Section 1 The Size and Scale of the Universe

Learning Outcomes

In this section, you will

- **Produce** a scale model of the solar system.
- **Identify** some strengths and limitations of scale models.
- **Calculate** distances to objects in the universe in astronomical units (AU), light-years, and parsecs (pc).

What Do You See?

Why is there a *What Do You See?* and *Think About It?*

The *What Do You See?* and *Think About It* are the **Elicit** and **Engage** phases of learning. You have already spent a number of years at school learning about many different subjects. You watch television, read, or listen to others talk. You have your own ideas about Earth and space and about why and how things happen. It is very important for you to think about what you know or what you think you know. In the *Getting Started*, you already took some time to think in general about what you know about astronomy. Now you will think about more specific topics. The **Elicit** phase of learning is thinking about what you already know.

The **Engage** phase is meant to capture your attention. The *What Do You See?* picture in each section has been drawn by Tomas Bunk. Tomas Bunk is not a scientist but a well-recognized cartoonist. He uses his artistic talent and enjoys drawing humorous illustrations that show real Earth and space science concepts in a very personal way. When you look at the drawings, what do you see? What do you not understand about what is happening in the illustration that you would like to learn more about? How much fun and how personal can you make your encounter with Earth and space science?

As you answer the *Think About It* question(s), what interests you and what other questions come to your mind that you would like answered? The **Engage** phase of the learning cycle is designed to get you interested in what you will be learning.

Think About It

Earth is part of a large number of objects that orbit a star called the Sun. The Sun is one of hundreds of billions of stars that make up the Milky Way Galaxy.

- **What objects make up Earth's solar system?**
- **Where is Earth's solar system in relation to the stars and galaxies that make up the universe?**

Record your ideas about these questions in your *Geo* log. Be prepared to discuss your responses with your small group and the class.

Why is there an *Investigate*?

The *Investigate* is the **Explore** phase of the 7E instructional model. The best way to learn is by doing. In *EarthComm*, whenever possible, you will explore a concept by doing an investigation.

One purpose of the investigation is to "level the playing field" and ensure that everybody has a common experience through which to discuss the science. For example, some students have spent time outdoors gazing into the sky at night, while others have not. Although it would be wonderful if everyone could have this experience, it is not always possible. However, it is possible to provide a classroom experience that everybody can relate to and talk about.

In *EarthComm*, you will not be limited to having to believe what somebody wrote in a book. You will have an opportunity to observe, record data, isolate variables, design and plan experiments, create graphs, interpret results, develop hypotheses, and organize your findings. Sometimes, the entire class will participate in a demonstration. This is a way you can learn when there is not enough equipment for everyone in the class, when the equipment is very expensive, or if the investigation is too dangerous.

All scientists value inquiry. The **Explore** phase is part of an inquiry approach to learning. In *EarthComm*, you are not science students, you are student scientists.

Scientists often record their results in log books. When you see the symbol ✎, you should record the information required for the *Investigate* in your *Geo* log.

Investigate

In this *Investigate*, you will be exploring the great distances between objects in space and how astronomers measure these distances.

Part A: Distances in the Solar System

1. Use the data in *Table 1* to make a scale model of the solar system. Try using the scale 1 m = 150,000,000 km (one hundred and fifty million kilometers).

   ✎ a) Divide all the distances in the column "Distance From Sun (km)" by 150,000,000. Write your scaled-down distances (in meters) in your *Geo* log.

   ✎ b) Divide all the diameters in the column "Diameter (km)" by 150,000,000. Write your scaled-down diameters (in meters) in your *Geo* log.

   ✎ c) Looking at your numbers, what disadvantage is there to using the scale 1 m = 150,000,000 km?

