Some natural questions to ask before teaching science are, “What is science?” “How is it different from the other subjects I teach?” “How is it similar to other subjects I teach?” If you do not ask such questions yourself, your students are sure to ask at least the first. The answer is not as common as you may think. Many teachers, even those specifically licensed to teach science, have difficulty answering the questions we have posed. This chapter will provide you with a variety of experiences and discussions that will hopefully start you on your way to finding answers to these questions. In particular, this chapter will help you to define the characteristics that distinguish science from other subject matter disciplines. We think the background this chapter provides will enable you to more
effectively teach science as well as teach about science to your students. In comparison to other textbooks that you have read, this text will ask you to complete a variety of both written and hands-on activities. It is important that you complete all of the activities.

**What Is Science?**

On any day, you can watch your local television newscast and hear claims made by scientists about a particular food or drug being harmful or healthy. For example, aspirin had been used as a headache remedy for many years before scientists informed us that it may be harmful to the lining of our stomachs. Taking aspirin carries the risk of possible development of ulcers. In response to this news, many companies began to manufacture alternative remedies (e.g., Tylenol, ibuprofen) that could relieve the pain of a headache without the risk of ulcers and stomach distress. More recently, doctors have found that aspirin is useful in decreasing the risk of heart disease. Consequently, many of those who had moved away from taking aspirin have returned to this old friend. Even more recently, researchers have found that ulcers are not caused by aspirin, drugs, or any of the foods known to increase stomach acid but rather are caused by bacteria or any number of other factors. At this point you may be thinking, "Why don’t they make up their minds? I think I’ll wait until all the facts are in." Aspirin is not unique. There are countless examples of foods and medicines (e.g., wine, fatty foods, milk, coffee) that at various times have been considered healthy and at other times have been considered harmful. Is something wrong? Are the scientists making premature claims? Should they wait until all the facts are in before making their recommendations? Actually this flip-flop of opinion is not a sign of poor behavior by scientists or bad science. It is actually symptomatic of good science.

You may now be considering a walk to your bathroom or kitchen to carefully inspect the contents of your medicine chest, refrigerator, or kitchen cabinets. Actually, we want you to walk to your kitchen or bathroom, but instead of inspecting the foods and medicines, remove the cardboard core from a roll of toilet tissue or paper towels. Now get some string, the kind you would use to wrap a package. If you do not have string, sewing thread will do. We made the tube you see pictured in Figure 1.1 using the same materials you have just gathered.

A series of actions is performed on the tube and consequences are noted. The actions and consequences are listed in Table 1.1. What is inside of the tube that can explain why the strings behaved as they did? Take a moment to draw yourself a picture of what you think the inside of our tube looks like. Using your diagram, can you predict what would happen if string C is pulled? On what basis have you made your prediction?

It’s time to find out the answer! If string A is pulled, string B moves into the tube. If you predicted correctly, you are catching on. If you predicted incorrectly,
reexamine the model you imagined for the inside of the tube and revise it based on the additional data gathered by the pulling of string C.

Using the tube and string you have collected, make the model you think explains the behavior of our tube and string. After completing the construction of your model, test its accuracy by sequentially performing the actions specified previously and noting the consequences. Did your tube work the same as ours? If so, you have developed a reasonably good model of what is inside of our tube. If your tube did not work the same as ours did, see if you can change your model so that it does work the same as ours.

We really have no idea how the inside of your tube looks. Does one of the diagrams shown in Figure 1.2 represent how your tube is constructed?

<table>
<thead>
<tr>
<th>Action</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>String A is pulled</td>
<td>String B moves into tube</td>
</tr>
<tr>
<td>String B is pulled</td>
<td>String A moves into tube</td>
</tr>
<tr>
<td>String D is pulled</td>
<td>String B moves into tube</td>
</tr>
<tr>
<td>String A is pulled</td>
<td>String D moves into tube</td>
</tr>
</tbody>
</table>
Regardless of whether either of these diagrams represents what you have constructed, would either of the two diagrams, if actually constructed, behave as the original tube we demonstrated? This leads us to a very important question. If your tube behaves the same as ours, do you definitely know how our tube is constructed? Do we know how your tube is constructed? Neither of us can say for sure how the other's tube is constructed. The only way to find out would be to look inside.

