History and Discovery of Asteroids

Where the Journey Began

TEACHER GUIDE—EXPLORATION

BACKGROUND

The eight "flashbacks" (readings) that make up the Exploration section of this module trace specific periods in the history of asteroid discovery and characterization from the time of Ptolemy (85-150 AD) to the present time. They provide students with some historical background and rationale for the Dawn mission to the asteroid belt to study Vesta and Ceres "up close."

The first two flashbacks explain some of the *new ways of thinking* that enabled the Titius-Bode law to be developed.

The **Thinking Outside the Box!** flashback describes how Copernicus' heliocentric theory sparked controversy in the 16th century scientific community by challenging Ptolemy's "geocentric" theory. It also emphasizes that early astronomers often worked in isolation as they made countless observations with their unaided eyes.

In 1596, Johannes Kepler wrote **"Between Jupiter and Mars, I Place a Planet,"** based on a "pattern in the sky" which developed as he analyzed Tycho Brahe's measurements of planetary movement. This pattern is now called the Titius-Bode law, which states that, *"The mean distances of the planets from the sun are approximately subject to an exponential rule."* The Titius-Bode law led to the discovery of a "missing planet" between the orbits of Mars and Jupiter.

> The **Patterns in the Sky** activity from the Development section could be used with this flashback.

The following flashbacks describe *how technology has played a role* in asteroid discovery and characterization.

Seeing Faraway Things as Though Nearby recounts what is known about the discovery of the telescope and describes how the astronomers called the "Celestial Police" used both refractor and reflector telescopes to search the heavens for the "missing planet."

It was a Dark and Starry Night of New Year's Day, 1801, that Giuseppe Piazzi, an Italian monk and a member of the Celestial Police, discovered Ceres. Illness prevented him from establishing that he had found the "missing planet"; and Ceres' orbit had taken it beyond view from his observatory when Piazzi recovered sufficiently to continue his observations of the skies. Ceres is the second of two asteroids that will be studied during the Dawn mission.

> The **In Search of** activity from the Development section could be used with any flashback in this section.

The Lost is Found highlights the role of mathematics in scientific discovery and communication between astronomers, as the "missing planet" is found, lost, and found again one year later.

Astronomical Serendipity recounts the early 19th century astronomers' amazement at Wilhelm Olbers' discovery of Pallas just as they were celebrating the return of Ceres. The first generation of asteroid searchers found four asteroids in the seven years between 1801 and 1807. Vesta, the last of these four, is the other asteroid that will be visited by the Dawn spacecraft. This flashback describes some historical factors that made it difficult for early 19th-century astronomers to make any new asteroid discoveries.

No additional "minor planets" were found for almost 40 years. One of the reasons, of course, was the fact that the "First Era" asteroid searchers found the four largest and brightest of the "minor planets." The remaining asteroids may have been too small and too dim to be seen, even with the best telescopes available in the early 1800's.

In **What Can You See With a Telescope?** students explore some physical properties of asteroids that make them difficult to observe from Earth. In addition to size, these characteristics include their shape, the distance of their orbits from Earth, and their albedo (the reflectivity of their irregular surfaces.) This flashback describes the role that better-designed telescopes played in new asteroid discoveries during the second wave of asteroid discoveries from 1845 to 1890.

> The **How Bright Are You?** and **Seeing Circles–Studying Albedo** activities from the Development section could be used with this flashback.

The flashback, **I Can See You More Clearly Now**, shows how the Hubble Space Telescope helped to close the distance so that astronomers could study distant celestial objects such as asteroids.

> The **Where Are You?** and **Modeling in 3-D** activities from the Development section could be used with this flashback.

TEACHER GUIDE APPENDICES

- Main Ideas and Leading Questions (with answers) that accompany each of the flashbacks(**Appendix A)**
- A list of standards addressed in this section of the module (**Appendix B)**
- Additional background resources—both online and print—for this module are provided in the Resource Section.
- Visit the Dawn Dictionary for a list of terms and definitions for this module.

MATERIALS

- Flashbacks:
  - "Thinking Outside the Box!"
  - "Between Jupiter and Mars, I Place a Planet"
  - "Seeing Faraway Things as Though Nearby"
  - "It was a Dark and Starry Night"
  - "The Lost is Found"
  - "Astronomical Serendipity"
  - "What Can You See With a Telescope?"
  - "I Can See You More Clearly Now"

- Materials as needed for student groups to prepare their presentations; possibly including butcher or poster paper, colored markers, computers with PowerPoint application, and props for skits.