Table 1: Diameters of the Sun and Planets and Distances From the Sun

Object	Distance From Sun (km)	Diameter (km)
Sun	—	1,391,400
Mercury	57,900,000	4879
Venus	108,200,000	12,104
Earth	149,597,890	12,756
Mars	227,900,000	6794
Jupiter	778,400,000	142,984
Saturn	1,426,700,000	120,536
Uranus	2,871,000,000	51,118
Neptune	4,498,300,000	49,528

2. Now try another scale: 1 m = 3,000,000 km (three million kilometers).

   ✎ a) Divide all the distances in the column "Distance From Sun (km)" by 3,000,000. Write your scaled-down distances (in meters) in your *Geo* log.

b) Divide all the diameters in the column "Diameter (km)" by 3,000,000. Write your scaled-down diameters (in meters) in your *Geo* log.

c) Looking at your numbers, what disadvantage is there to using the scale 1 m = 3,000,000 km?

3. Astronomers use special units for measuring the vast distances in space. The closest star to Earth is the Sun. Scientists call the average distance between Earth and the Sun one *astronomical unit*, or AU. The actual value of an AU is slightly less than this distance at 149,597,870 km. Astronomers most commonly use AUs to express distances within the solar system.

a) Convert all the distances in the column "Distance From Sun (km)" to astronomical units.

b) How do AUs compare to the other scales you used?

4. Using what you have learned about scaling distances and diameters in the solar system, make models of the Sun and the *planets*. Each of the planets can be drawn on a different sheet of paper using a ruler to measure the correct sizes for the different planets and the Sun.

5. To represent the distances from the Sun to the planets, you will need to use a tape measure. You may want to measure the length of your stride and use this as a simple measuring tool. To measure your stride, stand behind a line and take five normal steps forward, and note where your last step ended.

Now measure the distance from where you started to where you ended. Divide this number by five to determine how far you walk with each step. Knowing the length of your stride is a helpful way to determine distances.

a) Explain the scale(s) you decided to use and the reasons for your choice(s).

b) Is it possible to make a model of the solar system on your school campus in which both the distances between objects and the diameters of the objects are to the same scale? Explain your answer.

Part B: Distances Between Stars and Galaxies

1. After the Sun, the next star nearest to Earth is Proxima Centauri at about 40,000,000,000,000 (40 trillion) km away.

a) Calculate this distance in astronomical units.

b) Suppose that Earth and the Sun are dots 1 cm apart. Using that scale, what would be the distance from Earth to Proxima Centauri?

c) What disadvantage is there to using kilometers and astronomical units to express the distance from Earth to Proxima Centauri?

2. Astronomers commonly use two other units to express the great distances between stars and galaxies. A *light-year* is a unit that measures the distance that a ray of light travels in one year, or about 9,460,000,000,000 (9.46 trillion) km. The *parsec* (pc) is used to describe very large distances. One parsec equals 3.26 light-years.

   a) Calculate the distance from Earth to Proxima Centauri in light-years.

   b) Calculate the distance from Earth to Proxima Centauri in parsecs.

3. There are more than 100,000,000,000 (100 billion) galaxies in the universe. Some galaxies have only a few million stars, while others have several hundred billion stars. Read the following carefully.

   - The Milky Way Galaxy is 100,000 light-years in diameter.
   - The Sun is 25,000 light-years from the center of the Milky Way Galaxy.
   - The Andromeda Galaxy is the nearest galaxy to ours. It is 2,900,000 light-years away.
   - The Andromeda Galaxy is 150,000 light-years in diameter.
   - The Milky Way Galaxy is a member of a cluster of more than 30 galaxies known as the Local Group. The Local Group is 5,000,000 light-years in diameter.
   - The Virgo cluster of galaxies contains 1000 galaxies. It is 50,000,000 light-years away from Earth.

   a) Rank the distances listed from closest to farthest from Earth.

   b) Convert the distances to parsecs.

Why is there a *Learning Through Technology*?

Not every classroom has computers that all students or groups of students can access. Therefore, the *Investigate* activities have been written in such a way that computers are not required to complete them.

However, there are many useful and interesting Web sites that can be used to access real-time data or additional information. Often, it is easier and quicker to manipulate and analyze data using a computer. The *EarthComm* Web site provides you with a list of reputable sites that you can access to expand your understanding. You will find that the addresses are updated regularly.

