

Chapter 17

Avoiding De-Natured Science: Integrating Nature of Science into Science Instruction

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17.1 Introduction

It has been several years since the *Next Generation Science Standards* (NGSS 2013) in the United States were unveiled, and they continue to present challenging work for science teachers. In the United States alone, there have been no fewer than three major reform documents (along with ancillary materials) in science education since the early 1990s (AAAS 1993; National Research Council 1996; NGSS 2013). The appearance of new standards in science is not limited to the United States. Similar standards have recently been unveiled in Australia, China, Germany, Sweden, and numerous other locations worldwide. The visions of these reform documents vary in many ways, but there are similarities as well. When one looks past the specific details and nuances of the various reform documents, the desired outcome has always been scientific literacy, a perennial goal of science education (NSTA 1982).

Science is one of many ways of knowing and its focus is primarily on understanding the natural world. But knowing the laws, theories, concepts, and big ideas in science textbooks, as well as how these types of knowledge have been developed, is not enough. Rather, we want all citizens to be able to use their knowledge of science to make informed decisions about personal and societal issues that are grounded in science and to engage in scientific discussions that are of importance globally and locally.

Science as a way of knowing is difficult to define beyond statements about its general purpose or goals. One straightforward way to think about science is to con-

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sider it as having three basic components. First, science consists of a body of knowledge. Second, there are the processes and strategies for the development of the knowledge (i.e., inquiry/practices), and third, there are the characteristics of the knowledge that are directly and necessarily derived from how the knowledge is developed (i.e., nature of science). Obviously, these components of science are intimately related. Knowledge is developed using inquiry/practices and the resulting knowledge has specific characteristics that are derived from the manner in which the knowledge was developed (Lederman and Lederman 2014).

With respect to achieving the goal of scientific literacy, most science educators have realized that knowledge of how scientific knowledge is developed and the characteristics of the knowledge that are engendered by the development of the knowledge are critical to the informed decision making (NSTA 1982). Everyone must be able to weigh the claims made by scientists and understand the inherent limitations of scientific knowledge. Students' understandings of NOS and SI, and how together they support the attainment of scientific literacy, remain as inadequate as they have been since the 1960s (Lederman 2007).

The US *Next Generation Science Standards* (NGSS Lead States 2013) are organized into three dimensions (i.e., Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts). Understandings about nature of science (NOS), which also includes what was formerly known as knowledge "about" scientific inquiry (SI), are generally linked to statements with the dimensions of Science and Engineering Practices and Crosscutting Concepts. As important as inquiry and nature of science were considered as components of scientific literacy in previous years, neither the Benchmarks or NSES was successful at getting this message understandable to most students. In short, NOS refers to the characteristics of scientific knowledge that necessarily result from the conventional approaches (i.e., scientific inquiry) that scientists use to develop knowledge.

NOS statements related to the use of a variety of shared methods, the role of evidence, and the notion that science addresses questions about the natural world, science is a way of knowing, and science is a human endeavor are clearly found in Appendix H of the NGSS. Teachers will most likely not consult the appendix but will find many of NOS statements linked to the Science and Engineering Practices and Crosscutting Concepts on each page of the standards themselves.

We find that some statements such as science are a "way of knowing" and science is a "human endeavor" as too broad and vague to be of much instructional use. More useful for the teacher is that these characteristics include aspects of NOS such as scientific knowledge is subject to change, and is a function of human creativity/imagination, subjectivity, and necessarily includes both observations and inferences. Students' understandings of NOS and SI, and how together they support the attainment of scientific literacy, remain as inadequate as they have been since the 1960s (Lederman 2007). However, empirical research in the past three decades has clearly indicated that students' and teachers' learning about these critical areas was best facilitated through an explicit, reflective approach to instruction (Bell et al. 2003; Lederman and Lederman 2014).

The focus of this chapter is to provide concrete examples of how to facilitate students' understandings of NOS within the science curriculum. That is, the activities and experiences provided are not "standalone" activities focusing on NOS, but rather examples of how NOS can be emphasized within instruction that addresses scientific concepts and processes, within the disciplines of biology, chemistry, physics, and earth science. In short, the activities are not decontextualized. They are all embedded in the teaching of the science content specified in typical science curricula. This chapter is a new and revised version of the chapter written in a previous version of the current text (Lederman and Abd-El-Khalick 1998). Some of the activities/experiences are the same, but some are new. We highly recommend that you consult the previous chapter because the two together provide a much more comprehensive NOS resource.

As far as communicating proper understandings of the NOS to students is concerned, teachers have been led to believe that their students will come to understand NOS simply through the performance of scientific inquiry and/or investigations. This is no more valid an assumption than expecting that students will learn the details of cellular respiration by watching an animal breathe. Consequently, NOS is explicitly emphasized in each of the following activities/experiences as are the more traditional science concepts targeted.

17.2 About the Activities and Experiences Presented Here

This chapter introduces a set of activities/experiences designed to model an explicit approach to teaching science subject matter as well as crucial aspects of NOS. These activities have been successfully used with elementary, middle, and high school students as well as preservice and inservice teachers. Those interested in helping students learning about NOS can use the following activities to convey adequate understandings of NOS to students and teachers. The NOS aspects advocated in these activities/experiences are designed at a level of generality and developmental appropriateness that renders them virtually noncontroversial. That is, highly esoteric aspects of NOS that are developmentally inappropriate and unconnected to the common K-12 school curriculum are not included. For example, philosophers can successfully argue that there really are no true observations, just inferences. However, this esoteric notion is well beyond the reasonable comprehension of a seventh-grade student when they are looking at a chair or anything seemingly tangible.

Science educators can use these activities in either science courses or science teaching method courses. If the audience consists of precollege students, the appropriate grade level(s) for using a certain activity/experience are pointed out, but most can easily be adapted for audiences of varying levels of sophistication. Where appropriate, extensions that make an activity/experience more amenable for use with older students are included.

Each activity/experience specifies what students can learn, materials, setup, and/or procedure as well as a possible instructional scenario. The PowerPoint™ slides that are needed for the activities and experiences can be conveniently reproduced from the images included. The instructional procedure/scenario section provides an explicit idea about the kind of questions and answers that can be expected and the aspects of NOS that need emphasis during a certain activity/experience. These scenarios are not meant to be prescriptive in any respect. Rather, they are drawn from classroom experiences and genuine student reactions and are meant to provide a better idea about one possible discourse among many equally fruitful classroom interactions. The approach taken for a certain activity/experience is up to the professional judgment of the teacher.

17.2.1 Tricky Tracks

This activity is easily embedded within a biology unit focusing on fossil evidence or with an earth science unit focusing on fossils. When dealing with fossils, it is important for students to not only know how fossils are formed, but also how scientists use fossils to make inferences about structures, organisms, and events that existed or occurred many years ago. “Tricky Tracks!” conveys to students the message that every idea is important irrespective of it being the “correct” answer. Students completing this activity will gain experience in distinguishing between observation and inference and realize that, based on the same evidence (observations, or data), several answers to the same question may be equally valid.