PROCEDURE

Part 1: Assign Reading Groups

1. Divide your class into eight reading groups–one for each of the eight flashbacks. You may want to assign the groups by difficulty of reading material, since some of them contain more technical terms than others.

2. Make enough copies of each flashback for each reading group and distribute them. It would be best not to distribute them in the order in which they are described in the Background section above, since they are listed in chronological order.

3. If you used the Briefing PowerPoint to introduce the Dawn mission, your students should be aware that it will be launched in June of 2006 for a trip to study 1Ceres and 4Vesta. Explain to students that each reading group will be studying a different period of time in the history of asteroid discovery that led to the Dawn mission.

4. At the end of each flashback, some guided questions will help students determine the main ideas in that flashback. The group should reach consensus on the answers to those questions so that they can become “experts” on the period of asteroid discovery described in that particular flashback.

5. Explain that they will use their “expertise” in three ways as the class completes the *History of Asteroid Discovery* material:
   a) During this exploration of asteroid discovery, they will be identifying:
      - the period of time their flashback covers;
      - the scientific advancements made during the period;
      - any technological advances made during this time; and,
      - any historical events that occurred during this time.

   They will then design a classroom presentation that includes this information. This will be a verbal presentation, but it may be accompanied by a poster or PowerPoint or it may be done in skit form. All members of each group must have an assigned role.

   Allow sufficient time for development of the verbal presentations.

   In Appendix A, you will find a list of Main Ideas for each flashback and a copy of the questions (with answers) that are found at the end of each flashback for your use as you assist each group in the completion of their assignments.

   If you plan to use the assessment rubric found in the Interaction/Synthesis section, distribute copies to students before they begin this assignment so that they are aware of how the presentation will be evaluated. Call their attention to the time limit for the presentation.

b) As the class participates in activities during the next section (Development), group members will be responsible for describing the “setting” or background for those activities that relate their flashback to the activity.

c) In the Interaction/Synthesis section, they will make their verbal presentations and, after watching all presentations, determine the placement of their flashback material in the overall history timeline of asteroid discovery.

Teacher Guide Appendices for Exploration Section

APPENDIX A—Flashback Main Ideas and Leading Questions

Flashback Main Ideas—Thinking Outside the Box!

The study of astronomy is old. Humans were studying planets more than 2000 years ago.
The early astronomers' only "way of seeing" the planets was with the unaided human eye.
Early astronomers were usually amateurs, observing the heavens as a pastime.
From 150 to 1530 AD, Ptolemy's geocentric theory that the Earth was the center of the universe was the accepted theory.
In 1530, Copernicus proposed a heliocentric theory, in which the planets, including Earth, revolved around the Sun.
Copernicus' new theory was not immediately accepted by other astronomers.

Questions relating to Thinking Outside the Box!

1. What planets were known as the "classical planets"? Why were they considered "classics"? [Mercury, Venus, Mars, Jupiter and Saturn are considered to be "classical planets because they can be seen with the unaided eye and, therefore, were studied for over 2000 years]
2. What did the early astronomers use to make their observations of the planets? [their unaided eyes]
3. How was Copernicus' heliocentric theory of our solar system different from Ptolemy's geocentric theory? [Copernicus thought that the Earth and other planets revolved around the sun; whereas Ptolemy thought that the sun and other planets revolved around a motionless Earth. Ptolemy's order in which the planets orbited the Earth was different from the heliocentric order.]
4. On what did Copernicus base his theory? [Thirty years of observation.]
5. What important discovery did Christopher Columbus make 50 years before Copernicus' theory was published? [Christopher Columbus discovered a new continent, proving that the Earth is round, not flat.]
6. Did Copernicus publish his own theory? Why or why not? [No, it was published by a colleague, George Rheticus. Copernicus thought he needed to check and recheck his observations.]
7. Why was Copernicus' theory not readily accepted? [Skepticism of his colleagues. It is difficult to change the ideas of many intellectuals when an idea has been accepted for more than a thousand years.]
8. Were all these early astronomers professional scientists? [No, many of them were amateurs, making their living in other ways.]
9. Compare and contrast Copernicus' astronomy laboratory and technology with astronomy labs and technology available today. [Answers will vary and may include: Today's astronomers use high-tech telescopes often housed in observatories. Copernicus' used his unaided eyes and viewed from a tower built into a wall that surrounded a cathedral.]