In some cases, you will find an entire *Investigate* written with step-by-step instructions for how to use data that is available on the Internet. You and your teacher may wish to replace the *Investigate* in the book with the one available on the *EarthComm* Web site.

Learning Through Technology

To expand your understanding of the vast distances between stars, go to the *EarthComm* Web site at http://www.agiweb.org/education/earthcomm2/. There you will be able to investigate the different distances between stars that you can see from your own night sky.

Why are there *Geo Words?*

It is easier and more effective to communicate concepts when the appropriate vocabulary is used. In science, a single word is often used to precisely describe a complex idea. *Geo Words* highlight the important terms that you need to know and use. In the *Digging Deeper*, these words appear in **boldface type** the first time they are used. Sometimes these words first need to be used in the *Investigate* or the introduction of a chapter. You will recognize these words because they are printed in *italics* (a slanted type). The best way to learn new vocabulary is to practice using the words frequently and correctly. It is not useful to memorize a lot of terms and definitions. It is important to understand the concepts before you use the vocabulary. You can think of this as CBV (Concept Before Vocabulary).

Why is there a *Digging Deeper?*

The *Digging Deeper* is the **Explain** phase of the 7E instructional model. Reading the *Digging Deeper* and discussing it with other students and your teacher will help you make better sense of the concepts you just explored in the investigation. In the *Digging Deeper*, the results of your investigation are explained in terms of scientific models, laws, and theories. In this part, you will also be introduced to scientific vocabulary after the concepts are explained. The *Geo Words* highlight the vocabulary you need to know. You will find that using this vocabulary makes it easier to discuss the concepts with your class and answer the *Checking Up* questions. These questions will help you check that you have understood the explanation.

In *EarthComm*, you always **Explore** before you **Explain**. This ensures that you have some experience (**Explore**) with what is being described and discussed (**Explain**). You can think of this as ABC (Activity Before Concept). You will also be introduced to the science vocabulary after you understand the concept. This is what scientists do and how student scientists should learn.

The *Digging Deeper* may also include the **Elaborate** phase of the 7E instructional model. After you are able to explain the science in the *Investigate*, you will be introduced to additional science that is related to and makes sense in terms of the *Investigate*.

Geo Words

solar system: the Sun (a star) and the planets and other bodies that travel around the Sun.

planet: (in our solar system) a large, round body that orbits the Sun.

astronomer: a scientist who studies the universe.

astronomical unit: a unit of measurement equal to the average distance between the Sun and Earth (that is, about 149,600,000 [1.496×10^8] km).

Digging Deeper

YOUR PLACE IN THE UNIVERSE

Measurement in Space

You just investigated the very large distances between objects in space. You tried to make a model of the **solar system**. To do this, you needed to know the distance of each **planet** from the Sun. **Astronomers** often study objects that are far from Earth. As you saw in the *Investigate*, it is difficult to use units such as kilometers to describe these large distances. Even a million kilometers is too small of a unit. Astronomers solve this problem by using larger units to measure distances. When discussing distances inside the solar system, they often use the **astronomical unit** (AU). One astronomical unit is the average distance between Earth and the Sun. It is equal to 149,597,870 km.

Stars are so far away that even using astronomical units becomes difficult. For distances to stars and **galaxies**, astronomers use a unit called a **light-year**. A light-year sounds as though it is a unit of time, because a year is a unit of time. However, it is really the distance that light travels in a year. Because light travels extremely fast at 300,000 km/s, a light-year is a very large distance. Astronomers also use a unit called a **parsec** (pc) to describe even greater distances. One parsec equals 3.26 light-years.

Distances in the Universe

The solar system is made up of the Sun, eight planets, including Earth, and many smaller objects. Because of the Sun's pull of **gravity**, it is the central object in the solar system. All other objects revolve around it. The solar system includes a huge volume of space that stretches in all directions from the Sun.

The inner planets of the solar system include Mercury, Venus, Earth, and Mars. They are small, dense, and rocky planets with cores of iron. Mercury is the smallest planet, and it is closest to the Sun. Venus is similar in size to Earth. For this reason, it is sometimes called Earth's twin. Mars is about half the size of Earth.