What does any of this have to do with science? Actually, it has everything to do with science. What you did during the past few minutes was to manipulate some variables (i.e., the strings), collect some data (i.e., noting the movement of the strings in response to manipulation), draw some inferences in the form of a model (i.e., speculating or hypothesizing about the construction of the tube), and then test your hypothesis or inference (i.e., constructing your own tube and matching its behavior to ours). You did what scientists do all the time. Just like the world or universe that scientists study, the original tube could not be opened to find out an absolutely correct answer to our original question.

The tube and string activity is one you can easily do with your students. We have used it successfully with students as young as third grade and are confident it can be used with even younger students. However, we need to be a bit more specific about what this activity illustrates about science and scientists.
Science and the Characteristics of Scientific Knowledge

The simplest way to describe science is as an endeavor with three interrelated but distinct aspects. Science is (a) a body of knowledge, (b) a method or process, and (c) a way of knowing or constructing reality.

Body of Knowledge

The body of knowledge of science is what most people think about when they think of science. The knowledge is the laws, theories, concepts, principles, and so on of science. Although disciplines have a body of knowledge, what distinguishes the disciplines is the specific focus of interest comprising the body of knowledge. The structure and function of living things are the focus of biology; atoms, molecules, compounds, and their interactions are of interest to chemists; the forces that govern the physical world are of interest to physicists, whereas the characteristics of a painting are of interest to the artist. In the tube and string activity, the relationships among the movement of the strings and the proposed model for what was inside the tube would constitute part of the

A collection of science books.
body of knowledge of the study of tubes. How you went about developing your knowledge of the tube involved you in a second aspect of science.

**Method and Process**

How scientists, or practitioners within any discipline, develop the body of knowledge is another distinguishing characteristic. Although different disciplines often use similar methods and processes, the combination of the processes and the objects of concern usually can be used to distinguish one discipline from another. For example, scientists necessarily appeal to empirical data (i.e., observations) during the development of knowledge. Mathematicians, on the other hand, do not necessarily make observations or collect empirical data. The model you developed for the content of the tube was primarily based on the manipulations of the strings and the observations you subsequently made regarding these manipulations. It would not have been acceptable for you to simply develop a model for the contents of the tube without making any observations. Also, the model you finally developed needed to be consistent with your observations. Nobody has ever told us that there is a little man in the tube directing the behavior of the strings. You could have made such a conclusion, but in the scientific way of thinking you would not have been taken seriously. This would not mean you were wrong. It just means that you would have deviated from the accepted methods and processes of science in the development of your model. Some of the more common processes used by scientists in the development of knowledge are observation, organization and representation of data, data analysis, hypothesizing, testing of hypotheses, inferences, and concluding. With all this stress on the use of processes to develop knowledge, was the knowledge you developed about the tube derived totally from empirical data? You were never able to open the original tube and so your model was not totally based on observation. This leads us to some very important and unavoidable characteristics of scientific knowledge.

**Way of Knowing and Constructing Reality**

As we have emphasized, scientific knowledge is necessarily developed through the use of various methods and processes. A basic assumption of the scientific way of thinking is that the world is knowable through empirical observation. However, no matter how hard scientists try, most of the time they can never collect a complete and absolute set of data on any object of interest. The tube can be used as an analogy of our universe. You were unable to open the original tube just like scientists cannot open the universe and look inside to determine all of its hidden meanings and processes. At some point, scientists must speculate and infer about what they cannot see. You did this when you developed your model of the tube. Scientists do the same thing when they speculate about the actual structure of atoms. It may surprise you, but no one has ever directly observed a single atom.
These necessary inferences and speculations imbue scientific knowledge with certain unavoidable characteristics. These characteristics, sometimes referred to as the "nature of science," are as follows:

1. Scientific knowledge is partially a product of human creative imagination.
2. Scientific knowledge is tentative.
3. Scientific knowledge is partially a function of human subjectivity.
4. Scientific knowledge necessarily involves a combination of observation and inference.