Flashback Main Ideas—Between Jupiter and Mars, I Place a Planet

Later in the 16th century, astronomers like Brahe and Kepler based their ideas on Copernicus' work.
Early astronomers spent many years making observations.
Copernicus' heliocentric theory begins attracting secret followers.
Kepler applied mathematics to astronomical data to form new models.
Kepler incorporated physics and mathematics into laws of planetary motion. The first describes planetary orbits as ellipses rather than circles. The second relates equal times of the orbit to equal areas of the ellipse. This meant that planets did not travel the same speed throughout their orbits.

Questions relating to Between Jupiter and Mars, I Place a Planet

1. Tycho Brahe and Johannes Kepler worked together as they studied the solar planetary movements. Describe what part of the work each of them did. [Brahe made thousands of planetary movement measurements and Kepler used mathematics to analyze Brahe's data.]
2. How many years did Brahe make planetary movement measurements? [26 years]
3. How many years lapsed between the time Copernicus proposed his Sun-centered model and when Johannes Kepler decided there should be a planet between Jupiter and Mars? [About 50 years]
4. Why would Kepler's professor still teach Ptolemy's model if he believed in the Sun-centered theory? [Copernicus' theory was not widely accepted yet and considered controversial]
5. How did Kepler use his understanding of mathematics to form his planetary orbit model? [Kepler used classic geometrical solids as the basis of his orbit model.]
6. How did Kepler use his mathematics and physics background to describe his planetary motion laws? [He described the orbits of the planets as ellipses with the Sun as the foci, rather than circles with the Sun at the center. He also used the laws of physics to describe the different speeds that planets exhibited as they traveled in elliptical orbits around the Sun.]
7. Kepler's second law of planetary motion indicated that planets traveled faster at some points of the orbits than others. Where did planets travel the fastest—away from the Sun or close to the Sun? [close to the Sun]
8. How might you use an image or animation to explain the laws to your classmates? There are some helpful images/animations available at:
   http://csep10.phys.utk.edu/astr161/lect/history/kepler.html
   http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/circmot/ksl.html

Flashback Main Ideas—Seeing Faraway Things as Though Nearby

The first telescopes, invented about 1608, were the products of craftsmen, not astronomers.
Astronomers could make better observations with the telescope.
Two kinds of telescopes were developed—refracting and reflecting.
The use of the telescope by astronomers from England and Germany expanded rapidly during the 1600s.

Questions relating to Seeing Faraway Things as Though Nearby

1. Do we know exactly who invented the telescope? Why or why not? [No, because there are conflicting stories about the origin of the first telescope.]
2. Do we know when the telescope was invented? [No, we know that Lippershey applied for a patent for one in 1608.]
3. What is the difference between refracting and reflecting telescopes? [Refracting telescopes use lenses to focus light by refracting it from a distance. Reflecting telescopes use curved mirrors to reflect and focus light.]
4. What is the difference between convex and concave lenses? [Convex lenses are thicker in the center than on the outside; concave lenses are thinner in the center than on the outside.]
5. What was the magnification power of the refractor telescopes used by Galileo? What was he able to see with this refractor telescope? Did he discover any asteroids? [Galileo used refractor telescopes with lenses that magnified objects about eight times their size. With these instruments, he did not discover any asteroids but he did discover the satellites of Jupiter, the rings of Saturn, the changing shape of Venus, sunspots, and solar rotation in less than ten years.]
6. What were the Celestial Police looking for? [The missing planet between Jupiter and Mars.]
   Using the Internet, find and print two diagrams: one should show how a refracting telescope works, and the other should illustrate how a reflecting telescope functions. [Possible Web sites include:
   http://www.astronomynotes.com/telescop/s2.htm
   http://www.astronomynotes.com/telescop/s3.htm]

Flashback Main Ideas—It was a Dark and Starry Night

Asteroids move in relation to other known stars; this is how astronomers identified asteroids.
The first asteroid was discovered in 1801, almost 200 years after the invention of the telescope.
Conformation of asteroid sightings required many astronomical observations.
Early astronomers were in communication with each other and supported each other's findings.
A reliable orbit was essential to establishing the authenticity of any newly sighted object. Knowing the orbit allowed astronomers to predict where the celestial object will be when they want to study it.
The mathematical methods of calculating planetary orbits in 1801 required more information than was known about the newly observed object before it was "lost."

