In fact, astronomers estimate that Betelgeuse is so big, that if it were placed in our solar system, it would take up all of the space between our Sun and the planet Jupiter! The truth is that it's still getting bigger. Betelgeuse is swelling up and as it does, it's also cooling down which is why it looks red.

Do you think it will keep swelling up forever?

[No.]

10. Supernova

Most astronomers believe that Betelgeuse will soon begin to collapse back in on itself and when it does, it will heat up again. Because it is so massive, they believe that it will end its life in one last giant explosion.

Does anyone know what we call this event?

[A supernova.]

Supernovas only happen to the most massive stars. While we don't see them often, when they do happen they are spectacular events. The star gets so bright that in some cases it's even possible to see it during the daylight hours. While I can't show you a current supernova in action, we can take a look at a remnant of one that astronomers believe happened over 1000 years ago. We don't have far to go . . .

> **Action**
>
> Click on the word 'here' to label the Crab Nebula.

The Crab Nebula is located in the constellation Taurus. Let's take a close-up view.

Action

Click on the word 'here' to zoom in on the Crab Nebula.

Here we are at the Crab Nebula. Does it look like anything else that we've seen recently?

[It looks similar to the Orion Nebula.]

Both the Orion Nebula and the Crab Nebula are two big patches of dust and gas. The main difference is that the Orion Nebula is now contracting and gravity is starting to form new stars in it. The Crab Nebula is still expanding due to a supernova explosion that happened to a star in the area back in the year 1054 AD. How do we know this? Well it turns out that Chinese astronomers actually recorded the event. They reported seeing an extremely bright star for a few months right where the Crab Nebula is today.

Can anyone predict what might happen to the gas and dust of the Crab Nebula over time?

[Eventually it will stop expanding, it will cool down and then gravity will cause it to contract again forming new stars.]

Once a nebula from a supernova cools enough, the expansion stops, gravity takes control and then the process of new star formation kicks in. In this way, the material from old stars gets 'recycled' into new stars.

11. The Sun

We've talked a great deal about how stars look and form, but we haven't really focused on the most important star, our star, the Sun. Let's see how it fits into the picture.

As we said before, our Sun is a main sequence star. It is pretty average in size and it's not too hot or too cool. That is a good thing for us here on Earth because if the temperature range of our Sun were much different, we probably would not be here!

Before we said that our Sun appeared brighter than any star in the sky. The truth is, based on its luminosity or absolute magnitude, our Sun is not even close to being a bright star.

So why do you think it appears to be so much brighter than any of the other stars?

[The Sun is the closest star to Earth.]

Besides absolute magnitude, the other factor which controls how bright a star will appear in the sky is its distance from Earth. Our Sun appears to be the brightest star in the sky because it's the closest star to Earth — much closer than any other star because it's the only one in our solar system.

12. The Future

Because our Sun is not a 'heavyweight', it's using up its nuclear fuel at a nice slow, steady rate. Astronomers expect that our Sun will last another 4 or 5 billion years. It won't last forever, however. Eventually it will die out. Unlike Betelgeuse it won't end its life in a supernova, though. It's just not massive enough. What's more likely is that in a billion years or so it will begin to swell up and become a red giant.

What do you think will happen to us here on Earth when that happens?

[All life will die because it will get too hot.]

After the Earth gets toasted, the Sun will begin to collapse and then blow off its outer layers of gas. This is called a nova. The result will look something like this . . .

Action

Click on the word 'here' to show the Ring Nebula.

This is the Ring Nebula in the constellation Lyra. How does it look different from either of the two nebulae that we saw before?

[It looks like a circle or a bull's eye.]

The Ring Nebula formed when a star experienced a nova explosion sometime in the past. The ring structure is due to the fact that it blew off its outer shell of gas. In the center of the ring you see a small white dot. This is all that remains of the original star.

If you had to guess, what type of star would you think it is?

[A white dwarf.]

Astronomers think that this is the fate that awaits our own star. After the Sun novas, its remaining material will collapse into a white dwarf and it will slowly burn itself out over the course of a few billion years.