The outer planets are Jupiter, Saturn, Uranus, and Neptune. These planets are spaced farther away from each other than the inner planets. They are also much larger and made mostly of lighter substances, such as hydrogen, helium, methane, and ammonia. Jupiter, the largest planet, is more than 1300 times the volume and 300 times the mass of Earth. Saturn is the second-largest planet, but it has the lowest **density**, less than water. Density is the mass of a substance per unit of volume. Uranus is twice as far from the Sun as Saturn while Neptune, on the outer edge of the solar system, is 30 times as far from the Sun as Earth. Uranus and Neptune are much smaller than Jupiter and Saturn, but each is still over 60 times the volume of Earth.

Figure 1 This illustration shows the average distances of the planets in our solar system from the Sun. The relative distances, locations, and sizes of the planets are not to scale.

Geo Words

star: a celestial object that gives off its own light and is made up of a mass of gas held together by its own gravity.

galaxy: a large grouping of stars in space.

light-year: a unit of measurement equal to the distance light travels in one year (that is, 9.46×10^{12} km).

parsec: a unit of measurement used in astronomy to describe large distances. One parsec equals 3.26 light-years.

gravity: the force of attraction between two bodies due to their masses.

density: a physical property of a substance that is expressed as the mass of a substance per unit volume.

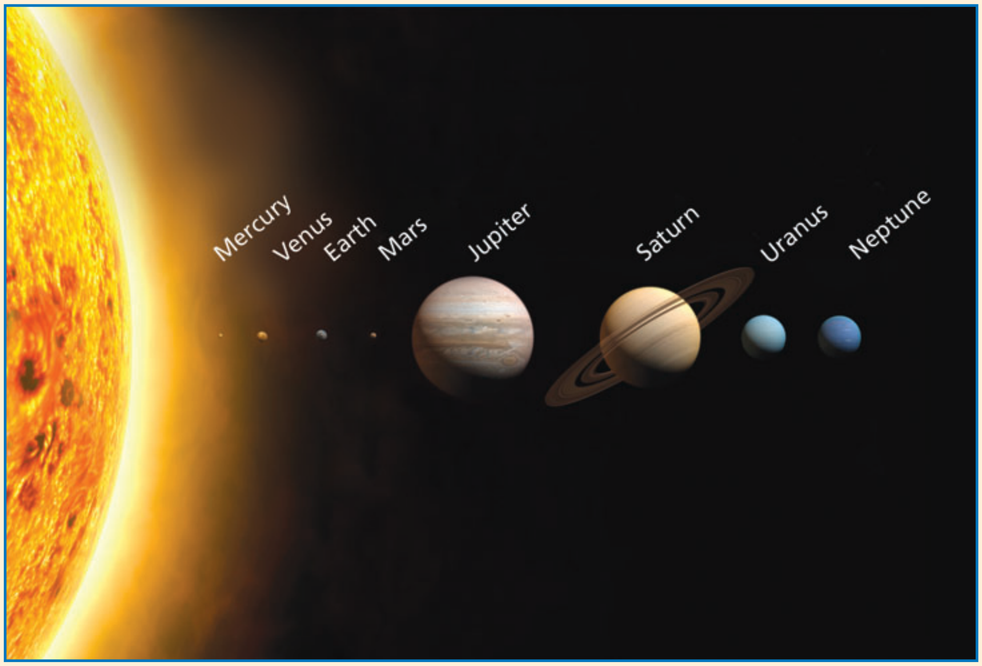


Figure 2 This illustration shows the planets in our solar system and their relative sizes. The distances from the planets to the Sun are not to scale.

If you could travel at the speed of light, it would take about 8 minutes to get to the Sun from Earth. It would take about 4.2 years to get to Proxima Centauri, the second-closest star. Stars belong to galaxies, larger groupings of stars in space. Galaxies are held together by the attraction of gravity. The Sun and Proxima Centauri are only two of the stars within the Milky Way Galaxy. The Milky Way Galaxy contains hundreds of billions of stars. Traveling at the speed of light, it would take 25,000 years to travel from Earth to the center of the Milky Way.