Grade Level: Any

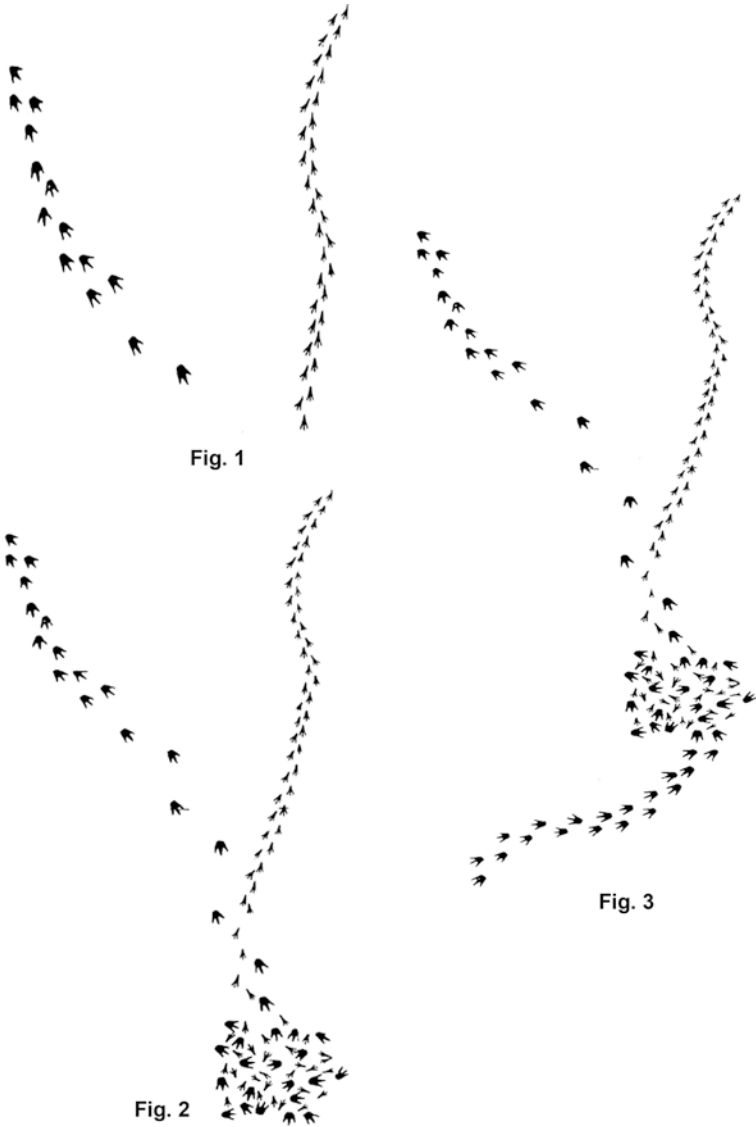
Materials: Create Separate PowerPoint™ slides of Figs. 17.1, 17.2, and 17.3.

Targeted NOS Aspects: tentativeness, subjectivity, observation, inference, empirically based

Discipline: Biology, Earth Science

Instructional Scenario:

1. Show students Fig. 17.1 and tell them that a group of scientists came upon this set of footprints on the ground. Ask the students to volunteer their ideas about what they are observing. As students offer their observations and inferences gathered from Fig. 17.1, list these on the board.
2. Ask students questions such as, “What kind of animals left these footprints?” “Are the two animals of the same type, but of different size or are they different types of animals?”
3. Ask students, “In which direction are the animals walking?” Then students defend their inferences.
4. Students will readily (without much prompting) offer their ideas of what is happening (by making inferences). When this occurs, ask students if they directly observed one animal seeing the other and walking toward it. You can



Figs. 17.1–3 Two partial (Figs. 17.1 and 17.2) and the full set (Fig. 17.3) of Tricky Tracks. We recommend showing students Fig. 17.1 (upper left), then Fig. 17.2 (lower left), and finally the entire set of tracks (right). It will be most effective to produce three PowerPoint™ images and reveal the tracks on set at a time

tell students these are inferences, or you can ask them about the difference between seeing the footprint and deciding that one animal sees the other and is walking toward it. Follow this with a discussion about the difference

- between observations and inferences and ask students if making observations and inferences are something that scientists do.
5. As the discussion proceeds let students offer their inferences of what happened. Let students “debate” with their classmates about the reasonableness of each of the inferences made. Students will weigh the merits of the various inferences.
 6. You can increase the discussion and help students to think further about what is occurring by asking why the footprints of the larger animal are not consistently the same distance apart. This will typically result with students converging on the idea that one animal (students typically think it is a bird) sees the other and starts to run toward it. Help students to question this idea by asking if there is another reason that footprints get further apart other than running or walking faster.
 7. On the board, continue to list students’ observations and inferences gathered from Fig. 17.1.
 8. Now show Fig. 17.2. Again, ask students what they see and what they think has happened. Some students will change their inferences about what they saw in Fig. 17.1 and others will see the additional data as confirming their initial ideas.
 9. Students will typically make the following inferences:
 - (a) One bird saw the other and ran toward it as a predator.
 - (b) The birds are mating.
 - (c) The birds are both eating something.
 10. Accept all answers at this point and avoid making any judgment. As much as possible, you want students to use the observations to make inferences that they feel they can defend. Point out to them that they are doing what scientists do when they collect data and draw inferences.
 11. As the discussion begins to wane, show Figures 17.1, 17.2, and 17.3. As previously done, have students make observations and inferences and defend their inferences. Again, avoid making judgments. After all, these events happened in the past and there is no way to actually know what happened. The students (just like scientists) are making inferences from the observations and from what they already know.
 12. Typically, once Fig. 17.3 is shown, the following inferences will likely be offered by students:
 - (a) One bird killed the other.
 - (b) One bird flew away.
 - (c) The larger bird was a parent, and he/she picked up the younger bird, and put he/she on its back or in its mouth and walked away. Throughout the discussion, be sure to have the students distinguish between their observations and inferences.
 13. Once the students have settled on one to three inferences about the events, it is interesting to get them thinking a bit more by asking them, “Why is every-

one assuming the footprints were made at the same time?” Maybe the two birds were not in the same location at the same time. This will lead to another set of inferences.

14. Throughout the discussion students should be asked if they have changed their ideas and why, and “Why, even though everyone was looking at the same data, different inferences were made?”

15. As you can see, the directions the class discussion may follow are endless. However, the ideas that scientific knowledge is tentative (subject to change), involves human creativity, is necessarily subjective, is based on observations and inferences and investigations can follow a variety of approaches can easily be emphasized. These characteristics of scientific knowledge and practice can easily be elicited from students (although they may use different words). That is, students can develop conceptual understandings of these aspects of NOS without being directly told the aspects by the teacher.

The crucial point to remember is that this activity integrates these NOS understandings seamlessly into science instruction about fossils rather than just teaching about NOS without a science content context and how they can be used within scientific investigations about historically earlier events. The activity is not designed to stand alone only to teach about NOS with no science context.

17.2.2 Core Sampling and the Construction of Topographical Survey Maps

This activity/experience provides a concrete way for students to understand how scientists infer what types of rock layers exist below the surface of the land we observe. In addition to teaching important science processes and geological concepts, it is also a perfect platform for emphasizing certain aspects of NOS, in particular, students’ understanding of observation and inference in science and the notion of creativity and its role in constructing scientific knowledge. After completing this activity, students should be able to appreciate that scientific knowledge is partly a product of human inference, imagination, and creativity, even though it is, at least partially, also supported by empirical evidence. Moreover, students will come to realize that science does not produce absolutely certain knowledge. All scientific knowledge is subject to change (i.e., tentative) as more evidence is accumulated or as already available evidence is reinterpreted in light of newly formulated hypotheses, theories, and/or laws.

Level: Upper elementary and middle school

Materials: One manila file folder, a sheet of construction paper that will fit inside the folder, one acetate sheet (per student or group of students). See instructions for

creating this below. Paper sheets of assorted colors, adhesive tape, glue. Sample geological survey maps from various locations.

Targeted NOS Aspects: tentativeness, subjectivity, observation, inference, empirically based

Discipline: Earth Science

Teacher Preparation: On the large or tab side of the manila file folder, punch several holes randomly (Fig. 17.4). It may be necessary to cover the folder with an opaque material (e.g., white opaque paint) to prevent seeing the shapes in the folder. Next, tape the folder leaving the tab end open creating an envelope (Fig. 17.5). Create an insert by gluing differently colored, randomly shaped pieces of paper to a sheet of construction paper (Fig. 17.6). The inserts need not be the same for all prepared folders. Insert the construction paper into the envelope with the colored pieces of paper facing the holes (Fig. 17.7).

At this point, tape an old overhead transparency (or sheet of clear plastic) over the side of the folder with the holes. With a nonpermanent pen, students can draw on the transparency and erase their drawing.