Questions relating to It was a Dark and Starry Night

1. When and where did Giuseppe Piazzi live and work? [In the 1800s, in a monastery in Sicily]
2. What was Piazzi doing when he saw a new point of light? [cataloguing and verifying the stars that other astronomers had discovered.]
3. What is a star chart? What technology is available today that makes handwritten star charts unnecessary?[A star chart is a chart of the sky, a method that astronomers use to keep records of the movements of the moon and planets. Early astronomers had to draw charts of the sky, recording all the stars they could see with their unaided eyes. On to these charts, the paths taken by the moon and planets could be plotted from night to night. Today, the recording, verifying, and communicating functions are performed with photographic and computer technology.]
4. What was different about the point of light that he discovered on New Year's Night, 1801? [It moved in the sky with respect to other stars.]
5. What did Johann Bode think that Piazzi had discovered? [the missing planet between Jupiter and Mars]
6. How did the brightness of this point of light compare with that of other stars in the sky? [It was quite dim.]
7. Why did Piazzi not think that the moving point of light he had discovered was a comet? [Because it did not have any nebulosity [*clouds of dust and gas*]; its movement was very slow and rather uniform.]
8. What historical event was occurring during this time that interrupted Piazzi's communication with other astronomers? [The Napoleonic war with Italy]
9. Who finally announced that Piazzi had discovered the "missing planet"? [von Zach]
10. Why was the discovery of Ceres not substantiated during the six weeks of Piazzi's observations? [Not enough data was collected to calculate Ceres' orbit before it disappeared from sight.]
11. How long after the invention of the telescope was the first asteroid discovered? How was the invention of the telescope instrumental to the work of the Celestial Police? [almost 200 years after the invention of the telescope; since the telescope magnified distant objects, it helped the Celestial Police observe the skies.]

Flashback Main Ideas—The Lost is Found

Astronomers and mathematicians worked together to re-discover Ceres.
Mathematicians were revising old methods and finding new methods to calculate the orbits of newly discovered objects in the sky.
Gauss's mathematical prediction of Ceres' orbit was crucial to its re-discovery.
Communication between astronomers and mathematicians helped them work together to re-discover Ceres.

Questions relating to The Lost is Found

1. How much time lapsed between Ceres' first discovery and its rediscovery? Who was involved in the rediscovery? [Exactly one year. Carl Friedrich Gauss' mathematical calculations helped to predict where Ceres should be. Baron von Zach used the calculations to re-discovery Ceres. Wilhelm Olbers was also able to locate Ceres.]
2. Why couldn't Hershel and other astronomers find Ceres during the early months of 1801? [Because Ceres' orbit took it out of their visible range from the Earth until the fall of the year]

3. What two important roles did Van von Zach play in the rediscovery of Ceres? Explain why each was important. [He re-discovered Ceres and communicated his discovery in his publication, Monthly Correspondence, which played a vital communication role in the recovery.]
4. Why was Gauss's new method of determining planetary orbits so important to the re-discovery of Ceres? [Because his new method didn't require as much information about Ceres' movement as the old methods did.]
5. Did Piazzi rediscover Ceres? [No, von Zach and Olbers did.]
6. Why was communication between astronomers and mathematicians so important in the re-discovery of Ceres? [Because none of the individuals had all the information that was necessary for the re-discovery. Piazzi had some observations, Gauss had a new mathematical method, and von Zach and Olbers used the results of Gauss' calculations to find Ceres.]
7. What was Piazzi's reward for discovering Ceres? Why do you think this was significant? [A new telescope was given to him by the King of Sicily. This showed that astronomy was beginning to receive political and financial support. Eventually, astronomy would become recognized as a profession.]

Flashback Main Ideas—Astronomical Serendipity

Olbers was surprised to find another "moving point of light." He named this one Pallas.
Gauss found that the revolutionary period (time it takes to make one orbit around the sun) of Ceres and Pallas was the same–4.6 years.
Hershel tried to measure the size of Ceres and Pallas, which he called asteroids.
Olbers formulated the first theory of how the asteroids originated in 1804.
Harding discovered Juno in 1804.
Olbers finds Vesta in 1807.
The First Era of Asteroid Discovery ended in 1807.