When you developed your model of the tube, the result was partially a function of your creativity and imagination. Your creativity and imagination differ from that of other individuals because of your past experiences and knowledge. Consequently, your model would not necessarily be the same as your friend's or another classmate's. Clearly, scientific knowledge has an element of subjectivity. None of these characteristics are a weakness of science. They are simply characteristics necessitated by the processes that scientists use to develop knowledge. What is especially important is that scientific knowledge is not a sterile set of objective and unchanging facts. Unfortunately, this is likely the view that was promoted in the science courses you have taken. We will be emphasizing throughout this text an approach to teaching science that is very different from what you probably experienced. We will be emphasizing an approach that is more consistent with the way science really is.

Look carefully at the picture of a fossil fragment in Figure 1.3. A fossil fragment is an actual fossil, but it is only a small portion of the complete organism. If you have a fossil fragment and would prefer to use it instead of our picture,
that would be fine. The only restriction is that you cannot use a fossil fragment from an organism you already know.

As carefully and accurately as possible, draw a picture of the fossil fragment. Create your drawing in the center of your sheet of paper. If you want to draw the picture on a larger or smaller scale, please note the scale (e.g., 2 x). After finishing your drawing, please complete the rest of the fossil or organism. Fill in the missing parts of the fossil. When you have finished, ask yourself the following questions:

1. Where did the organism live?
2. How did the organism get its food requirements?
3. How did you decide how to fill in the missing parts?
4. On what basis did you decide where the organism lived?
5. On what basis did you decide how the organism satisfied its nutritional requirements?
6. Did you quickly decide what organism the fossil was from and complete your picture accordingly, or did you make totally unbiased inferences?

The activity you have just completed closely approximates what paleobiologists do as part of their work. That is, they often collect fossil fragments and complete the organism from which it came. In this particular activity, you were given only a single fragment (actually just a diagram), whereas paleobiologists usually work with numerous fragments pieced together to form the complete organism. The dinosaur skeletons that you often see in museums have been constructed from only various remains because the complete skeletal system is typically not excavated. Nevertheless, the mental activity you performed is quite similar to what these scientists do as part of their work.

Take a moment to return to the list of four statements describing the nature of science. Which of these characteristics of science were illustrated in the fossil fragment activity? We think you would agree that both observation and inference were involved. You made some very specific observations of the fossil fragment diagram while drawing your own picture, and then you inferred the appearance of the missing parts of the organism. While completing the diagram of the organism, your creative imagination was used. We say “creative imagination” because you will find that your classmates’ pictures are not identical to yours. Their pictures will differ from your picture as well as each other’s because each of you expresses your creativity in different ways and each of you has a different level of background knowledge and experience. Figure 1.4 shows how a sixth-grade student completed the fossil fragment we pictured. We have also provided additional pictures in Figures 1.5 and 1.6 (fragment plus completed organism) that were completed by other sixth graders when asked to perform the same task as you.

Obviously, the final pictures that were drawn have some element of subjectivity as well. Subjectivity was involved because the completed organism (just like the model for the internal contents of the tube) was different depending on
Figure 1.4 Depiction of Possible Organism from Which a Fossil Fragment Was Derived

Figure 1.5 Fossil Fragment with Possible Source

Figure 1.6 Fossil Fragment with Possible Organism from Which It Was Derived
the individual. Furthermore, it is because of the critical dependence on human beings that scientific knowledge is tentative. Therefore, all four statements about the nature of science were evident in the activity you just completed. In fact, there are several other aspects of the nature of science that we did not mention before that can now be noted.