Instructional Scenario:

1. Tell students that they will be engaging in a situation like what scientists do when they are trying to determine what types of rocks are below the visible surface of the Earth.
2. Hand each student, or group of students, a manila folder (with the insert inside) and an erasable or nonpermanent pen. The erasable pens allow you to re-use the folders in other or future classes.
3. Inform students that the inserts have certain colored shapes glued to them. Without removing the inserts, students need to figure out those shapes and colors. The only available information to the students is what they see of the colored paper through the holes.
4. Have students trace their proposed shapes on the overhead transparency.
5. When your students finish their proposed shapes, take the time to make explicit the similarities between what they are doing and what scientists usually do. Faced with a natural phenomenon (the insert), scientists pose certain questions to which there usually are no readily available answers – What is

Fig. 17.4 Open file folder (left) with randomly spaced holes on one side

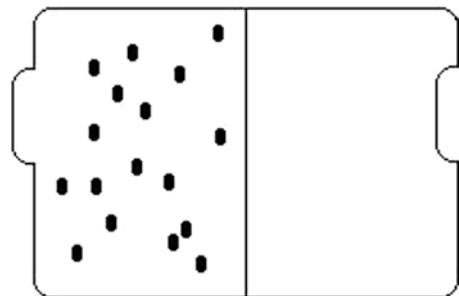


Fig. 17.5 Closed file folder (right) with sides taped shut so that the sheet shown in Fig. 17.6 can be slipped into the open top

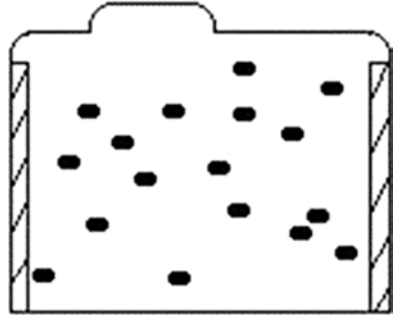
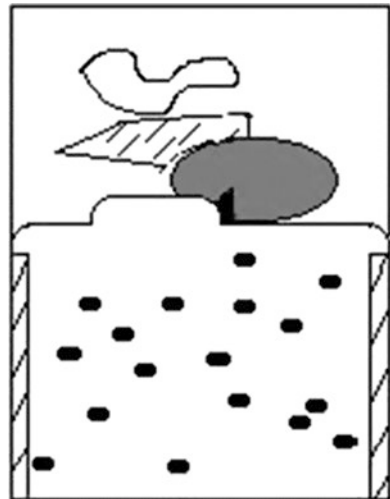


Fig. 17.6 Illustration (Left) showing the construction paper shapes glued to the insert that will be slipped into the open top of the file folder



Fig. 17.7 Illustration (Right) of the insert being placed into the file folder



the shape of the colored pieces of paper on the insert? The activity aims to put students in a situation similar to the ones that geologists face when constructing geological survey maps. Just like your students, scientists would rather handle the phenomenon first hand, which in the present case would be to simply pull out the insert and see how it looks. This, however, is rarely possible.

For example, for a few 100 years, physicists theorized the presence of atoms, formulated many atomic theories, investigated the structure of the atom, and accumulated a great deal of knowledge about the atom and its components. This knowledge in turn has allowed many advances in physics and related fields. All of this occurred even though scientists never saw atoms directly. (It is true that using super-accelerators/super-colliders physicists could break atoms into smaller pieces. However, another problem of “visibility” arose. The now-famous “Higgs” particle seems to “block the vision” of scientists who again seem not able to “see” what they would like to see firsthand). In a similar fashion, astrophysicists have produced scientific knowledge about the inside of the sun and the kinds of reactions taking place within, all without splitting the sun open!

6. The question arises, “How do scientists produce a seemingly reliable body of knowledge about such phenomena?” Scientists collect data about the phenomena they study. The holes on the folder represent data points (i.e., core samples) allowing us to view a part of the object of investigation. The data points that can be collected about different phenomena vary in several ways. Some of those ways include the:
 - Amount of data (e.g., number of holes) which may depend on the feasibility and the practicality of collecting the data. For example, in geological surveys, it is possible, but not at all practical, to collect rock samples from every square meter of terrain. Samples are usually collected from a much larger unit area.
 - Quality (such as small versus larger holes) which relates to the accuracy, precision, etc. of the data. The quality of data depends on a multitude of factors. Technology is one. For example, the quality of the Hubble telescope photos of distant galaxies now available to astronomers is by far more informative than earlier photos taken by observatories on Earth.
 - Availability (e.g., it may not be practical for us to indefinitely punch holes in the folder to see the whole insert below). For example, astrogeologists would certainly like to examine every meteorite, but they can only hope to locate some of the meteorite samples available on Earth.
7. After collecting data, scientists, will infer answers – as your students did – to their questions consistent with the data. Creativity and imagination are essential to this process. In much, the same way that your students have literally filled in the gaps between the holes to generate a final picture of what they thought the colored pieces of paper look like, scientists engage in a

creative process to make sense of the data they have collected and come up with a final picture or an answer.

8. Ask a few of your students to remove the insert from their folders (other students should keep their inserts inside). Ask those students to compare, in front of the class, their proposed drawings with what the inserts actually look like. If you were careful to glue randomly shaped pieces of paper to the insert, your students will be surprised with the differences. Point out that scientists, very often, are not able to “pull out their inserts and examine them.” Rather, they must infer an answer from the available data.
9. Hand out geological survey maps from the United States and Canada. Each group should get one map from the United States and one from Canada. Have the students investigate the color coding for different rock layers on the two maps. Ask students to describe any differences they notice.
10. Students will quickly notice that on the United States maps each rock layer is represented as a homogeneous color, while on the Canadian maps each rock layer is a combination of a lighter and darker shade of the same color. Ask students what they think the lighter color represents (what has been inferred) and what the darker colors represent (what has been observed in the field through outcroppings and core sampling).
11. Ask students to draw analogies between the maps and the folders. The discussion should result in students’ explaining that the holes in the folders are analogous to actual observations or outcroppings and the parts that they drew on the acetate sheets are analogous to the inferred parts of the survey maps.
12. Ask some of your students whose inserts are still inside their folders how certain they are about their proposed drawings! Ask your students whether they think scientific knowledge can be absolute or certain. (A good discussion usually results). With older students, it might be a good idea not to permit them to remove their inserts. This provides an experience that is more consistent with actual scientific investigations. With younger students, you might let all of them remove their inserts, especially if they show signs of frustration. (In most cases, scientists do not stop at the initial phase of collecting and inferring as was the case with this folder activity. Rather, they then derive predictions based on their hypothesized answers and test those predictions by collecting more direct or indirect data. This aspect of NOS is dealt with in following activities.)

In summary, this activity helps develop students’ understandings of the work of geologists as they attempt to map the layers of the Earth, as well as help students develop understandings of important aspects of NOS.

17.2.3 *Doing Real Science with Real Fossils*

This activity/experience helps students realize that scientific knowledge is partly a product of human inference, imagination, and creativity. The advantage of this activity is that students work with the same artifacts and data (i.e., fossil fragments) as paleobiologists. In addition to helping students develop informed understandings of NOS, this experience will assist students in their understanding of the relationship between structure and function of organisms and how organisms are adapted to their environment.

Level: Upper elementary through High school

Materials: Fossil fragments (not complete fossils), construction paper, scissors (per student or pair of students). Depending on where you live, fossil fragments can be gathered at the beach, purchased from a science supply company or borrowed from the zoology department of a local university or museum.

Targeted NOS Aspects: tentativeness, subjectivity, observation, inference, empirically based

Discipline: Biology

Instructional Scenario:

1. Give each student (or pair of students) a fossil fragment (examples may be seen in Fig. 17.8) and ask them to make a detailed diagram of it. The diagrams may be larger than the actual fragments, but students must include the appro-



Fig. 17.8 Representative fossil fragments that may accompany this activity

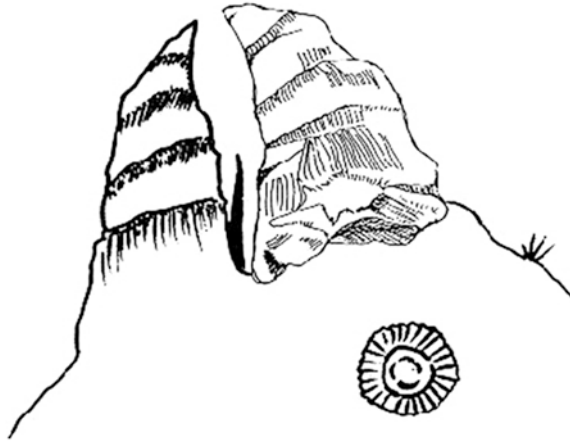
Fig. 17.9 Image of the original fossil fragment



priate scale with their diagrams. If possible, provide students with sets of similar or identical fossil fragments so that different student groups can compare their inferences at the end of this activity.

