PARALLAX AND LUMINOSITY : DEVELOPING A 3-D MODEL OF THE GALAXY

grades 6–8

Objectives

In building a three-dimensional model of a constellation, students practice skills of observation, inference and modeling that scientists use to study the structure of the universe. Students also learn about scale, perspective and distance by building a three-dimensional model of something they usually perceive as two-dimensional.

Introduction

One of the things that scientists do is to build descriptions and understandings of the way the world around us works that allow us to make useful predictions. These descriptions are called "models". Models can take many forms. Some models are mathematical formulas, like those used to calculate acceleration or velocity. Some models are graphic descriptions of how the pieces of something are arranged or how they interact, such as the various models for atoms. Other models take the form of small scale versions or physical constructions that approximate some, but not all, of the elements of the original object or event.

Astronomers use models all the time to study the planets and the stars. That is because almost everything that astronomers are interested in is located far from Earth. Our view from Earth can make the universe seem like a two dimensional dome over the planet. In order to get a sense of how objects we observe from Earth fit together in three dimensions, astronomers build models of the universe.

To build these models accurately, astronomers are reliant on their powers of observation. Because the objects they study are incredibly distant, astronomers cannot touch, smell, hear or taste them. The one sense that scientists can use to gather information is sight – and even this is difficult because other planets, stars and galaxies are so far away from Earth. Astronomers have therefore had to come up with clever ways to find out more about the distant objects they study.

In this activity, students will start with something familiar — a well-known constellation — and attempt to study it in the way that an astronomer would. They will start out by modeling the constellation Orion as it looks from Earth by making a two-dimensional picture. Then they will reconsider their models as scientists, using two techniques that astronomers use — observing the stars' relative luminosity and their parallax – to hypothesize about the real spatial relationships between the stars in the constellation. They will then reconstruct their models in three dimensions to reflect their hypotheses. Finally, they will use the Digital Universe software to "fly" out into Orion and observe the actual relationships that scientists observe between the stars that make up the picture.

This lesson consists of both hands-on and computer-assisted activities. Students will use the Museum's Digital Universe software to visualize and "explore" the constellations in three dimensions. They will use pen and paper, rulers and scissors and cardboard and aluminum foil to build their own three-dimensional constellations. After observing a two-dimensional "night sky view" of a constellation, e.g. Orion, students will construct a two-dimensional model.

Requirement

The American Museum of Natural History's "Digital Universe" program, including the Partiview software and Milky Way Atlas data set. The software can be downloaded at http://www.haydenplanetarium.org/hp/vo/du/index.html.

Additional Materials

Ruler
Pen and paper
Sheet of cardboard (approximately 2 x 2 feet)
Scissors
Spools of thread, dental floss or other lightweight string
Paper clips (10–20)
Aluminum foil (6–8 feet for stars)
Supplemental configuration file to Partiview (Parallax_and_Luminosity) and related data sets
Individual computers running Digital Universe software and configuration files (optional)
LCD projector (optional)

Additional Resources for Educators

Other astronomy activities are available in the "Resources for Learning" section of the American Museum of Natural History Website:
http://www.amnh.org/education/resources/index.html.

Procedure

Part One: Introducing the Constellations

1] Show the class a Digital Universe rendering of the night sky with the constellation data set and labels turned on [Run the **Milky Way Atlas** config file to open Partiview]. (Ideally, the computer is connected to an LCD projector.)
Explain: This is a computer model of the galaxy and right now we are looking at a view of the night sky as it looks from Earth. The connecting lines are there to make it easier to spot the constellations.
Ask: What do you know about constellations? Which ones do you recognize? Do you know any of the stories associated with the different constellations?
Discuss: Depending upon the students' level of understanding of basic cosmology, discuss the difference between the constellations as we see them from Earth and the actual stars in the galaxy that make up the constellations. While we see tiny points of light in the sky that are all about the same size and seem to be the same distance away, in reality these points are giant stars — some of them far larger than our own sun. What looks like a small two-dimensional picture is actually an arrangement of giant stars that may be millions of light years away from one other.