So there you have it, the life and death of a star! Thanks for joining us here today!

Have students recap their observations. The main concepts are: 1) Stars are born from large clouds of gas, give off energy due to nuclear fusion reactions deep inside them and eventually die out when their fuel is used up. 2) The more massive a star is, the faster it will go through its life cycle. 3) Stars can be classified by their apparent magnitude, absolute magnitude and luminosity. 4) The H-R diagram is used by astronomers to classify and identify where in its life cycle a particular star is. 5) Our Sun is a main sequence star on the H-R diagram and it's about half way through its life cycle.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson G2 — The Stars.

Extending the Lesson

Making a Magnitude Scale

One of the easiest ways for students to see how stars can be classified into different groups is for them to construct their own magnitude scale. This activity can either be conducted in the planetarium or with the stars in the real sky. Start by having students draw a section of the night sky by simply plotting the relative positions of about two dozen visible stars within a small area. Have them all plot the same stars so that they can compare their results. Using a coding system of their choice, have the students place the stars into one of four different brightness classes with class 1 being the brightest and class 4 being the dimmest. Once they have completed their plots, have them compare their results to see if everyone placed the same stars in the same brightness classes. While there may be some overlap, chances are that there will be quite a bit of variation as well, demonstrating just how subjective early classification schemes were.

Researching Star Types

Using new technology like the Hubble Space telescope, astronomers have been able to dig deeper into the life cycles of stars to determine the different conditions under which different types of stars form and die. As a class project, have students select different star types and ask them to research and report on how each develops and progresses through its life cycle.

The Life of our Sun — Using the H-R Diagram

While the Sun is important to us here on Earth, astronomers tell us that it's really a pretty average star. Right now, our Sun is considered to be a medium temperature main sequence star but it hasn't been that way it's entire life. As it ages, the Sun will continue to change its position on the H-R diagram moving off the main sequence. Have students research the history of our Sun and predict its future using the H-R diagram as a key. Based on current estimates, how long will it be before the Sun becomes too hot for us to live here on Earth?

Lesson 12 — The Milky Way Galaxy

NSES Connections

- The Sun, Moon, planets and stars all have properties, locations and movements that can be observed and described.
- Objects in the sky have patterns of movements.
- Early in the history of the universe, matter clumped together by gravitational attraction to form trillions of stars. Billions of galaxies, each of which is a gravitationally-bound cluster of billions of stars, now form most of the visible mass in the universe.
- Many individuals have contributed to the traditions of science. Science has been practiced by different individuals in different cultures.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, models and explanations proposed by other scientists.

Background

While the Sun may be the only star located within the confines of our solar system, it is not the only star in our region of space. It is actually one of perhaps 200 billion stars found within our local galaxy which is called the 'Milky Way'. A galaxy is a gigantic collection of stars that occupy a similar region in space and are held together by their mutual gravity. Even before people knew about galaxies, however, they knew about the Milky Way. If you get far from the city lights and look up the middle of summer or winter night sky, you can see what looks like a faint white band of clouds stretching from the southern horizon across the sky. The Romans called this band 'via lectea' meaning 'milky road' because it reminded them of milk. Thanks to Galileo and his telescopic observations in the early 1600s, we now know that these milky patches are made up of billions of stars packed together into several discreet bands. If you could leave Earth and look back at the Milky Way from outside our galaxy you would see what looks like a giant pinwheel in space with a central hub and several large spiral arms extending out into space. We live out on one of these spiral arms about 26,000 light years from the galactic center. When we see the band of the Milky Way in the sky, we're looking at the next closest arm to ours.

Up until the early 1900s, most astronomers were convinced that the entire universe was made up of stars found within the Milky Way galaxy. Using the most advanced telescope of his day, Edwin Hubble began looking at a fuzzy patch of light called a 'nebula' in the constellation Andromeda. After many observations, he discovered that the Andromeda nebula was really another galaxy. As his observations continued, Hubble soon discovered dozens of other galaxies occupying space outside of our own Milky Way. Using the light coming from these galaxies, Hubble not only concluded that the universe was made of hundreds (now known to be billions) of other galaxies, but these galaxies all seemed to be moving away from each other at incredible speeds. His observations formed the basis of what would become known as the Big Bang Theory and the idea of an ever-expanding universe.