2. Ask students to trace the outline of their fossil fragment on a separate sheet of colored construction paper. This tracing is cut out, and the inside is discarded to form a window so that when the construction paper border is placed over the paper containing the fossil fragment diagram, only the diagram appears.
3. With a different colored pencil, instruct students to complete their fossil drawing (to scale) on the construction paper containing the fossil fragment diagram. Students should end up with a drawing of an organism from which they believe the fossil fragment has come. This drawing task can occur in class or be assigned as homework.
4. The result of the previous steps is that each student ends up with a complete fossil drawing with two parts: the original fossil fragment drawing in one color and the inferred drawing of the complete organism in another color.
5. Ask students to staple together the construction paper with the previously cut window and the paper with the complete drawing. The papers should be stapled on one side such that they can be flipped open. The fossil fragment diagram should only show through the construction paper window. This format enhances the presentation of the original (fossil fragment) and completed diagrams to other students (Figs. 17.9 and 17.10).
6. Ask students to make an oral presentation in which they describe the habitat, diet, behavior, and other characteristics of the organisms they have extrapolated from the fossil fragments. Ask whether the students knew in advance what organism their fossil fragment came from (e.g., coral). Ask those students whether their prior knowledge affected the inferences they made about the habitat, diet, etc. of the complete organism that they inferred from the fossil fragment. This is a good time to make the point that that scientists' prior

Fig. 17.10 View of the completed fossil diagram



knowledge often influences their interpretations of the data and affects their conclusions.

7. If fossils from the same organism were assigned to several students, have students compare the organisms that different students inferred from these similar or identical fossil fragments. If the inferred organisms were different, ask students: “Can we tell for certain from which organism the original fossil fragment come?” Also ask, “How can two students looking at almost identical fossil fragments develop very different “complete” organisms?”

Explain to students that we might not be able to give a definite answer. Continue by asking: “Is it possible that scientists face a similar situation?” “Can scientists differ in the inferences they derive from data?” “If yes, how can such differences be settled?” Explain to students that all too often scientists may reach differing conclusions based on the same evidence, just as the students have done in this activity. Provide some contemporary examples that come from current debates in the scientific community. Scientists also often hold their views strongly and do not give them up easily.

8. Make it explicit to students that what they have done is very similar to what paleobiologists and other scientists who investigate fossils do. Point out that creativity is involved in extrapolating or inferring from fossils the kind, habitat, and lifestyle of the organisms whose fossils or fossil fragments are investigated.
9. Conclude this activity by talking about the famous case of the dinosaur *Iguanodon*. When it was first reconstructed, the thumb was originally placed as a spike above the nose! It is useful to remind students that any reconstruction should be considered tentative – just like all the products of science.

17.2.3.1 High School Extensions

Initiate a discussion about the extent to which creativity plays a role in science with the case of hominid evolution. Tell the story of the evolution of humans over the course of the past five million years. Scientists have formulated several elaborate and differing story lines about this evolution. It is noteworthy that all that is available to those scientists is a few teeth, tools, and parts of skulls and skeletons! Inference, imagination, and creativity serve to fill in the gaps, which in this case seem to be enormous!

The same discussion can be carried further to introduce students to the notion that scientific knowledge is affected, to varying degrees, by the social and cultural context in which it is produced. The different story lines in the above example about the evolution of humans were heavily influenced by social and cultural factors. Until recently, the dominant story was centered about “the man-hunter” and his crucial role in the evolution of humans to the form we now know (See Lovejoy 1981). The hunter scenario was consistent with the white-male culture that dominated scientific circles up to the 1960s and early 1970s. As the feminist movement grew stronger and a female voice appropriately emerged in the narrative about human evolution, the story about hominid evolution changed. One story more consistent with a feminist approach is centered about “the female-gatherer” and her central role in the evolution of humans (see Hrdy 1986). It is noteworthy that both story lines are consistent with the available evidence.

Scientists are often portrayed as being totally objective. As they engage in their work, scientists are thought to set aside their personal prejudices, perspectives, and beliefs.

This objectivity, among other things, is believed to allow scientists to:

- Conduct “objective” observations. Scientists make theory-free observation. They simply describe and measure things as they are. These observations are independent of what the scientists know, believe, or how they view the world.
- Reach “objective” conclusions. Based solely on their objective observations, scientists use the rules of logic and inference to formulate hypotheses or theories to explain the phenomenon under investigation.
- Evaluate new evidence objectively. After they formulate an idea, scientists collect more evidence to test the adequacy of these ideas or to test their predictive power. Hypotheses and theories are “objectively” evaluated against this evidence. Confirmatory evidence tends to strengthen the hypothesis or theory and eventually leads to its acceptance by scientists. However, if the hypothesis or theory is not supported by the evidence, it is rejected.

It may be tempting to accept the above claims, but this history of science, however, is full of instances that counteract each of them. It is often the case that scientists interpret the same evidence differently, formulate different hypotheses to explain that evidence, and fiercely defend those explanations or hypotheses. In fact, controversies are commonplace in science. Notions of high levels of objectivity have been discounted by many philosophers and historians of science.

For instance, Kuhn (1970) suggested that all scientific observations and interpretations are in some respect subjective. Kuhn advanced the notion of “paradigm” to account for what usually happens in science. A paradigm defines, for a certain research community, the phenomena that are worth researching, acceptable questions to ask of those phenomena, appropriate research methodologies, adequate instrumentation, and the relevant and admissible evidence. For a scientist, a paradigm acts as a lens through which his/her observations are filtered. In a sense, the interpretations and explanations that a scientist formulates are consistent with that paradigm.

Although you may not want to formally introduce your students to all the above notions, certain ideas are worth emphasizing to your upper middle and high school students. Scientists’ beliefs, previous knowledge, training, experiences, and expectations all combine to influence the work of those scientists. All these background factors form a mindset that affects what scientists observe (and don’t observe) and how they make sense of or interpret their observations. It is this individuality that accounts for the role of subjectivity in the production of scientific knowledge.

17.2.4 Construction of a Model of the Atom (Also known as, The Mystery Tube)

There are numerous situations in science in which theoretical models are developed from incomplete data and the resulting model has never actually been seen (e.g., the center of the earth, an individual atom). Students of all ages have a difficult time understanding that many of the pictures in their science textbooks are not exact mirrors of reality and that scientists often infer scientific knowledge from the incomplete data they possess. This is certainly true of the model of the atom.

The following activity/experience is perfect for a chemistry class or any class that investigates the structure of the atoms and how they behave. In addition to learning about the structure of the atom, the activity can also facilitate students’ understandings that scientific knowledge is tentative, involves subjectivity, and is necessarily a function of observations and inferences, among other aspects of NOS.

Grade Level: Any

Targeted NOS Aspects: tentativeness, subjectivity, observation, inference, empirically based, theory/law

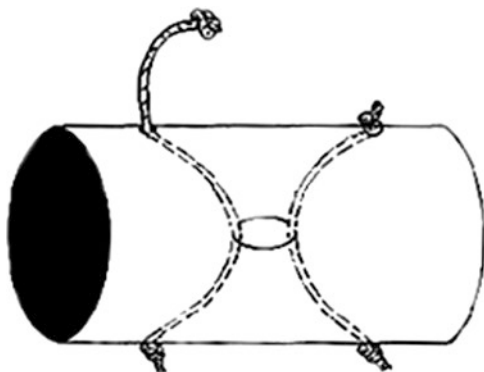
Discipline: Chemistry, Biology, Physics

Prerequisite knowledge: None

Model Construction: Individual students

Materials: 1 tube (mailing tube, core of toilet paper roll, or PVC pipe, approx. 30 cm), 1 plastic ring (optional, you can simply loop the lower rope over the upper rope), rubber stoppers or tape (to seal tube ends), 1 roll of clothesline rope

Fig. 17.11 The construction of the mystery tube. Students see only the knotted ropes that appear on the outside of the tube



(for whole class), 1 toilet paper roll core or other cardboard tube (these can be provided by the students) (Fig. 17.11).