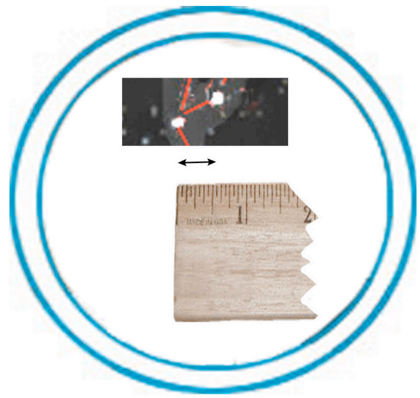
Part Two: Making Two-Dimensional Constellation Model

2] Introduce students to the activity of making three-dimensional models of constellations that represent the way constellations “really” look — they way you would see the stars if you could move around between them in outer space.

3] Divide the class into groups - with each group stationed at a computer - and have each group open the Parallax_and_Luminosity file. If there are not sufficient classroom computers for each group to have its own terminal, then all groups can work from a single projected image. [Students should view the file with the following data sets turned on: stars, Orion, OrionCluster, OpticalMilkyWay, and SunLabel.]

4] Pass out a ruler, cardboard, scissors, spools of thread or string (students will likely need 6–8 feet), aluminum foil and paperclips to each group.

5] Working in groups, measure the distances between the stars in Orion in two dimensions (along x and y axes) and record the distances (cm. or in.) in height and width between the stars.
Explain: This will let you know how far apart to space the stars in your models.

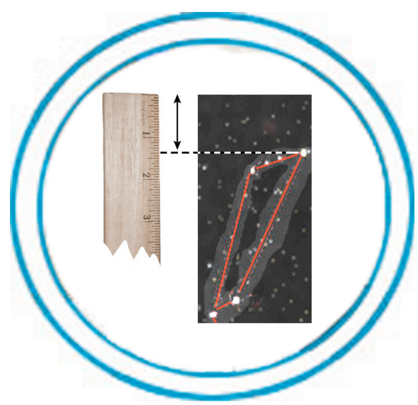


6] First, measure the distances between each star along the x (**horizontal) axis.**
Explain: There are a number of ways you can measure:

a. Using the Digital Universe, you can zoom in on Orion so that it fills the computer screen. (With Orion in the center of the screen, select ‘fov’ from the Slider Menu (top, center menu) and decrease the field of view (move the slider to the left) until Orion fills the screen.) You can then use a ruler to measure the distances between stars right on the screen. You should move from left to right, measuring from the left-most star to the next star, from that to the next one, etc.

b. You can make a printout of a screenshot of your constellation by first zooming in on the image and then hitting PrintScreen. Then you can measure the distances between the stars on paper. (Teachers may also wish to make printouts of Orion in advance).

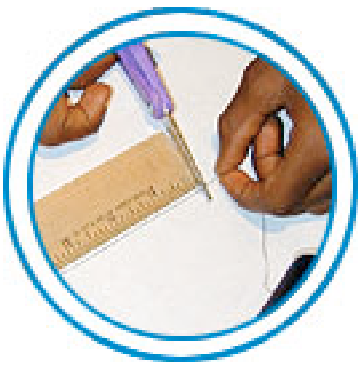
7] Measure the vertical (**y axis**) distance from the top of the screen or printout to each star. This will tell you how long to cut the strings from which you will hang each star.