Questions relating to Astronomical Serendipity

1. Herschel attempted to estimate the sizes of Ceres and Pallas. How did he do it? What did he determine? [He measured the sizes by looking at each "planet" through a telescope while comparing it to a disk of a known size at a given distance. He determined that these "planets" were so much smaller than the other known planets.]
2. Identify the astronomers involved in the first era of asteroid discovery. Where did they work and what contributions did they make? [Some possible answers include
   Guiseppe Piazzi worked in Sicily; discovery of Ceres, 1801
   Carl Freidrich Gauss from Germany; discovered new mathematical method for determining orbit of planets, 1801
   William Olbers worked in Germany; discovered Pallas and Vesta, 1801-1807
   Johann Bode from Germany; convinced Piazzi that he had found "the missing planet"
   Baron von Zach worked in Germany; re-discovered Ceres and published scientific journal
   Karl Harding from Germany; discovered Juno in 1804
   William Herschel worked in Germany and England; measured size of Ceres and Pallas
   Johann Schröter worked in Germany; President of the Celestial Police.]
3. What surprise did Wilhelm Obers find as he continued to observe Ceres after it had been re-discovered? [Another moving point of light! Another asteroid, which was named Pallas.]
4. How did the period of revolution (time that it takes to orbit the Sun) of Ceres and Pallas compare? [They were the same—4.6 years]
5. Who first called Ceres and Pallas "asteroids"? [Hershel]
6. Who was the first astronomer to formulate a theory about how asteroids were formed? What was his theory? [Olbers formulated the theory that Ceres and Pallas were a pair of fragments of a once great planet.]
7. How many asteroids were discovered during this first era of asteroid discoveries? What were these asteroids named? [Four. Ceres, Pallas, Juno, and Vesta.]
8. What historical events took place as the first era of asteroid discoveries was ending? [French army burned Lilienthal, Germany, destroying Schröter's observatory and astronomical records.]

Flashback Main Ideas—What Can You See With a Telescope?

No new asteroids were found between 1807 and 1845.
Most asteroids are too small and too dim to be seen with early 19^{th} century telescopes.
Most asteroids have irregular shapes and surface textures. This means that they do not always reflect the same amount of sunlight.
The term albedo describes how much sunlight an asteroid reflects.
An asteroid's orbital position and its distance from the Earth also affect how much reflected sunlight an observer on Earth can see.
Asteroids rotate on one of their axes. Their rate of rotation also affects how much light is reflected can be seen on Earth at any specific time.
Brightness is measured on a scale in which the larger the value of an asteroid's brightness, the dimmer the asteroid appears to an observer on Earth. So, an asteroid with a brightness of 4.0 is brighter than one with a value of 6.3.
Asteroids are numbered in order of their discovery. 1Ceres is the scientific name of the first asteroid discovered by Piazzi.
During the second era of asteroid discovery, starting in 1845, astronomers attempted to make quantitative measurements of asteroid size and rotation rates, using the telescopes available to them at this time.

Questions relating to What Can You See With a Telescope?

1. How long after Vesta was discovered in 1807 was the next asteroid found? What was its name? Why was there a lull in asteroid discoveries between 1807 and 1845? [Astraea was found in 1845. The first four asteroids were the largest and brightest. The rest were too small and dim to be found with the early 19^{th} century telescopes. Once telescope technology improved, scientists were able to discover new asteroids.]
2. How does Astraea's brightness compare with that of Ceres? Explain which of these asteroids is the brightest and why. [Astraea has a brightness of 6.6 while Ceres' brightness is 4.0. Since the smaller the number, the brighter the asteroid, Ceres is brighter than Astraea.]
3. What factors affect how much sunlight asteroids reflect to observers on Earth? [These factors include: its size and shape, the albedo of different surfaces, its rate of rotation, its distance of the asteroid from Earth, its position in its orbit relative to the Sun.]
4. In your own words, define albedo. [The answer should include a reference to the relative brightness of a space object. Albedo is the amount of reflected light compared with the light that the object receives.]
5. In the asteroid names, 1 Ceres and 5 Astraea, what do the numbers stand for? [The numbers indicate the order in which they were discovered. Ceres was the first asteroid discovered and Astraea was the fifth.]
6. Hershel attempted to measure the size of Ceres and Pallas. Schröeter tried to measure the rotation rate of Juno. How accurate were these early measurements? [Hershel's measurements were smaller than those being made now. Schröeter's measurement of Juno's rotation rate was longer than what is now accepted.]
7. One person tells you that it is a long way to the next large city. Another person says that it is 150 miles to the next large city. Which of these statements includes a quantitative measurement and which is a qualitative observation? Which gives you the most precise information? [The quantitative measurement is 150 miles; "a long way" is a qualitative observation. The quantitative measurement gives you the most precise information.]
8. Why do you think that it is important that astronomers are able to make quantitative measurements? What kept the early astronomers from making reliable quantitative measurements?[Quantitative measurements give us more precise information. Early astronomers didn't have the technology available to make reliable quantitative measurements. When they observed asteroids through their telescopes, asteroids appeared as bright or not-so-bright pinpoints of light.]
9. What asteroid features could 19^{th} century astronomers observe through their telescopes? [The only asteroid features that early 19^{th} century astronomers could observe with their telescopes were dependent upon the brightness and the variations in brightness of their reflected light. These included: size, brightness as affected by albedo, and rotation rates.]