Have you ever seen the Milky Way? It is a band of light that stretches across the dark night sky. It is formed by the glow of the billions of stars it contains. From Earth, this band of light is best seen from dark-sky viewing sites. Binoculars and backyard-type **telescopes** magnify the view and reveal individual stars. Unfortunately, for those who like to view the night sky, light pollution in densely populated areas makes it impossible to see the Milky Way even on nights when the **atmosphere** is clear and cloudless.

Galaxies are classified according to their shape: elliptical, spiral, or irregular. Look at *Figure 3* on the next page. Our home galaxy is a flat spiral, pinwheel-shaped collection of stars held together by gravity. The Milky Way is shown in *Figure 4*. Our solar system is located in one of the spiral arms about two thirds of the way out from the center of the galaxy. What is called the Milky Way is the view along the flat part of our galaxy.

Geo Words

telescope: an arrangement of lenses and/or mirrors that can be used to view distant objects.

atmosphere: the thin layer of gases that surround planets and stars being held by gravity.

When you look at the Milky Way, you are looking out through the galaxy parallel to the plane of its disk. The individual stars you see dotting the night sky are just the ones nearest to Earth in the galaxy. When you view the Milky Way, you are "looking through" those nearest stars to see the more distant parts of the galaxy.

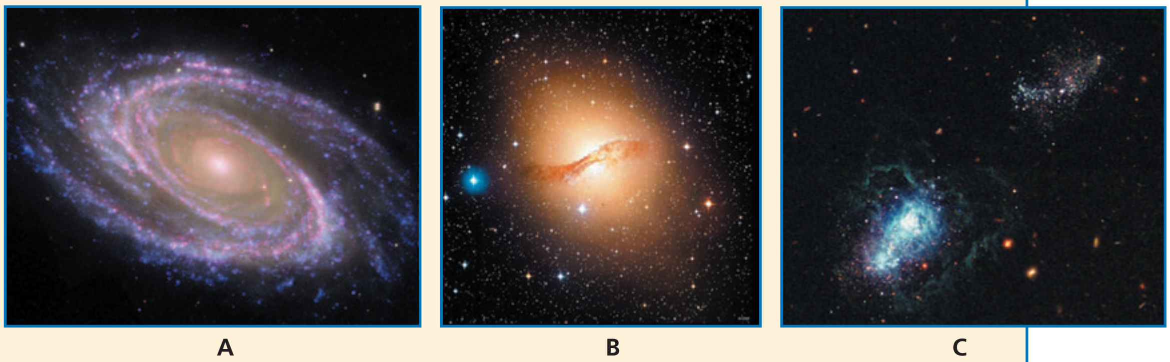


Figure 3 A: The M81 spiral galaxy is 11.6 million light-years away. **B:** The Centaurus A elliptical galaxy is 11 million light-years away. **C:** The I Zwicky 18 irregular galaxy is 45 million light-years away.