Instructional Scenario:

1. Begin class by having students look at a picture of an atom. (This could be an image from a textbook, online source, or handout.) Ask, “How do scientists know what an atom looks like?” Most students will answer with a comment about some version of a microscope or electron microscope. Then, tell the students that no one has ever seen an individual atom. Allow them to respond to this fact or immediately move to your demonstration of the “mystery tube.”
2. Hold a preconstructed tube in front of the class and asking various students to provide one observation. Be sure not to let the students pull any of the ropes or open either end of the tube.
3. As observations begin to wane, help students by directing their attention to certain parts of the tube. For example, it is a good idea to use rubber stoppers that contain one or more holes to cover the two ends of the tube. Students will not initially look at the stoppers carefully.
4. It is typical for students to quickly begin speculating about what is inside the tube. When this occurs, be sure to state that you are only asking for observations not inferences. Ask them why discussing what may be inside the tube is an inference.
5. After about 10 min of observations, ask students to observe carefully as you pull on various ropes. Ask students what they predict will happen when a rope is pulled.
6. Begin by pulling on one of the ropes at the top end and after the opposite side rope moves inward, do the reverse. This is not interesting to students because the predicted results and actual behavior of the ropes are intuitive.
7. Now begin pulling various ropes in any order you desire and the students will see behaviors that are not predicted. This will create much interest by

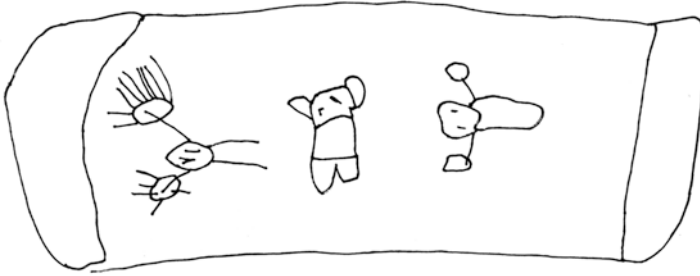


Fig. 17.12 A student's serious or not-so-serious inference about the contents of the tube. (Redrawn from the original)

the students and they will start speculating about what is inside the tube to explain what they are observing.

8. Have students, individually or in pairs, draw a model of what they think is inside the tube that would explain the data that they have collected/seen on a sheet of paper.
9. Let the students suggest new ways to manipulate the ropes (e.g., pulling half way). As you follow their requests, ask the students if any of their ideas have changed and if so, why?
10. At this point there should be a variety of different ideas about what is inside of the tube.
11. Ask a few students to draw their models on the board. Continue until all possible models are exhausted. You will likely get about four to five different ideas. On occasion, you may get an inference that looks like the one below (Fig. 17.12), drawn by a third-grade student.
12. A proposal such as this will inevitably result in laughter from other students, but this is an important teachable moment. Ask the students why they are laughing. The responses will focus around the idea that no one has ever seen a person this small or the answer makes no sense given what we know. This can be used to stress to the class that not all inferences are equal. Inferences from data must be consistent with the data and what we already know about the world.
13. Ask the students: "If we are all looking at the same thing, why are there different ideas?" This will lead to a discussion about how students are all different and have different interpretations. Ask students, "Is this situation the same as with scientists?" Ask why they think so. Stress how subjectivity and creativity always surface when scientists are interpreting data. Ask, "How do we find out who is right?" Students will ask you to open the tube, but you should respond that the tube is like the world, you cannot open it up to see what is inside or like the atom we are not yet capable of seeing.
14. Other suggestions will be made, but wait until someone suggests that each student makes their own tube. Ask students what this would accomplish. They will readily say they are testing their ideas. You can relate this to what they were doing when they were asking for certain manipulations of the

ropes. Remind the students that they are doing exactly what scientists do when they investigate phenomena.

15. Next, in class or at home, have students make a physical model of their drawings. If students do this in class, you can provide them with the inside core of a roll of toilet paper, string (instead of rope), and whatever else you want. But keep in mind that the students will try to incorporate whatever materials you provide.
16. After all students have completed their tube model, have the students pull the same ropes that you pulled to see if their model works the same as yours. You will inevitably have several different student models behave in the same manner as yours.
17. Ask the students this very important question, “If your model works the same as mine, do you know what is inside my tube?” It will not take long for students to conclude that the answer is “no” because several different models work the same as yours. At this point, you can stress that in science, inferences are made based on data and different scientists may interpret the data differently, just like they did.

Furthermore, the inferences that scientists make about the structure of the atom (or what is in the tube) involve human creativity and are necessarily subjective to some degree.

18. The vital job for the teacher is to help students make the transition from the tube, with ropes extending out of it to the science of chemistry. Have the students recall what was discussed at the beginning of the lesson about atoms. That is, there is a picture in the textbook of an atom, yet no one has ever seen an atom. The ensuing discussion should elaborate on the analogy between what the students did with the tube model and what scientists have done to determine what an atom looks like. The discussion should focus around how the development of scientific knowledge (or what students think is in the tube) involves human creativity, is necessarily subjective and tentative, and is based on observations and inferences.

Note that this very well-known activity created by Norman Lederman in the 1980s has often been misinterpreted to be a context-free activity. This interpretation is incorrect. Who would do such an activity and not have it relate to the subject matter students are expected to learn? The activity can be referred to throughout the year whenever students are learning about science models or ideas that have not been directly observed, but inferred.

17.2.5 The Power and Pressure of Air

Air pressure is a very challenging concept for students to understand because students have difficulty understanding how something they cannot see can exert pressure and move other forms of matter. This activity is appropriate for introducing air pressure in a biology or chemistry class. It can be used to teach about air pressure and its interaction with other forms of matter, and represents a unique way to help

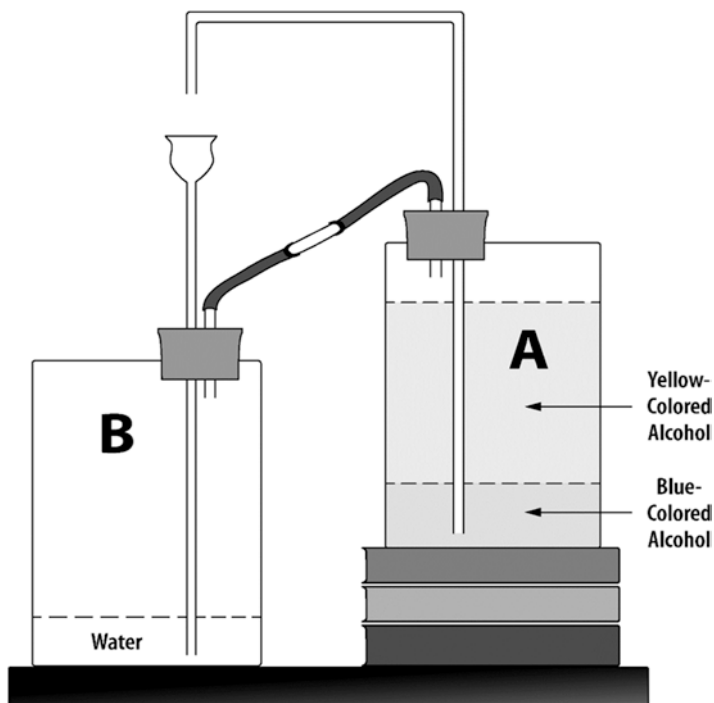


Fig. 17.13 Details of the construction of the demonstration. (Shown as if the cans were transparent)

students understand that scientific knowledge is tentative, a function of observation and inference, involves creativity, and is empirically based.