Flashback Main Ideas—I Can See You More Clearly Now

The Hubble Space Telescope was a technological breakthrough first implemented in 1990. As it orbits Earth, it sends back "close-up" images of distant celestial bodies.
Compared to Earth-bound telescopes, Hubble is able to capture more detailed images of and data.
Hubble images of Vesta helped astronomers to identify specific surface features such as impact basins, an exposed mantle, ancient lava flows, and a gigantic impact crater nearly equal to Vesta's diameter.
Compared to Vesta, less is known about the more distant asteroid, Ceres. Hubble images are fuzzy, revealing a large, dark spot; however, it is unknown what the spot actually is.
While Hubble offered a "window on the universe," it has limitations with regard to how "close-up" it can get. To be able to learn more specifics about asteroids, for example, scientists have to apply new technologies.

Questions relating to I Can See You More Clearly Now

1. When was Hubble first used? What space shuttle lifted it into orbit around Earth? [Space shuttle Discovery lifted Hubble into orbit in April 1990]
2. How long does it take the Hubble Space Telescope to orbit the Earth? [Hubble orbits Earth every 97 minutes.]
3. What changes were made to the Hubble Space Telescope three years after it was lifted into space? Why was it necessary to make these changes? [Astronauts above the space shuttle Endeavor installed different mirrors and replacement parts to correct the distorted images Hubble had been capturing.]
4. Compare the images seen from an Earth-based telescope with the images captured by the Hubble Space Telescope. [Images available through Hubble offer a "close-up" perspective with more details. For instance, using an Earth-bound telescope, Vesta would look like a potato in the distance. Hubble enables one to see the bumps and cracks in Vesta's surface]
5. How close was Vesta to Earth when Hubble was able to capture the most "close-up" images? [Vesta was 177 million kilometers away from Earth.]
6. What have scientists learned about Vesta from Hubble? [It has a complex surface with an exposed mantle, ancient lava flows, impact basins, and a gigantic impact crater that stretches 460 kilometers across and 13 kilometers deep.]
7. What have scientists learned about Ceres? [Less is known about Ceres than Vesta. Ceres has a large dark spot on its surface; however, it is unknown if the spot is a crater or different colored terrain. There is evidence of water content and the formation of seasonal polar caps.]
8. If Hubble offers a more close-up "window on the universe," then why is the Dawn mission necessary? [Images are still too unclear for scientific study. In order to learn more about asteroids Ceres and Vesta, scientists need to close the distance. A robotic mission is the next logical step.]

Teacher Guide Appendices
For Exploration Section

APPENDIX B—STANDARDS ADDRESSED

National Science Education Standards addressed:

Science As Inquiry
Understandings about Scientific Inquiry

The flashback **"Thinking Outside the Box"** demonstrates the importance of checking and rechecking observations (emphasizing evidence) when Copernicus challenged the classic view of an Earth-centered universe that was accepted at the time. This also demonstrates how science was advanced through Copernicus' skepticism of the geocentric theory, and how curiosity and unaided visual observations defined the scientific process of early astronomy.

In the activity "**Patterns in the Sky**" students look at planetary distance information and use mathematics (algebra) to "discover" a gap between Mars and Jupiter, leading to questions and the search for something that might be located in this gap. Students may use calculators to find distances of the planets to the Sun and compare their findings with modern planetary distances. This mathematical evidenceis then used to stimulate a hunt for something between Mars and Jupiter.

In the flashback "**Between Jupiter and Mars, I Place a Planet**" students read about scientists that used measurements of planetary movements to develop planetary orbit laws, a new area of astronomical study.