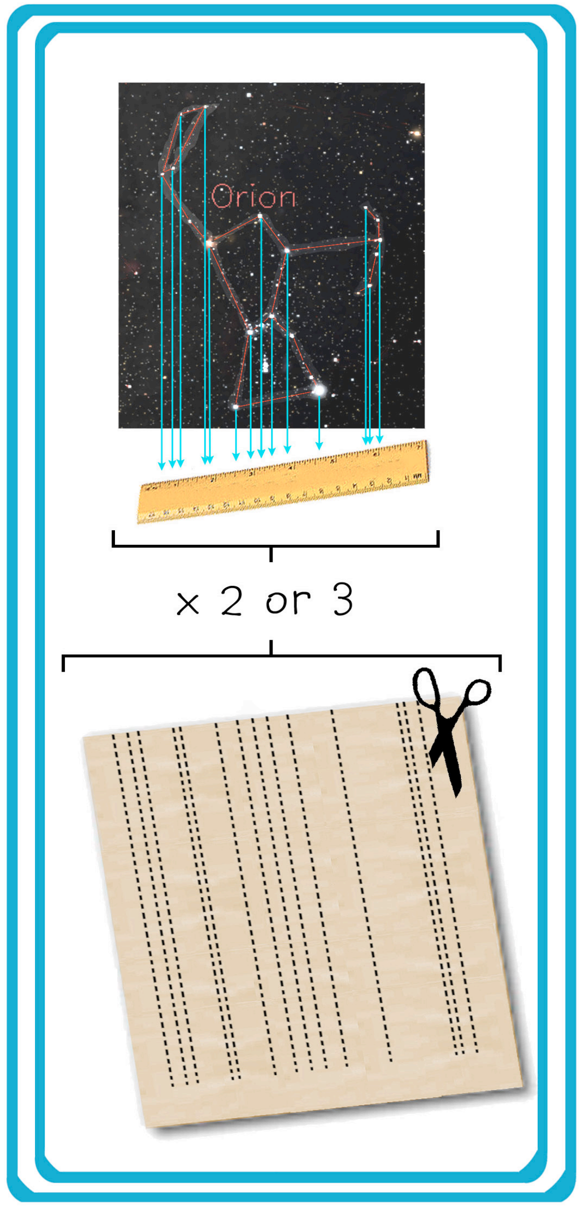
8] Next, multiply each of your measurements by three and record the results for each distance. For example, if you measured and found that the first star in the constellation is 3/4 inches from the top of the screen,

multiply that by three and record the new distance as 2 and1/4 inches.
Explain: By tripling our measurements we are changing the *scale* of the model. A model made on the same scale as the image on the computer screen would be too small to work with.

9] Now, make the cardboard frame from which the stars will hang. Cut long vertical slits in your cardboard — starting from one side and stopping an inch or two before you reach the other side. The slits should be the same distance apart as the stars in the constellation, so use the measurements you made (again, doubled or tripled) on the horizontal (x) axis to determine the distances between each slit.



10] String your stars. First cut your thread into 2–foot strings — one string for each star in your model. So if you are including the fifteen most important stars in Orion, you will need fifteen two-foot threads.



11] Tape one end of each piece of thread to a six-inch square of foil.

12] Crumple the foil into a ball around the end of the string to make a "star." First wrap it into a loose ball around the end of the thread.

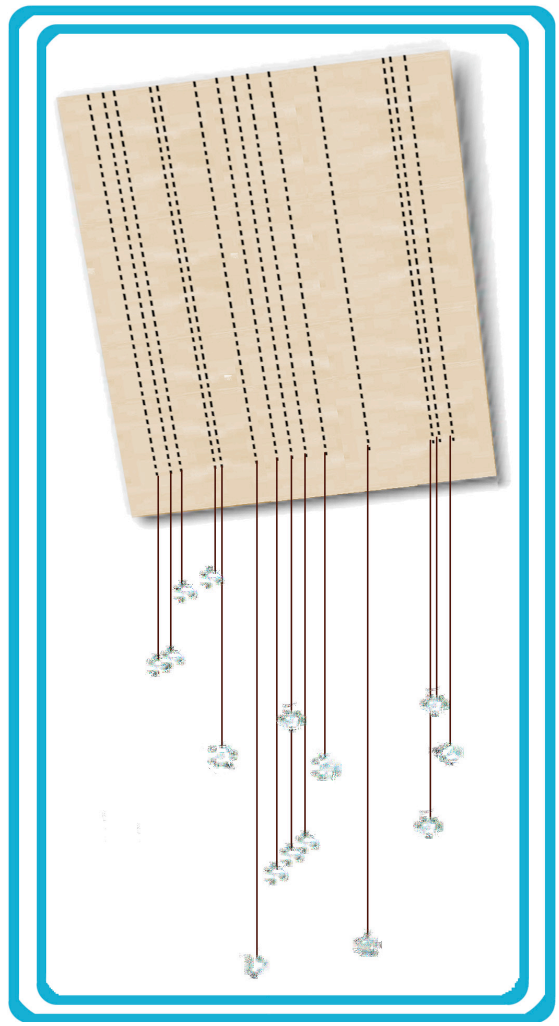
13] Then crumple the foil as tightly as possible to make a hard little ball.

14] Repeat this process for each star.

15] Hang your stars. Slide the first thread into its appropriate slot in the cardboard frame, and pull the thread until the star is hanging at the proper length.
Explain: This is where you should use the measurements you made along the vertical (y) axis. Pull the thread to match the length you recorded for the star (again, tripling the length to scale up the model, if necessary).