Grade Level: Middle and High School

Targeted NOS Aspects: tentativeness, subjectivity, observation, inference, empirically based

Discipline: Biology, Chemistry

Prerequisite Knowledge: Introductory knowledge of pressure (liquid and air)

Materials: Two empty metal cans (available in the paint section of many building supply stores, two rubber stoppers, rubber tubing, one thistle glass tube funnel, glass tubing, ethyl alcohol, and food coloring).

Constructing the Demonstration: The initial levels of liquid in cans “A” and “B” are shown in Fig. 17.13. Can “B” contain plain tap water. Can A contain a tap water colored with blue food coloring at the bottom (about 1/3 of the can), and the rest of the can is filled with ethyl alcohol dyed yellow with food coloring. When adding the yellow-colored alcohol, do this slowly to prevent any unnecessary mixing or agitation. A small segment of glass tubing should be inserted within the rubber tubing that connects cans “A” and “B”.

Instructional Scenario:

1. Begin class by having the students make observations of the demonstration setup (Fig. 17.13). Have students offer observations of every aspect of the setup. For example, they might say things like “Can A is higher than Can B,” “A tube connects the two cans,” or “Each can has two tubes entering it.”
2. Begin the demonstration by pouring a red-colored liquid from a reagent bottle labeled with a “bogus” chemical formula (e.g., $\text{CH}_2\text{H}_7\text{O}_4$) into the thistle tube. The red liquid is nothing more than tap water colored red with food coloring.
3. Pour enough liquid into the thistle tube until a blue liquid starts flowing out of Can A and into the funnel inserted into Can B. The water will keep running for approximately 20 min. If the flow stops pour more of the red liquid into the thistle tube to restart the flow.
4. Initially, blue-colored water will flow from Can A to Can B. This will eventually turn into a green color at the interface of the blue water and yellow alcohol, and finally into a yellow-colored liquid.
5. As the demonstration proceeds, ask students, in groups, to explain what they see and then to offer inferences about the original contents of the cans and how far each glass tube extends into each can.
6. Students can be invited to the front of the room to look at the cans more closely.
7. After students have speculated about the contents of the cans at the start of the demonstration, ask if there is anything they want you to do to the apparatus. As students make suggestions, discuss that what they are really doing is testing their hypotheses, just as scientists would do. Typically, students will ask you to squeeze some of the rubber tubing, lower Can A to a level beneath that of Can B or squeeze either can.
8. Have students record their conclusions, which should include the initial contents of each can, how far each glass tube extends into each can, and an explanation for both the continuous flow of water and noted color changes.
9. Students typically conclude that the red liquid created a chemical reaction in Can B, which then liberated a gas. This gas traveled to Can A and then chemically interacted with the liquid in Can A to change its color.
10. As the discussion proceeds, the teacher can emphasize how the pressure of air in the cans changes and how air pressure, or any pressure in a gas, can provide enough force to move liquids or solids if the liquids or solids are between a pressure gradient. That is, air moves from high pressure to low pressure and if there is a solid or liquid between the two pressures enough force can be created to move the liquid or solid. Ultimately, after discussion, students should understand that the flow of liquid was caused by changes in air pressure within the cans. Students usually do not arrive at the idea that the color change was unrelated to a chemical reaction.
11. In addition to teaching students about air pressure and its potential effects, this demonstration also provides the opportunity for the teacher to ask students to reflect on the nature of the scientific knowledge created (i.e., the model about the contents of the cans). This activity can help students under-

stand that scientific knowledge is tentative, that their models were a function of their own creativity and subjectivity, as well as their prior knowledge. For example, ask students how their models were a function of their own creativity and to reflect on the observations and inferences they made that were a focal point of the lesson.

17.2.6 *Mystery Bones*

This activity/experience takes 3–4 days (depending on students' grade level) and is ideal for introducing skeletal systems within a biology or life science course. The overall focus of the lesson is on structure and function, as opposed to the less useful memorization of bones and their locations. As students also learn about the skeletal system, they also learn about various aspects of NOS. Here students have the particular opportunity to learn that scientific knowledge is tentative, scientific conclusions are a result of human creativity and subjectivity, scientific knowledge is derived from observations and inferences, and that scientific investigations can take a variety of forms as opposed to a single step-wise scientific method.

Grade Level: Middle and High School

Targeted NOS Aspects: tentativeness, subjectivity, creativity, observation, inference, empirically based

Discipline: Biology

Prerequisite knowledge: minimal knowledge of skeletal systems

Instructional Scenario:

Fig. 17.14 A typical owl pellet as found (left)

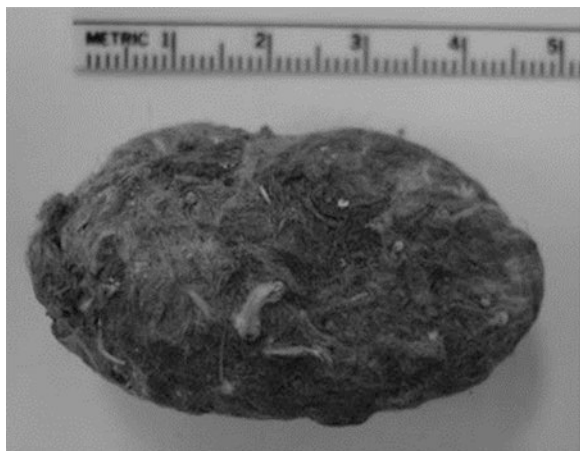


Fig. 17.15 Common bones and other materials found in a typical owl pellet (right)

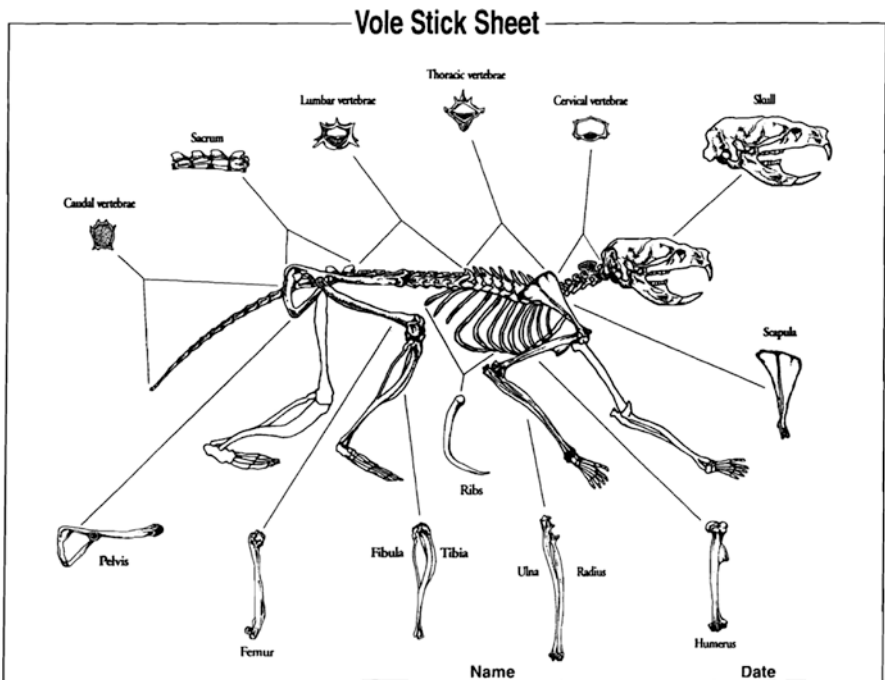


Fig. 17.16 Vole bones as an example of a typical animal found in an owl pellet

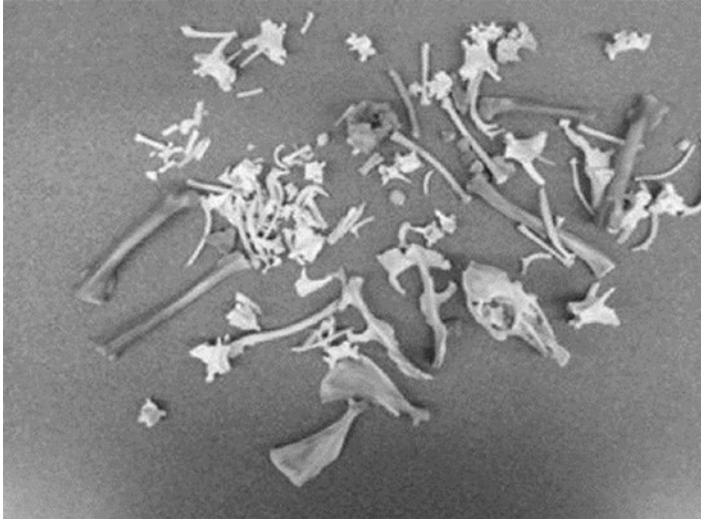


Fig. 17.17 Disarticulated skeleton (note that cat, rabbit, and mink skeletons are very similar)