In the "**It Was a Dark and Starry Night**" flashback, students learn about the discovery of Ceres at an observatory in Sicily and the importance of verifying scientific findings using evidence. Scientists tried to verify the discovery of the "missing planet" but had difficulty due to the interference of the weather. In this case, scientists worked with mathematicians to attempt to calculate the orbit of the newly discovered "Ceres" in order to be able to find it again.

In "**The Lost is Found**" flashback, students learn that new investigations can occur through mathematics. In the case of Ceres, the mathematician Gauss applied a new mathematical method to determine Ceres' orbit. This new method proved accurate when Ceres was rediscovered by Zach exactly one year after Piazzi discovered it. The new method for finding a planet's orbit was refined and became the standard procedure for calculating planetary orbits.

In "**Astronomical Serendipity**" students read about how the understanding of the solar system in the early 1800s led Olbers to continue to study Ceres, which resulted in the discovery of a second body named Pallas. Through mathematical calculation. Gauss determined the orbital period of Pallas. Herschel used a telescope and comparisons of Ceres and Pallas with objects of known sizes and determined these new objects to be smaller than the other planets. He thus coined the term "asteroid." This resulted in the "Celestial Police" being reactivated with the task of looking for more asteroids, which then led to the discovery of Juno and Vesta. The discovery of these asteroids resulted in two theories of their formation.

The flashback "**I Can See You More Clearly Now**" describes how the questions and investigations that require advanced technologies like the Hubble Space Telescope have been used to provide detailed information about the asteroids, especially Vesta, but that there is still a need to learn more about the mysterious first asteroid, Ceres.

Physical Science
Transfer of Energy

In the flashback "**What Can You See With a Telescope?**" students learn that the brightness of an object in space depends on the distance from the Earth, its orbital position, the reflective power (albedo), and its rotation rate.

Earth and Space Science
Earth in the Solar System

In the flashback "**Between Jupiter and Mars, I Place a Planet**" students learn about how the laws of planetary motion in our solar system were developed.

In the flashback "**It Was a Dark and Starry Night**" students read about the discovery of what became the first known asteroid, Ceres.

In the flashback "**What Can You See With a Telescope**?" students learn about the discovery and brightness of asteroids discovered from 1801 through 1849 and how this revealed the increasingly complex nature of the solar system.

In "**Astronomical Serendipity**" students read about a new class of objects in the solar system called asteroids and the four specific asteroids that were discovered in the early 1800s: Ceres, Pallas, Juno, and Vesta.

Science and Technology
Understandings about Science and Technology

The flashback **"Thinking Outside the Box"** shows that many people have made contributions to science, including Ptolemy, Copermicus, and Rheticus. The scientist glossary is a resource students can use in this module to understand these contributors.

In the flashback "**Between Jupiter and Mars, I Place a Planet**" students read about the work of Brahe and Kepler.

In the flashback "**Seeing Far Away Things as Though Nearby**" students learn that it was most likely a craftsman. not a scientist. that invented the telescope and that people then tried to patent and sell these magnifiers for different purposes. They also learn that Galileo used the telescope to make better observations of the moon and satellites of Jupiter, and that the use of the telescope in this way led to better telescopes and new uses for them.

In the flashback "**It Was a Dark and Starry Night**," students learn about a team of "Celestial Police" who pool their talents and time in order to make systematic observations of the sky. Scientists in this group include: Zach, Lalande, Bode, Schroeter, Harding, Olbers, von Ende, Gildemeister, and Piazzi. Students also read how Piazzi discovered Ceres and how he worked with colleagues (i.e., Bode, Zach, and Herschel) to verify his discovery.

In "**Astronomical Serendipity**" students learn about the contributions of astronomers who used telescopes and mathematics to discover new asteroids. These scientists include: Olbers (Pallas, Vesta), Gauss, Herschel, and Harding (Juno).

The limits of telescope technology in the mid 1800s is described in the flashback "**What Can You See With a Telescope?**" When this technology advanced, smaller and dimmer asteroids could be discovered.

In the flashback, "**I Can See You More Clearly Now**" students learn that advancing technologies like orbiting telescopes can contribute to our knowledge of the solar system (i.e., Vesta). Yet there is more work to be done to understand the origin and nature of Ceres. Further studies will require additional instruments and a spacecraft. In this flashback, students also read about the initial difficulties with Hubble, and that even after it was fixed, it provided only limited information on Ceres. The constraints of Hubble necessitated the Dawn mission to answer many remaining questions about this asteroid.