16] Once the star is hanging in place, tie a paperclip onto the thread at the point where it pokes through the cardboard. This will hold the star in place.

17] Repeat steps 11 and 12 for each star. When you have slid all the stars into place, you should have a two-dimensional model of Orion.
Explain: When you are ready to add the third dimension of depth, the slits in the cardboard will allow them to slide each star forward or backwards.



Part Three: Introducing Parallax and Luminosity.

17] Tell students they are now going to turn their two-dimensional models into three-dimensional models that represent the distances between the stars that make up Orion.
Explain: The models as they look right now do a good job of showing Orion as it looks from Earth. But in reality the stars in Orion aren't all lined up in a flat plane — some of them are much closer to Earth than others. When scientists study the stars, they try to think about where the stars really are placed in relation to one another — not just how they look from Earth. So as scientists, we want our models to show those three-dimensional relationships.
Explain: Since astronomers can't actually go out to the stars to see which ones are nearer and which are farther from Earth, they have to use specialized ways of observing to try to make educated guesses about where objects are placed. Today, we are going to examine two factors — called luminosity and parallax — that real astronomers use, in order to determine the relative distances of the stars in our model from Earth.

18] Discuss luminosity.
Explain: "Luminosity" is the apparent brightness or dimness of a star (or other light source). To a certain extent, astronomers can use luminosity as a clue to whether a star is nearby or far away. If you have two stars that emit the same amount of light, the one that's closer will look brighter, and the one that's farther away will look dimmer — the same way that if you're driving at night, the nearby streetlights are brighter than the ones that are far away. At the same time, luminosity only helps you estimate distance if stars are all about the same actual size and brightness. A big, really powerful star (like a blue supergiant) that's far from Earth might still look brighter than a small weak star — just like a far-off halogen headlight is still brighter than a nearby candle. This means that astronomers can use luminosity as one clue when trying to determine the distance of a star, but they can't base their entire hypothesis on that one piece of evidence.

19] Discuss parallax.
Explain: It's easier to show you how parallax works than to tell you — at first. Have your students hold their thumbs close to their noses. Tell them to look at an object on the far side of the room, first with their right eye closed, then with their left eye closed. (They should select a particular object such as map or picture, not just stare at a blank wall.)
Ask: What happened to the thumb?
Explain: It should have appeared to jump from one side of the distant object to the other. This effect is called parallax.

20] Repeat the exercise with your thumbs held at arm's length.
Ask: How far did the thumb jump this time compared to what happened when they held their thumb closer?
Explain: The farther you hold your thumb from your eye the less it jumps from side to side. The amount of this shift indicates how far away the object is. This is how your eyes judge distances. Astronomers use parallax to judge the distances to stars. To get two different perspectives on a star, astronomers view it from two different locations in the Earth's orbit — about 186 million miles apart. The amount the star seems to move indicates its distance. Parallax can only be used to judge the distance to the nearest stars, however. When objects get

too far away, they do not appear to move at all. This demonstrates the limitations of judging distance by parallax. The perspective from each eye is the same for distant objects because your eyes are only a few inches apart. Similarly, for extremely distant stars, even having two viewpoints separated by 186 million miles is not enough to make a star appear to move from side to side. So, both parallax and luminosity can be "clues" to a star's distance from Earth, but neither one is totally reliable, and in some cases, it may be that neither parallax nor luminosity will help at all!

21] In the next part of this activity, we are going to try to use parallax and luminosity to adjust our constellation models in three dimensions. Just like real astronomers, we will only be making educated guesses about how far away the stars are. Sometimes we'll be able to make pretty confident guesses, but other times we will be less sure of what the evidence is really telling us. It should be noted that while the luminosities represented in this model are an accurate representation of what we know about the luminosity of these stars, the parallax you will see is not the actual parallax we see in the sky, it is an approximation we will use to estimate distances in this exercise.

Part Four: Using Parallax and Luminosity.

22] Once again, use the Digital Universe to view the night sky from Earth [Open the Parallax_and_Luminosity file.] You should have the "stars" data set turned on [stars]. Turn on the "Orion" data set so that students can see the constellation [Orion].
Ask: Do you see a variation in the luminosity of the stars in Orion?
Explain: Keep the differences you see in mind — that's going to be one set of clues you can use to adjust your constellation models.