**Is There a Single Scientific Method?**

Did you notice any differences between the fossil fragment activity and the tube and string activity? In the fossil fragment you simply observed and then inferred. Did you do anything else in the tube and string activity prior to inferring? The various strings were manipulated and you were asked to note the results. In a perfect world, you would have been able to manipulate the strings on our original tube prior to making your own. Nevertheless, we think you get the idea. With the tube and string activity there was an opportunity to do something to the object you were observing and note any consequences. You were able to develop some hypotheses and test your hypotheses. There was no opportunity to do this type of manipulation with the fossils. In each case, you were simulating what scientists actually do when collecting data and arriving at conclusions. However, the methods and approaches you used were clearly different. Contrary to popular belief, the sequence of processes and the specific processes used by scientists can vary from one investigation to another. *There is no single set and sequence of steps known as the scientific method.*

Although this idea is more related to science method or process, it would be a good idea to add it to the previous list of four statements describing the nature of science. The tube and string activity was more closely related to an experiment, whereas the fossil fragment activity was more descriptive. Our critical question now is, "Did either of these activities follow the scientific method?" The tube and string activity is, perhaps, close to what you were taught as the scientific method, but the fossil fragment is not even close. Although some scientific investigations follow procedures similar to the steps most likely listed in the science text you will be using, they are not representative of most scientific research. Scientists use a multitude of procedures and methods. These methods and procedures differ between and within scientific disciplines. The procedures and approaches that are used depend on the question to be answered.

**How Objective Is Science?**

Prior to beginning the fossil fragment activity, we mentioned you could use a fragment of your own. Our only restriction was that the fossil fragment not be from an organism you already knew. We wanted you to make inferences about
the organism's structure, habitat, and nutrition without any bias. We wanted you to make totally objective observations. Let's consider the feasibility of our desire to have you make unbiased and objective observations and conclusions. Did you have some idea about the source of the pictured fossil fragment? That is, did you already know or try to guess the identity of the fossil fragment before beginning? Most people do this, and the subsequent completion of the organism and inferences about habitat and nutritional sources are actually biased by these preconceived ideas instead of being objective and based totally on empirical evidence. The same is true with scientists. In particular, the scientific theories and laws currently accepted by the scientific community guide scientists' data collection and interpretation. In fact, it is virtually impossible for humans to approach any situation without preconceived ideas and background knowledge. The same will be true of your students. This is an important idea but a difficult one to easily explain, so let's try an example. Read the following passage:

The procedure is actually quite simple. First arrange things into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step. Otherwise, you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise. A mistake can be expensive as well. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell. After the procedure is completed, arrange the materials into different groups again. Then they can be put into their appropriate places. Eventually, they will be used once more and the whole cycle will have to be repeated. However, that is part of life. (Bransford & Johnson, 1972)

Do you know what the passage is describing or does it just seem like a paragraph of meaningless words and description? As you begin to speculate about the meaning of the paragraph, start reading it again. You have probably already started doing so. Did you notice as you read the paragraph again, with a particular idea in mind, that the individual words began to take on meanings consistent with your idea? Actually, the paragraph is about doing laundry. Now, read the paragraph again with doing laundry in mind, and notice how each of the words and phrases takes on a specific meaning that was not necessarily evident before. Suddenly, it is clear what the different groups and piles are. It also becomes clear what "lack of facilities" means.

Sometimes people think the passage is about life. If you read the paragraph with this in mind, the words and phrases take on still other meanings. The point we are trying to make is that our perceptions and interpretations of empirical data are influenced (i.e., biased) by our preconceptions of what we are seeing or investigating. Look at the diagram in Figure 1.7. Do you see a triangle between the three circular patterns?
Actually, there is no triangle. Your brain perceptually completed the triangle because it expected to see a triangle between the curved lines. We do this all the time, whether we are pursuing scientific knowledge or just walking down the street. The influence of prior conceptions on observation means that science is not objective. It means that all observations are biased by our theories, laws, and beliefs. We can diagram the situation as shown in Figure 1.8.