Pre-Visit Activity

Understanding Light Years

Space is large. While our solar system is relatively small, the distance between our Earth and the Sun (the closest star) is still over 150,000,000 kilometers (93,000,000 miles). Once we get outside our solar system, however, measuring distances in kilometers or miles gets very difficult to do because the numbers become so large. To measure distances between stars and galaxies, astronomers use a unit of measurement called a light year. While many people mistakenly think this is a unit of time, a light year is a unit of distance. It is the distance that a beam of light travels through a vacuum in a year. To get students to understand just how large a light year is, a good exercise is for them to actually calculate the distance in kilometers or miles. To do it, you must take the speed of light (300,000 km/sec or 186,000 miles/sec) and multiply that by the number of seconds in a year. How many seconds in a year? First multiply the number of seconds in a minute (60) by the number of minutes in an hour (60) by the number of hours in a day (24) by the number of days in a year (365). Depending on how accurately they do the math, they will discover that one light year is on the order of 9,460,000,000,000 kilometers or 5.8 trillion miles. Using these conversion figures, you can then have them attempt to calculate the distance to the next nearest star which is about 4.3 light years away or to the next closest galaxy, which is almost 2,000,000 light years away.

Modeling the Expanding Universe

Most students have probably heard that the universe is expanding, but they have a difficult time understanding how space itself can be getting larger. For a simple model to show how this works, take a large round balloon (12' diameter or so) and inflate it so that it is only about 3 inches across. Using a felt tip marker, put about 10 -15 dots on the surface of the balloon. Explain to the students that the dots represent galaxies and the surface of the balloon represents space itself. Slowly inflate the balloon and they will see that each dot will move away from every other dot at a constant rate. If you want to quantify the motion, you can even have them measure the distances between dots at several different times as you inflate the balloon.

The Digital Lesson: The Milky Way Galaxy

This lesson is designed to introduce students to the size and shape of the Milky Way galaxy. The following text is identical to the one displayed on the computer screen of the Digital STARLAB projector when the program is running. The words written in italics are the 'script' to be used by the instructor. Rather than read the script verbatim, it is suggested that you review it before conducting the lesson and then present the material in your own words. Suggested questions for students are included in the narrative and typical answers are presented in brackets following the questions. **Specific directions for the instructor are written in bold face type.**

During the course of the lesson, there will be several places labeled **Action** at which point you must either click on the highlighted word to change a setting or use the time control commands found on the Starry Night Toolbar. The controls look like this:

1. Introduction

Good morning/afternoon boys and girls. Welcome to our planetarium. A planetarium is a special place that allows us to show what happens in the sky. We can either show the sky in the daytime or at night. During today's lesson, we're going to take a look at our little island in space.

Let's begin by taking a look at the night sky the way it looked to people a few hundred years ago. To do this, we're going to have to take a little trip, far out in the country away from the glare of the city lights.

2. The Milky Way in Winter

Instructor's Note

In order to see the Milky Way in the sky, you may want to increase its brightness. To do this, under the Options Pane, select Milky Way options and move the slider to the right to make it appear brighter.

Here we are looking at a typical night sky during the winter in the Northern Hemisphere.

What are some of the things you see?

[There are lots of stars, there is the Moon, perhaps a planet or two, and there is the Milky Way.]

If you look from the east to the west you see something that looks like a faint white cloud extending up from the ground.

Does anyone know what this is?

[The Milky Way.]

Can anyone explain what the Milky Way is?

[It's our galaxy.]

In the past, people had all sorts of interesting ideas about what the Milky Way really was. Some thought it was dust, others thought it was clouds and I suppose that even a few people thought it was milk. It was Galileo who finally figured it out when he looked at it with his telescope back in the early 1600s. He discovered that the Milky Way was really made up of stars — billions of stars that were so far away that you couldn't resolve them with your naked eyes.