1. On the first day that students begin their study of skeletal systems, give pairs of students an owl pellet (Figs. 17.14 and 17.15). Have them dissect the pellet to find the bones within the pellet. (Teacher background information: Owl pellets are indigestible food regurgitated by barn owls several times a day. Since bones are not digestible by the owls they are embedded within the pellets. These can be collected from barns or purchased from many biological or scientific supply companies).
2. After all the bones are removed from the pellets, ask students to match the bones on the vole diagram (Fig. 17.16) and tape the dissected bones in the appropriate position on the diagram.
3. Next, hold a class discussion about the structure/form of the various bones and their locations in the vole skeleton. Students are asked where the largest and thickest bones are found and where the smallest and thinnest bones are found. The goal of the discussion is to have students realize that the structure/form of the various bones is related to their function and location (e.g., supporting weight, protection, etc.).
4. Next, give students a disarticulated skeleton of an unidentified animal and, in groups of 4–5, have them assemble the skeleton. Students should use the background knowledge of skeletons that they learned from the owl pellet activity to infer the structure of this new and unidentified animal (Fig. 17.17). (Note: We have used disarticulated skeletons from rabbits, cats, and minks that have been purchased from a biological supply company or borrowed from a local university.)
5. Following this, engage students in another discussion about the structure and functions of the bones in the skeleton. The point of this discussion is to

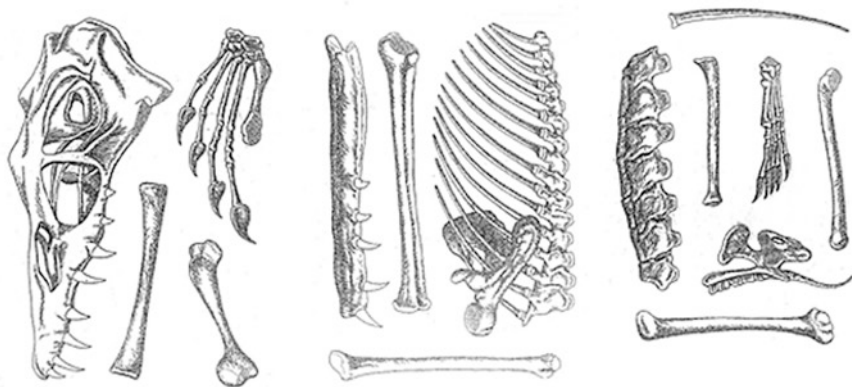


Fig. 17.18 Mystery bones

solidify the relationship between the structure and functions of bones in the skeletal system rather than to identify the animal from which the bones come. Ask students if what they have been doing is related to the work of scientists. That is, do some scientists spend their time piecing together fossilized bones? Ask students if this type of scientific investigation follows the “scientific method” as it is portrayed in their textbooks.

6. To equate the work of the students to that of scientists, give each student group an envelope containing the set of bones from an extinct animal which you have printed on laminated paper (Fig. 17.18). Have students use their knowledge of skeletal systems to construct the animal’s skeletal system, just as paleobiologists do.
7. Students should be encouraged to circulate and view the constructions of other groups out of curiosity or to help them with their own constructions. As constructions near completion, the teacher should take pictures of the various constructions with available technology for later projection in the classroom.
8. The construction of each group is projected for class discussion. Each group explains the reasons for the placement of the bones in the constructed skeleton. As this is done, the teacher questions students about the process and the various aspects of NOS that are evident in students’ construction of the skeletal (e.g., creativity, tentativeness, subjectivity, etc.).
9. The teacher should now reveal scientists’ construction of the skeleton and the inferred appearance of the animal with its skin on (Figs. 17.19 and 17.20). Students are often surprised to see the placement of the bones extending from the forearm digit of the animal because they have previously only seen the skeletons of terrestrial animals.
10. The teacher explains that the organism for which they constructed the skeleton was believed to be one of the first dinosaurs or reptiles that could glide. In the discussion, emphasize its resemblance to a reptile, which constitutes

Fig. 17.19 Reconstructed skeleton of *Scaphognathus crassirostris* (left)



Fig. 17.20 One paleontologist's imaginative reconstruction of *Scaphognathus crassirostris* (right)



the lingering debates between the relationship between dinosaurs and reptiles (Teacher background information: This creature lived in Europe during the Late Jurassic period). From its first discovery in 1831 there has always

Fig. 17.21 Another reconstructed skeleton of *Scaphognathus crassirostris* (left)

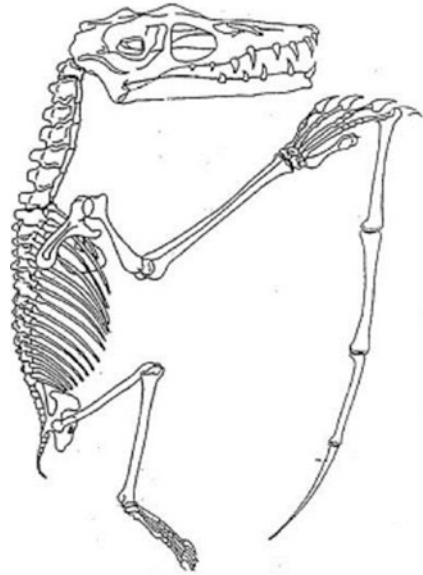


Fig. 17.22 Another paleontologist's reconstruction of *Scaphognathus crassirostris* (right)



been some confusion concerning whether this creature was an early dinosaur or extinct reptile.

11. Inform students that recently, scientists have decided that the bones supporting the wing in Fig. 17.19 should be moved to the second forearm digit to

better support the wing. Ask students how this relates to NOS. They should identify that scientific knowledge is subject to change.

12. Now, show students Figs. 17.21 and 17.22 and ask them to compare the appearance of Fig.17.19 to Fig. 17.20.
13. The students quickly notice that Fig. 17.22 is more birdlike as opposed to resembling a reptile. The teacher explains that we now currently believe that dinosaurs are related to birds, and this has led to a different interpretation of what the animal looks like with skin. If it is a high school class that has studied, or are studying, evolution, the teacher could ask students why the inferred appearance has changed. In summary, this activity fits quite nicely in a biology class during the study of skeletal systems and the form and function of bones while simultaneously integrating aspects of the nature of science.

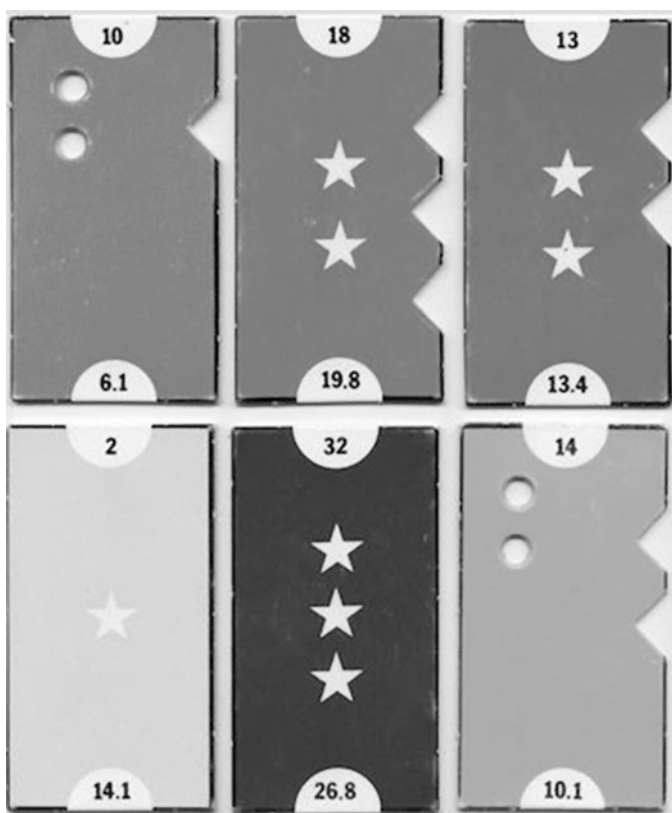


Fig. 17.23 Periodic table activity cards. (Available from American Educational Products)

17.2.7 *The Periodic Table*

The periodic table is presented in every chemistry and physical science class, and it is used repeatedly throughout the course. The table serves as an organizational scheme for the elements. Unfortunately, few students understand how the table was developed. The following activity is a concrete representation of how the periodic table was developed by Mendeleev in the 1860s.