Science In Personal and Social Perspectives
Science and Technology in Society

The flashback "**Thinking Outside the Box**" describes how Copernicus made observations from a tower that resulted in a revolutionary theory of the solar system which has forever changed our perception of the universe and our place in it.

Kepler's work with planetary orbits while a mathematics professor at a Protestant seminary is described in the flashback "**Between Jupiter and Mars I Place a Planet.**"

In the flashback "**Seeing Far Away Things as Though Nearby**" students read how different people (i.e., Lippershey, Metius, Galileo, and Newton) have advanced science through inventions like the telescope. Advances in technology (i.e., the telescope) have uses in society. such as children seeing distant objects more clearly.

While a new group of scientists looked for this missing planet, it was an Italian monk named Piazzi who finally discovered it, in 1801 at an observatory in Sicily. Students learn about this in the flashback "**It Was a Dark and Starry Night**." This discovery, which came to be known as an asteroid, would forever change our view of the solar system.

In "**The Lost is Found**" the rediscovery of Ceres by Gauss and Zach, and Olbers led to Piazzi being rewarded with a new telescope for the Palermo Observatory by the king.

In "**Astronomical Serendipity**" students learn that many scientists contributed to the discovery of asteroids from different places in Europe in the early 1800's.

History and Nature of Science
Nature of Science

The flashback **"Thinking Outside the Box"** demonstrates the importance of being persistent in making observations and checking and rechecking these observations. It clearly shows the dedication of Copernicus' observations in forming the new heliocentric theory. This flashback also shows how George Rheticus reviewed Copernicus' work and encouraged him to publish.

In “**Between Jupiter and Mars, I Place a Planet**” students learn how Kepler formulated his laws of planetary motion based on careful observation and the data from Brahe.

In the flashback “**It Was a Dark and Starry Night**” students read how Piazzi discovered Ceres through systematic observations of stars in the night’s sky. Through communications with Bode, Piazzi was convinced that he had discovered the “missing planet.” After making observations for six weeks, Piazzi and his colleagues did not have enough information to calculate the orbit and therefore thought that this new discovery was lost.

In “**The Lost is Found**” the new methods developed by Gauss were tested by Zach and Olbers, who effectively used them to rediscover Ceres.

In “**Astronomical Serendipity**” students learn how Herschel used observations and measurements to determine the relative size of these newly discovered asteroids. This flashback also illustrates how scientists reviewed and evaluated each others work leading to new theories and explanations of the solar system based on new discoveries.

History and Nature of Science
History of Science

“**Thinking Outside the Box**” provides an example of how difficult it was for scientific innovators like Copernicus to break through the accepted ideas of their time to reach the conclusions that we currently take for granted, as his theory was rejected outright by many of his colleagues.

In the flashback “**Between Jupiter and Mars, I Place a Planet**” students learn how Kepler developed mathematical models of planetary motion based on measurements and data of Brahe.

In the flashback “**Seeing Far Away Things as Though Nearby**” students learn about the many individuals that contributed to science through the invention and use of the telescope.

The “**It Was a Dark and Starry Night**” flashback can be used to show the many different individuals contributed to the eventual discovery of Ceres. The flashback describes how Piazzi discovered Ceres and how he worked with colleagues (i.e., Bode, Zach, and Herschel) to verify his discovery. It details the difficulty experienced in attempting to calculate the orbit of Ceres due to limited data.

“**The Lost is Found**” flashback demonstrates how Piazzi, Gauss, Zach, and Olbers worked together to rediscover Ceres.

In “**Astronomical Serendipity,**” students read about the scientists and mathematicians that have contributed to the study of our solar system in the 1800s. Only after careful observations, measurements, and some “serendipity” did scientists have enough information to add asteroids as a new class of objects that make up our solar system.

History and Nature of Science
Science as a Human Endeavor

In the flashback “**It Was a Dark and Starry Night**” students read how Piazzi worked with friends and colleagues to verify his discovery of Ceres and to calculate the orbit of the new body.

In “**The Lost is Found**” the rediscovery of Ceres required the abilities of a mathematician (Gauss) who, using the same observations from Piazzi, was able to rapidly predict where this new “planet” would be found.

Students learn that scientists needed to have the ability to use mathematics and technology in order to advance what was known about our solar system in the flashback “**Astronomical Serendipity.**