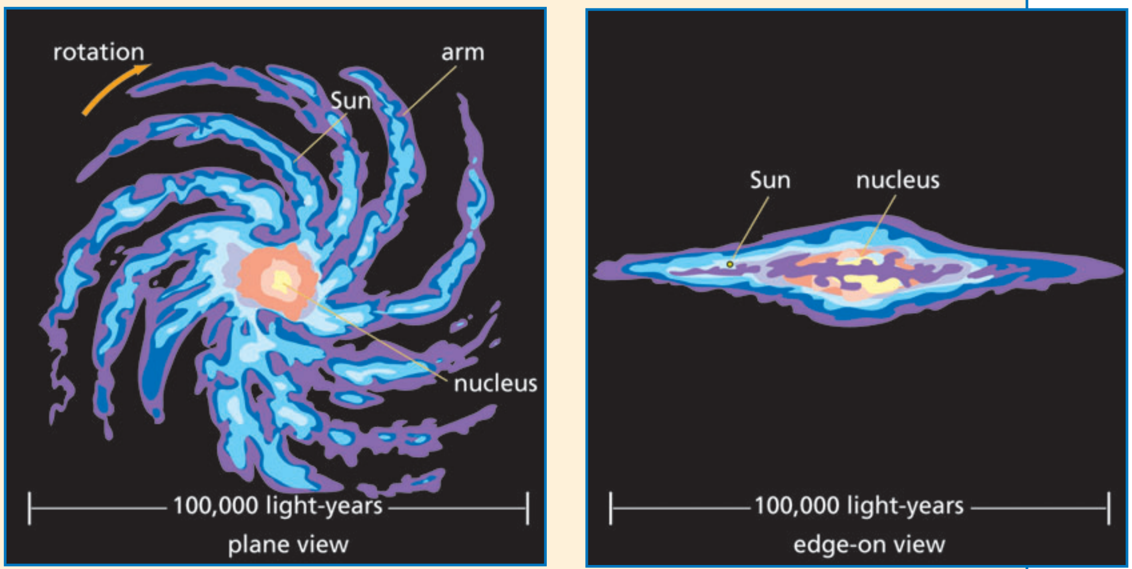


Figure 4 The Milky Way Galaxy. Our solar system is located in a spiral band about two thirds of the way from the nucleus of the galaxy.

Geo Words

universe: all of space and everything in it.

parallax: an apparent shift in the position of an object when viewed from different positions.

There are billions of galaxies in the **universe**. Astronomers define the universe as all of space and everything in it. Galaxies are very far apart, often millions of light-years. Most of the universe is empty space. At the speed of light, you would have to travel more than 2.9 million years to reach the galaxy closest to ours, the Andromeda Galaxy. The largest galaxies contain more than a trillion stars, while some of the smaller ones have only a few million.

Measuring Distances to Stars

How have astronomers found a way to measure the distances to stars? Astronomers often use **parallax** to measure the distance to a star. Parallax is the apparent shift in the position of an object when you look at it from different positions. You can experience parallax by extending your arm and holding up your thumb. Look at your thumb first with your left eye closed and then with your right eye closed. Your thumb appears to change position with respect to the background. Just as your thumb appears to move, a star seems to move when compared with more distant stars as Earth revolves around the Sun.

When Earth is on one side of the Sun, astronomers look at the position of the star against a background of stars that are much farther away. Then, when Earth is on the other side of the Sun, six months later, they look again at the star's position against the same background of stars. (See *Figure 5*.) They measure how much the star's location appears to shift. Then they use this measurement to calculate how far away the star is from Earth. The less the star appears to move, the farther away it is.

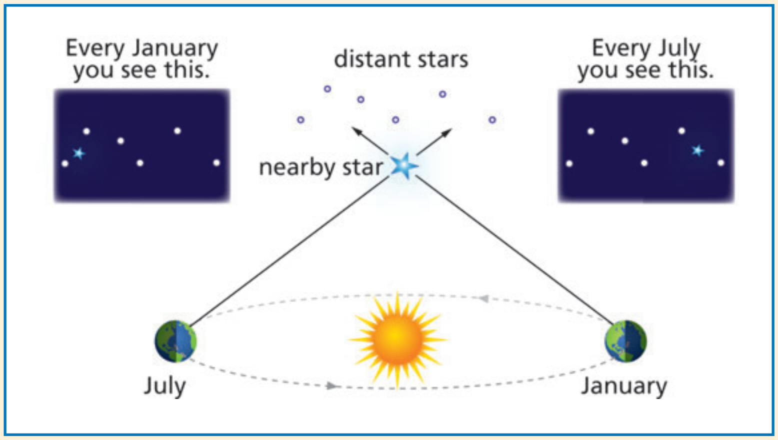


Figure 5 Astronomers use parallax by observing the same star when Earth is at two different points during its orbit of the Sun.

Checking Up

1. What is the distance represented by a light-year? By an astronomical unit? By a parsec?
2. Which of the units in *Question 1* would you use to describe each of the following? Justify your answers.
   a) Distances to various stars (but not our Sun)
   b) Distances to various planets within Earth's solar system
   c) Widths of galaxies
3. In your own words, explain parallax and how it is used to measure the distances to stars.