The observations or data collected during scientific observations are influenced by our theories and laws (or beliefs) and these data then influence the development of scientific laws and theories. You can add this statement to the list describing the nature of science. You should now have six items on your list. This last characteristic may seem like a problem for scientists. After all, isn’t scientific knowledge supposed to be based on empirical evidence and not on personal bias? On the other hand, if we do not have preconceptions about what we are looking at or going to see, would we see anything at all?

Have you ever driven into a supermarket parking lot immediately after a fresh snow? You are the first car there and the painted lines directing you where to park are not visible. How did it feel? Did you worry about whether you were driving in the lanes or over the parking spaces? Did you wonder where to park your car, or did you feel the exhilaration of being able to drive wherever you wanted? Once you or someone else is the first to park, everyone else parks his
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or her car relative to the first car. The point is that it is uncomfortable not having reference points. If you have ever driven through a whiteout during a snowstorm, you very clearly know what we mean.

If you carefully inspect the list of six statements concerning the nature of science, you may be led to the conclusion that all inferences derived from a set of data are okay. After all, the knowledge of science is tentative, subjective, biased, and so on. This is true up to a point. If the inferences are consistent with the data and previously developed knowledge and beliefs, highly varied inferences are fine. The key phrase in the last sentence is “and previously developed knowledge and beliefs.” If you choose to do either the tube and string activity or fossil fragment activity with your students, there is at least some chance that one of your students will conclude there is a girl in the tube directing the movement of the strings or will complete an alien-like creature from the fossil fragment. Perhaps you felt a little playful during these activities and did the same. If this happens to occur in class, it will most undoubtedly create a humorous response from the other students. This is not a problem and can be used productively to illustrate additional characteristics of science and scientific knowledge.

In practice, scientists will usually select the simplest explanation for any phenomena and draw inferences that are consistent with prior knowledge and
understandings. Although there may be a miniature girl in the tube, we have
never noted a human being that small and there also exists a much simpler
explanation for the movement of the strings. This is no different than the rea-
son why scientists do not explain plants turning toward the sun as the result
of a conscious decision by the plant. The chemical explanation is much simpler,
as it does not require the existence of a complex nervous system in plants.
Furthermore, nervous tissue has never been observed in plants. This may be true
some day, but it is not considered true at the moment. With respect to the
alien-like creature, scientists reconstruct organisms from fossil fragments using
previously identified organisms as a reference point. Therefore, acceptance of
an organism that looks nothing like anything we have ever seen before would
be doubtful unless the amount of fragments was much greater than the miss-
ing pieces. What does this mean? It means that the subjectivity and creativity
that are necessarily a part of the development of scientific knowledge are not
unbridled but rather are within limits set by convention within the scientific
community.

There is one more interesting thing we would like you to experience. Copy
the following diagram shown in Figure 1.9 onto a blank sheet of paper.
Cut out the pattern and fold it into a cube.

You should have a cube with the sides labeled hat, bat, mat, cat, and fat. One
of the sides is not labeled because we did not want you to see the answer. Place
the cube on your desk so that the blank side is face down. Using the observations
you can make from the other sides, decide how the blank side is supposed to be
labeled.

If you came up with pat, you correctly arrived at the intended answer. Think
about the list of characteristics describing the nature of science and determine
which of those items are illustrated by the cube activity. A good argument can
be made that each of the six statements on your list is evident in the cube ac-
tivity. Now let us consider how you arrived at the answer of pat. The Intended
pattern for the cube was that each side contains a word ending in at, and the
first letter is a consonant beginning from the start of the alphabet. So, both eat
and oat were not considered because e and o are vowels. Is this the pattern you
found? Some individuals arrive at pat by deciding that all sides have a word end-
ing in at and the actual words have a numerical relationship. b and c have no let-
ters between them, c, f, and h have one letter between them, and m and p have
two letters between them. Is this the pattern you used, or did you use an entirely
different pattern and arrive at a label other than pat? Clearly, there are several
different ways of getting the intended answer, and there is also the possibility of
interpreting the data to arrive at an answer that is consistent with the data but
that is incorrect. This is all consistent with how science proceeds, with the big ex-
ception being that in science we rarely get a chance to look on the bottom of the
cube to find the answer.