23] With your mouse over Orion, press the 's' key. This should make the image on the screen turn into a double image, with one side in red and one in blue.
Explain: Now I've changed the image so you can see a doubled view of the stars that represents their parallax.
Ask: Do you notice any difference in the distances between each Orion star and its double?
Explain: This is your second set of clues. Now you need to use what you can observe about parallax and luminosity to make some guesses about which of the stars in Orion is closest to Earth, which is the next farthest, the next and so on. You can come up to the computer [or use your own computer, or come up to the projection – depending on how the classroom is configured] and measure the distances between stars if you want to make more precise calculations about parallax. You should also keep in mind that parallax and luminosity only give clues — they're not totally reliable — so you still will have to do some guesswork. You may also find that your clues contradict one another — a star might be brighter than another star but have a smaller parallax. In those cases you'll have to think about which clue you believe to be more reliable, and then make your best guess.

24] Give students some time to figure out the relative luminosities and parallaxes of the stars in Orion.

25] Instruct students to adjust their models — by sliding stars forward or back — to reflect their hypotheses about the relative distances of the stars.

Part Five: Viewing Orion in Three Dimensions

26] Using the Digital Universe software, look again at Orion. Return to the normal view by typing 's' once again.
Explain: Now we are going to fly out into space towards your constellation. As we fly, you'll be able to see which of the stars in Orion are actually closer to Earth and which are farther away. Check these against your models, and the estimates you made based on luminosity and parallax.

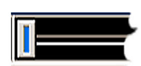
27] Run the Digital Universe animated flight path to Orion, which approaches and then passes through the constellation. Draw the students' attention to signposts along the way that will tell them how far, in light years, they have traveled.

- Use the data-set control bar to make sure all of the data sets are turned **on** (in this picture, all data sets are on except for g4)
- Once you have introduced students to this view of the sky and pointed out Orion, you will want to turn the Constellations data set **off** so that only the lines connecting Orion are displayed.
- In the flight-path control bar, press **play**.

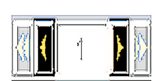
- When you have shown the film once at regular speed, you will probably want to show it again more slowly, to give students a chance to note the order of stars and the distances between them:
- Return to the beginning of the film, either clicking and holding down the fast-reverse button: or dragging the slider all the way to the left:

- Now go through the flight path at a slow pace, stopping or moving backwards if students want to take a second look at something. You can control the flight in this way by either

  (a) dragging the slider, which allows you to precisely control the progress of the flight,



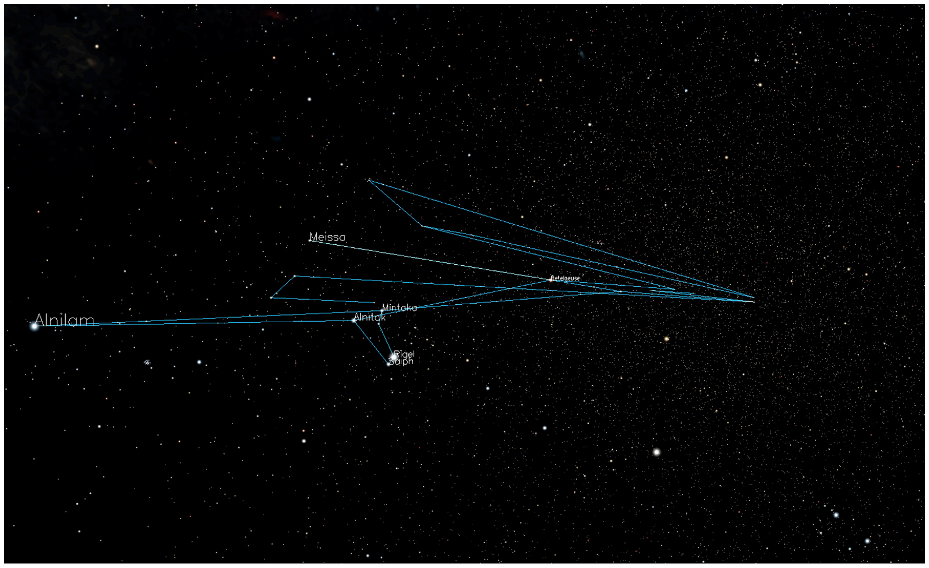
  (b) using the fast-forward and reverse buttons, which will move the flight forward or backward about one or two light years each time you touch the button, or



  (c) using the skip-forward or skip-reverse buttons, which will move the flight forward or backward approximately 22 light years each time you touch the buttons.