Grade Level: Middle and High School

Targeted NOS Aspects: tentativeness, subjectivity, creativity observation, inference, empirically based

Discipline: Chemistry

Prerequisite knowledge: Minimal knowledge of elements and matter

Materials: Colored cards with figures and numbers can be purchased directly from the manufacturer *American Educational Products* (<https://www.amep.com/>) and perhaps through other online retailers.

Instructional Scenario:

1. Using the set of cards illustrated in Fig. 17.23, remove the light green card with the number 14 at the top from each set of cards. Without any introduction to the periodic table, give each student group a set of the remaining 23 cards.
2. Ask students to arrange the cards into some organizational scheme based on the properties they observe on the cards. Give them no more than 2 min for this task.
3. Have the students in their groups share results. Students' patterns might be organized by the numbers at the top and bottom, the color of the card, or the notches or shapes within the cards. Ask the students why different groups prioritized different attributes on the cards to organize them? This presents an opportunity to discuss subjectivity and creativity.
4. Next, the teacher informs the students that there is a missing card from the sets and asks the students to use their original organizational scheme or create a new one to determine what the missing card might look like. Give the students at least 20 min for this part of the activity.
5. Have a volunteer from each group draw their missing card on the board, making sure they include all the attributes that they infer are on the card. This will allow them to compare the groups' conclusions (inferences) are different. This can extend to a discussion of observation and inference in science.
6. Ask students if their organizational scheme changed when they were trying to describe the missing card. Many groups will say yes, and this is a good time to discuss that scientific knowledge is subject to change with the introduction of new data (i.e., there is a card missing). The discussion of students' organizational schemes and inferences about the missing card can also address other aspects of nature of science and scientific inquiry. For exam-

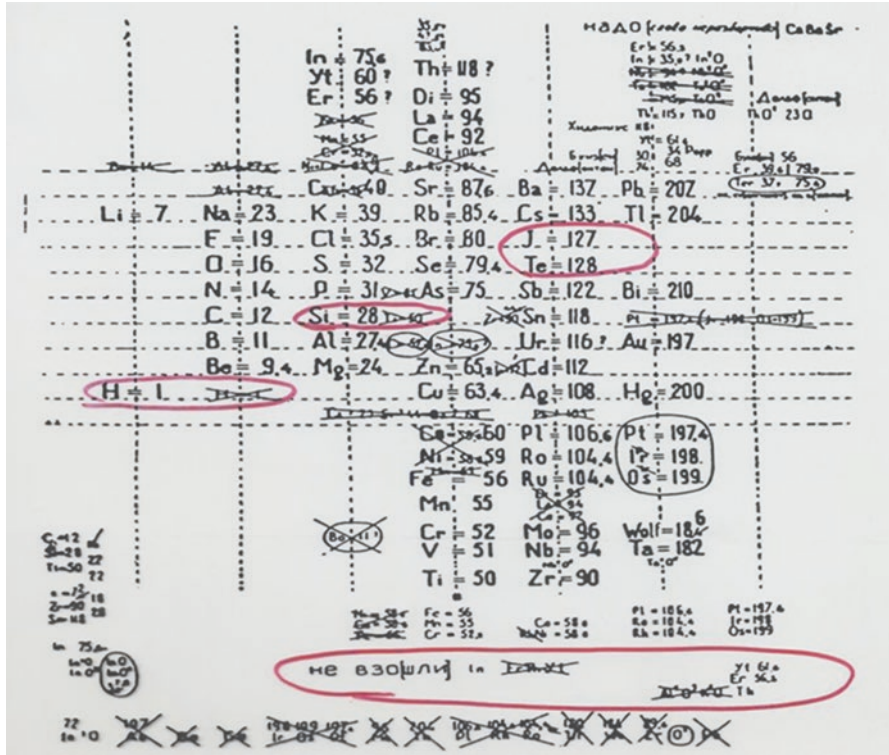


Fig. 17.24 English translation of Mendeleev’s periodic table. (Hoffmann and Torrence 1993, p. 33)

ple, in arranging the cards, students may not consider all the properties (color, a decimal number, an integer, a set of side notches, a set of holes, and a set of stars) of the cards.

Some students may ignore some of the properties. In addition, even though the same properties of the cards were considered, the classification schemes of the cards may be different from each other. Ask your students “Why did you consider different properties?” “Can scientists develop different inferences from the same data?” Explain to students that scientists’ investigations are conducted in the matrix of their background knowledge (theories). Scientists often reach different conclusions based on the same data, just as the students have done.

7. Ask students, “How can you resolve the different inferences about the missing card?” Explain to students that not all inferences in science are acceptable. Inferences should be based on and consistent with empirical data. At this point, the class can evaluate which inferences were more valid and consistent with the data.

8. At this point, the teacher can increase student interest by showing them the missing card or the teacher could choose not to show students the card if the goal is to emphasize that scientists cannot usually see the real answer in nature, but they must infer from the empirical evidence obtained through investigations.
9. It is important to let the students know that this activity mirrors what chemists such as Mendeleev did in developing the periodic table. It was not just a problem-solving activity using cards. At the time, there were numerous organizational schemes for the chemical elements proposed throughout the late nineteenth century. Mendeleev himself proposed several. In the end, the unique vision of Mendeleev was that he organized the elements based on their atomic weights.
10. Mendeleev wrote out his plan in his native language of Russian but there is an English translation (Fig. 17.24). Mention to students that the chart is rotated 90 degrees to the left of how we presently represent the table. Be sure to direct their attention to the portions of the table that are circled.
11. Ask students to look carefully at the table and see if they notice anything interesting or, to be time efficient, point out certain intriguing observations. For example, have students note that titanium (Ti), next to silicon (Si), is crossed out and hydrogen's (H) position has been moved. At the bottom of the table is a tally of elements to be placed into the table. Above the tally, in abbreviated Russian, it says "Don't Fit: In, Ee, Th, Y." Finally, the atomic weight of tellurium (Te) was thought to be greater than iodine (I), but tellurium is placed before iodine in the table. For some reason, Mendeleev felt that the estimated weights were slightly incorrect. The table also had gaps in it. Mendeleev felt that there are elements yet to be discovered, much like the missing card in the activity.
12. After noting the above observations about the table, the class should discuss the role of creativity in science and that the table was really a creation by Mendeleev, with ongoing changes being made as new elements were discovered.
13. If you have a class of preservice or inservice teachers, they might be interested to know that Mendeleev had been asked to teach a chemistry class at a local university and the periodic table was his way of organizing everything he knew about the elements. In effect, the periodic table was his instructional plan or course syllabus.

17.3 Summary

We believe that these activities illustrate how aspects of NOS can easily be integrated into existing science curriculum. It is important to note that the activities are not stand-alone activities to teach NOS. Rather, each includes a suggested science content context into which these activities can be included to facilitate students' understandings of subject matter as well as NOS. Teachers should not feel a need to create totally new instructional activities to integrate NOS into the curriculum. Most science activities can be modified to stress one or more aspects of NOS in addition to the traditional science content intended. With some careful planning the related NOS aspects will rise to the surface.

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