Why is there a *Think About It Again*?

At the beginning of each section, you are asked to think about one or more questions. At that point, you are not expected to necessarily come up with a correct scientific answer, but you are expected to think about what you know. Now that you have completed the section, you have investigated the Earth and space science you need to answer the questions. Think about the questions again.

Compare your answers now to the answers you gave initially. Comparing what you think now with what you thought before is a way of "observing your thinking." Remember, research shows that stopping to think about your learning makes you a better learner.

Think About It Again

At the beginning of this section, you were asked the following:

- **What objects make up Earth's solar system?**
- **Where is Earth's solar system in relation to the stars and galaxies that make up the universe?**

Record your ideas about these questions now. Be sure that you describe the various distances among the objects within the universe.

Why is there a *Reflecting on the Section and the Challenge*?

This part of the section is the **Extend** phase of the 7E instructional model. It gives you an opportunity to practice transferring what you learned in a section to another situation. In the case of *EarthComm*, you will need to apply your knowledge to complete the *Chapter Challenge*. Each section of a chapter is like another piece of the puzzle that completes the challenge. Transfer of knowledge is an important element in learning. This component presents a connection between each section and the chapter. It will guide you to producing a better *Chapter Challenge*.

Reflecting on the Section and the Challenge

You used various scales to make a model of Earth's solar system. Scale models helped you appreciate the vastness of distances in Earth's solar system. You discovered that there are some drawbacks to using scale models. You then found the distance to the next-nearest star (after the Sun) to Earth in astronomical units, light-years, and parsecs. These distances were compared with the distances to other objects in space, including the Andromeda Galaxy and the Virgo cluster. You also examined the widths of the Milky Way Galaxy, the Andromeda Galaxy, and the Local Group. Although the distances between the Sun and planets are great, you observed that the distances between stars, galaxies, and clusters are far greater. This discovery will help you to describe Earth and its place in the universe for the *Chapter Challenge*.

Why is there an *Understanding and Applying*?

The *Understanding and Applying* is another opportunity for you to **Elaborate** on the science content in the section. It also provides an additional chance to extend your knowledge. Often, you will be assigned *Understanding and Applying* questions as homework. They are excellent study-guide questions that help you to review and to check your understanding.

The *Understanding and Applying* is also a part of the **Evaluate** phase. This is one place where you evaluate your learning. However, it is not the only place. You also evaluated your learning during the *Investigate* (**Explore**) and the *Digging Deeper* (**Explain**). One difference between beginning and expert learners is that expert learners are more aware of their understanding through a constant evaluation of what they know and do not know.

Understanding and Applying

1. Using the scale 1 m = 3,000,000 km you used for distance in your model of the solar system, answer the following:
   a) How far away would Proxima Centauri be from Earth?
   b) How far away from Earth would the Andromeda Galaxy be on your scale, given that Andromeda is 890 kiloparsecs or 2.9 million light-years away?
2. The Moon, on average, is 384,400 km from Earth and has a diameter of 3475 km. Calculate the diameter of the Moon and its distance from Earth using the scale of the model you developed in the *Investigate*.
3. What is the largest possible distance between any two planets in the solar system?
4. Use your understanding of a light-year and the distances from the Sun shown in *Table 1* to calculate how many minutes it takes for sunlight to reach each of the eight planets in the solar system. Then use the unit "light-minutes" (how far light travels in one minute) to describe the distances from Earth to each object.
5. Express your school address in the following ways:
   a) As you would normally address an envelope.
   b) To receive a letter from another country.
   c) To receive a letter from a friend who lives at the center of our galaxy.
   d) To receive a letter from a friend who lives in a distant galaxy.