Explain: As we move through the film, pay special attention to the signposts — those will give you an idea of how far away each star is from Earth, and how far the stars are from each other. [If you are using the skip-forward button, you might add:] Every time we jump forward, we're moving ahead about 22 light years, so if you count the number of jumps between each star, you can get a good idea of how far apart the stars are.

28] Now, for a complete view of the relationships between stars in the constellation, run the Digital Universe animated flight path to the *side* of Orion. The movie will fly around to the side of Orion, so the class can see what the stars in the constellation look like compared to students' models.



Hit the 'Path…' button to load the flight path. A file explorer will open initially showing you the contents of the folder that contains the Partiview program. Navigate to the 'data' folder, then to the 'activities' folder where you'll see two flight path files. Select 'orbit-orion.wf' and the flight path will be loaded and ready to use. Now, you can control this flight path just as you did the first one. You can then control the flight path just as you did the first one.]

29] You [the teacher] may wish to choose one model as a class example and adjust it to match the true arrangement of the constellation as revealed by the Digital Universe flight paths. Students could then compare this model to their own.
Explain: This is what scientists think Orion really looks like from the side.
Ask: How does this compare to your models? How do you think scientists made their model? Given the differences between scientists' model and the models we made in class, what did this activity tell us about the nature of scientific evidence and inference?

Relevant Standards

From the National Science Education Standards: Science Content Standards: 5–8

Content Standard A: Science as inquiry.
As a result of activities in grades 5–8, all students should develop: abilities necessary to do scientific inquiry; understandings about scientific inquiry…. Fundamental abilities and concepts that underlie this standard include:

- [Ability to] identify questions that can be answered through scientific investigations.

- [Ability to] design and conduct a scientific investigation.
- [Ability to] use appropriate techniques to gather, analyze and interpret data.
- [Ability to] develop descriptions, explanations, predictions and models using evidence.
- [Ability to] think critically and logically to make the relationships between evidence and explanations.
- [Ability to] recognize and analyze alternative explanations and predictions.

Content Standard G: History and nature of science.
As a result of activities in grades 5–8, all students should develop understanding of: science as a human endeavor; nature of science; history of science…. Fundamental abilities and concepts that underlie this standard include:

- Nature of science: Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science there is much experimental and observational confirmation….
- …[I]t is normal for scientists to differ with one another about the interpretation of…evidence….
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists….

From the National Science Education Standards: Science Content Standards: 9-12

Content Standard A: Science as inquiry.
As a result of activities in grades 9–12, all students should develop: abilities necessary to do scientific inquiry; understandings about scientific inquiry…. Fundamental abilities and concepts that underlie this standard include:

- [Ability to] identify questions and concepts that guide scientific investigations.
- [Ability to] design and conduct scientific investigations.
- [Ability to] use technology and mathematics to improve investigations and communications.
- [Ability to] formulate and revise scientific explanations and models using logic and evidence.
- [Ability to] recognize and analyze alternative explanations and models.
- [Ability to] communicate and defend a scientific argument.

Content Standard D: Earth and Space science.
As a result of activities in grades 9-12, all students should develop understanding of:… origin and evolution of the universe.

Fundamental concepts and principles that underlie this standard include:

- Early in the evolution of the universe, matter, primarily the light atoms of hydrogen and helium, clumped together by gravitational attraction to form countless 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 of the universe.
- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

Content Standard G: History and nature of science.
As a result of activities in grades 9-12, all students should develop understanding of: science as a human endeavor; nature of scientific knowledge; historical perspectives…. Fundamental concepts and principles that underlie this standard include:

- Science as Human Endeavor: Individuals and teams have contributed and will contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question….
- …Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work….
- …Science is not separate from society but a part of society….
- Nature of Scientific Knowledge: Science distinguishes itself from other ways of knowing and other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.
- Scientific explanations must meet certain criteria….
- …[A]ll scientific knowledge is, in principle, subject to change as new evidence becomes available….

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