Modern astronomers tell us that this band of stars that we see crossing the sky makes up a much larger structure called a galaxy. Today, it's getting harder and harder to see the Milky Way because of the effects of light pollution.

What is light pollution?

[Light pollution happens when the light from streets, cars and buildings create so much glare in the night sky that it interferes with our ability to see stars and other celestial objects.]

Here let me show you . . . Let's head back to the city.

3. Light Pollution

Action

Click on the word 'show' to turn on the light pollution.

As you can see, because of the glare from street lights, headlights and buildings, the Milky Way virtually disappears from view. Fortunately in our planetarium, we can get rid of the light pollution any time we want. Watch . . .

Action

Click on the word 'fade' to turn the light pollution off again.

That is better.

4. The Milky Way in Summer

As it turns out, the winter isn't the only time that you can see the Milky Way in the sky. You can also see it quite clearly in the summer. Let's take a look.

Action

Click on the word 'here' to change setting to summer sky.

Here we are in the middle of the summer. Does anyone see the Milky Way now?

[It stretches out from the northern horizon to the southern horizon.]

Since we've changed seasons, do you think that this is the same part of the Milky Way we were looking at before?

[No.]

If you look carefully, you'll see that the stars the Milky Way passes through in the summer are very different from the winter. To help you out, let me draw in the constellations.

5. Constellations

Action

Click on the word 'here' to add the constellation drawings.

Can anyone name some of the constellations that the Milky Way appears to be passing through?

[Scorpius, Sagittarius, Aquila, Cygnus, and Cassiopeia.]

Since this part of the Milky Way passes through the constellation Sagittarius, astronomers call it the 'Sagittarius Arm'. Now let's go back to the winter sky and see how the stars compare.

Action

Click on the word 'here' to return to the original setting.

Here we are back in the winter again. Which constellations does the Milky Way pass through now?

[Orion, Auriga, Perseus, and Cassiopeia.]

Because it passes through Orion in the winter, astronomers call this part of the Milky Way the 'Orion Arm'.

6. Measuring Distance

When we say that the Milky Way has arms, we're not talking about some large creature in the sky. To get a real understanding about what our galaxy looks like we're going to have to take a little trip out into space.

Action

Click on the word 'here' to change to the view of the Milky Way from space.

Now we're about 130,000 light years from Earth looking back at our galaxy.

Can anyone explain what we mean by the term light year?

[A light year is the distance a beam of light would travel in a year.]

While it sounds like a unit of time, a light year is really a unit of distance. Basically, if you took the speed of light (300,000 km/sec) and multiplied it by the number of seconds in a year, you'd have a light year. In round numbers a light year equals about 9.5 trillion kilometers or 5.9 trillion miles.

Why do we use light years to measure distances in space instead of miles or kilometers?

[The distances in space are so great that using small units like miles would leave you with enormous numbers to work with.]

Now I said that we were looking back at the Milky Way in space. Do you think that this is an actual photograph of the Milky Way?

[No, it can't be, because we've never traveled that far into space.]

So far, most of the space probes that we've sent from Earth have not even left our solar system, so getting a picture of our entire galaxy would be impossible! This is a drawing based on what astronomers think our galaxy looks like. They figured it out by measuring the position and motion of stars from inside of it. In addition, we believe that the Milky Way galaxy looks similar to other distant galaxies that we can see in space using telescopes.

7. Shape of the Milky Way

How would you describe the shape of the Milky Way?

[It looks like a giant pinwheel.]

Our home galaxy is a big place. It's called a spiral galaxy and astronomers estimate that it has something like 200 billion stars. The Milky Way is not standing still. Like a giant pin wheel it is rotating in space. It takes about 250,000,000 years to complete one rotation!

If you were to measure across the diameter of the Milky Way you'd find that it was about 100,000 light years across but only about 3,000 light years wide at its thickest part, which is a central bulge called the 'galactic core'.