6. How far away in astronomical units would the following stars be?
   a) Sirius (8.6 light-years)
   b) Vega (26 light-years)
   c) Etamin (130 light-years)
   d) Rasalgethi (550 light-years)
7. ***Preparing for the Chapter Challenge***

   Begin to develop your script for the *Chapter Challenge*. In your own words, explain your community's position relative to Earth, the Sun, and other planets in our solar system. Explain the position of Earth's solar system in the Milky Way Galaxy, and its place in the universe. Include distances as part of your explanation. Write a few paragraphs that explain what your scale model represents and how you chose the scale or scales you used.

Why is there a *Preparing for the Chapter Challenge?*

This feature serves as a guide to get part of the *Chapter Challenge* completed. As you complete each section or a couple of sections of a chapter, you need to take time to organize the knowledge that you are gaining and to try to apply it to the challenge. The *Preparing for the Chapter Challenge* is another **Extend** phase of the 7E instructional model.

Why is there an *Inquiring Further*?

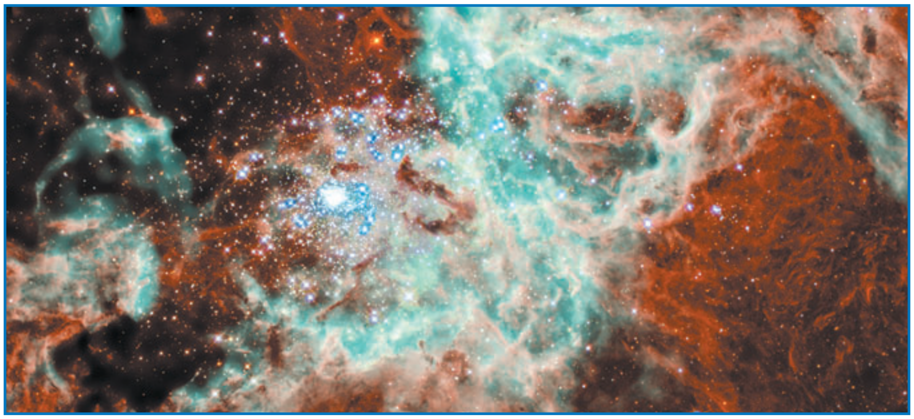
EarthComm uses inquiry as a way of learning. Inquiry lets you think like a scientist. It is the process by which you ask questions, design investigations, gather evidence, formulate answers, and share your answers. Inquiry is not just what you do in the *Investigate*. You are involved in inquiry during each part of each section of a chapter. However, *Inquiring Further* gives you an additional opportunity to do inquiry on your own. Sometimes you will be asked to design an experiment and with the approval of your teacher, carry out your experiment. Other times, the *Inquiring Further* will ask you to answer questions that require additional sources of information, or to solve more challenging, in-depth problems.

Inquiring Further

1. **Solar-system walk**

   Construct a "solar-system walk" on your school grounds or your neighborhood. In chalk, sketch the Sun and the planets to scale on a surface such as a sidewalk. Mark the distances between the Sun and the eight planets at a scale that is appropriate for the site.
2. **Scaling the nearest stars**

   Look up the distances to the five stars nearest to the Sun. Where would they be in the scale model you completed in your solar-system walk? To show their location, would you need a map of your state? Your country? Your continent? The world?



Why is there a 7E instructional model?

At the beginning of this chapter, you were introduced to the 7E instructional model. You were also asked to think about why you are asked to do certain things in *EarthComm*. Review the components of this section, and think about what instructional-model phase is addressed by each component.

Phases of the 7E Instructional Model	Where is it in the section?
Elicit	*What Do You See?* *Think About It*
Engage	*What Do You See?* *Think About It*
Explore	*Investigate*
Explain	*Digging Deeper* *Geo Words*
Elaborate	*Digging Deeper* *Think About It Again* *Checking Up* *Understanding and Applying*
Extend	*Reflecting on the Section and the Challenge* *Preparing for the Chapter Challenge* *Inquiring Further*
Evaluate	*Formative evaluation*—You evaluate your own understanding and your teacher can evaluate your understanding during all components of the chapter. *Additional evaluations may include:* Lab reports, *Checking Up*, *Think About It Again*, *Understanding and Applying*, and *Practice Test*.