We want you to make one final cube now. Use the diagram shown in Fig-
ure 1.10 to make a cube similar to the one made previously.
Figure 1.9 Diagram of a Word Cube

This cube should have the sides labeled with the numbers 1, 1, 2, 3, and 4. Again, one of the sides has no number on it, and this side should be placed face down on your table. As you did before, try to determine what was on the blank side before we removed the original number.

Most people decide that the blank side should have a 9. It actually was labeled with a 5. When we made this cube, we made it with the intention of there being no pattern. Interestingly, people will always find some pattern to predict what is on the blank side of the cube. Sometimes they even correctly identify the label as 5 for reasons other than what we used when creating the cube. It is quite possible to come to a solution of 5 if it is determined that all of the sides do not contain relevant data. For example, what would it mean if you decided that one of the sides with a 1 was not relevant to the solution? Then 5 becomes the solution for the blank side simply by following the sequence of numbers on the sides considered to have relevant data. When scientists make decisions concerning the inclusion of data, there is clearly some subjectivity. How are data that are very different (i.e., outliers or anomalous data) from the majority of data handled? Are they included or ignored as the consequence of
some type of error? Sometimes the deviant data turn out to be the most important. Selection of data for analysis is just another example of how creativity, inference, and subjectivity come into play when scientific knowledge is developed.

There is a more important lesson, however, to be learned from this last cube. The lesson is closely related to our previous discussion of how human beings always bring preconceptions, prior knowledge, and beliefs to every situation. It appears that one very strong characteristic among human beings is their assumption that a pattern does exist. Is it possible that there are no patterns in certain parts of nature? Perhaps; nevertheless, we always seem to be searching for patterns and eventually find them. On the other hand, would it be more correct to say that we create these patterns? You may feel that you already know the answer to this question. On the other hand, you may not. We want you to keep this question in mind as you proceed through this textbook. We feel that how you choose to answer this question will significantly impact how you conceptualize the teaching and learning of science.
A Few Words about Teaching the Nature of Science

At the beginning of this chapter, we mentioned that the instructional approach in this text may be very different from what you have previously experienced. Our approach is meant to be consistent with the way science actually is, as opposed to how it is most often presented in elementary schools. In addition, we have made every effort to use instructional approaches that research has shown to be effective. The same is true for this chapter's approach to teaching you about the nature of science. The various aspects of the nature of scientific knowledge (e.g., tentativeness, subjectivity, etc.) were explicitly addressed. The fossil activity could have been used to simply teach about fossils and the relationship between form and function. However, we explicitly included various aspects of the
nature of science within the debriefing of the activity. It is very common for teachers to involve students in investigations similar to the ones we have without making the nature of science explicit. Often the assumption that students will necessarily reflect on what they have done and implicitly learn about the nature of science is made. This assumption has proven to be incorrect. If you want students to learn about the nature of science as they are also learning science concepts, you will need to include discussions about the nature of science with your discussions about the science concepts.

Summary

This chapter has attempted to answer the question, "What is science?" In doing so, we have characterized science as consisting of three basic components:

1. A body of knowledge
2. A method or process
3. A way of knowing or constructing reality

This last component (also commonly known as the "nature of science") was given the most emphasis because, unlike the other two, it is the most widely misunderstood, and its emphasis in current reforms permeates both subject matter and pedagogy. This enigmatic phrase most commonly refers to the values and assumptions inherent to scientific knowledge and its development. The values and assumptions to which we refer include tentativeness, unavoidable subjectivity, the importance of human creativity and imagination, the importance of both observation and inference, and a basis in empirical evidence. As scientists attempt to answer questions of identified importance, their observations and inferences are influenced by subject matter paradigms and personal biases held by the scientist as he or she grapples with limited data sets in an attempt to derive generalizations about the natural world.

Suggested Readings