As you can see, our Sun is out on one of the spiral arms of the galaxy, about 26,000 light years from the core. To get a true appreciation for the size of our galaxy, let's take a little trip around it.

Action

Click on the word 'here' to change to the view of the Milky Way from space.

Okay everyone, hold onto your seats! We're going for a little ride!

Action

Click on the button to move around the Milky Way. Stop when the time counter reaches 6:50 PM.

Now we're looking at the galaxy edge on where you can really see the central bulge. In a way, our galaxy is a lot like the solar system, looking like a flat disk in space. Let's continue around the bottom side.

Action

Click on the button to move around the Milky Way. Stop when the time counter reaches 8:00 PM.

For many years, astronomers thought that our Milky Way was the entire universe. As telescopes got bigger and better, however, they found that we were not alone! Back in the early 1900s, an astronomer named Edwin Hubble was looking at a fuzzy patch of light in the constellation Andromeda with a brand new telescope. This spot was known as the Andromeda Nebula. Let's take a look at what he saw . . .

8. The Andromeda Galaxy

Action

Click on the word 'here' to change to the view toward the Andromeda galaxy.

Here you see the Andromeda galaxy in the sky the way it would look with your naked eye. I labeled it so you can see where it is. Now let's zoom in on it to see what Hubble saw with his telescope.

Action

Click on the word 'here' to zoom in on Andromeda galaxy.

Here's the Andromeda galaxy close up. Does it look like anything else that we've seen recently?

[It's very similar in shape to out Milky Way galaxy.]

Astronomers think that the Andromeda galaxy is quite similar to the Milky Way in

size and shape. Even though it's more than two million light years away from us, it's the next closest large galaxy to our own.

The Andromeda galaxy was the first galaxy that astronomers were able to see close up. At first, they called it an 'island universe' because they thought that it was unique. As telescopes improved, however, they discovered more and more galaxies of different shapes and sizes.

Today, we believe that the universe is filled with billions of galaxies each one containing billions of stars! So the big question is, are we really alone? Stay tuned . . . we're just getting started!

Have students recap their observations. The main concepts are: 1) Our galaxy is called the Milky Way and it looks like a giant pinwheel composed of over 200 billion stars. 2) The Sun is located on one of the spiral arms of the galaxy about 26,000 light years from the center. 3) A light year is a unit of distance that equals about 9.5 trillion kilometers or 5.9 trillion kilometers. 4) The universe has billions of galaxies. The next closest galaxy is called the Andromeda galaxy and it's about two million light years away.

Starry Night High School Link

Students who have access to the Starry Night High School™ computer program should refer to Lesson H1 — The Milky Way Galaxy and H2 — The Universe.

Extending the Lesson

Observing the Milky Way

While seeing the Milky Way in the planetarium is nice, nothing beats looking at the real thing. If you live in an area where light pollution isn't a major problem try to arrange an evening field trip to view the Milky Way. If possible, bring some sketch pads and a lounge chair or two so that students can sit back and draw the position of the Milky Way as well as the constellations in the background.

Hubble Classification of Galaxies

After discovering the fact that the Andromeda nebula was really another galaxy like our own, Edwin Hubble set his sites on finding other galaxies. One of his first sources of information was the Messier Catalog, a list of faint fuzzy objects that a French Astronomer and comet hunter named Charles Messier had compiled to keep other astronomers from confusing them with comets. As it turned out, many of these Messier objects were indeed galaxies, and soon, Hubble had assembled a collection of different-shaped galaxies. Some were spiral galaxies like our Milky Way while others were shaped like giant ellipses. Hubble developed a classification system for galaxies based on their shapes and tried to use it to show how galaxies change or evolve over time. Have students research some of the modern theories of how galaxies form and compare them to the Hubble Classification system to see how they compare.

Modeling the Milky Way

One of the best ways for students to visualize the structure of galaxies is to build a model of one. Using the Hubble Classification system, have students try their hand at modeling some of the different shapes of galaxies. This type of project will not only enhance student's understanding of the structure of galaxies, but allows them to explore the artistic side of astronomy.