

Inquiry in the Earth Sciences

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Teaching Earth science in the K–12 classroom presents a challenge compared to other sciences in the curriculum. Earth science is an interdisciplinary science, encompassing ideas from physics, chemistry, and biology but applied through geology, meteorology, oceanography, and, in K–12 curricula, space science and astronomy. Earth science is not a narrow set of ideas, but a synthesis of many ideas in science.

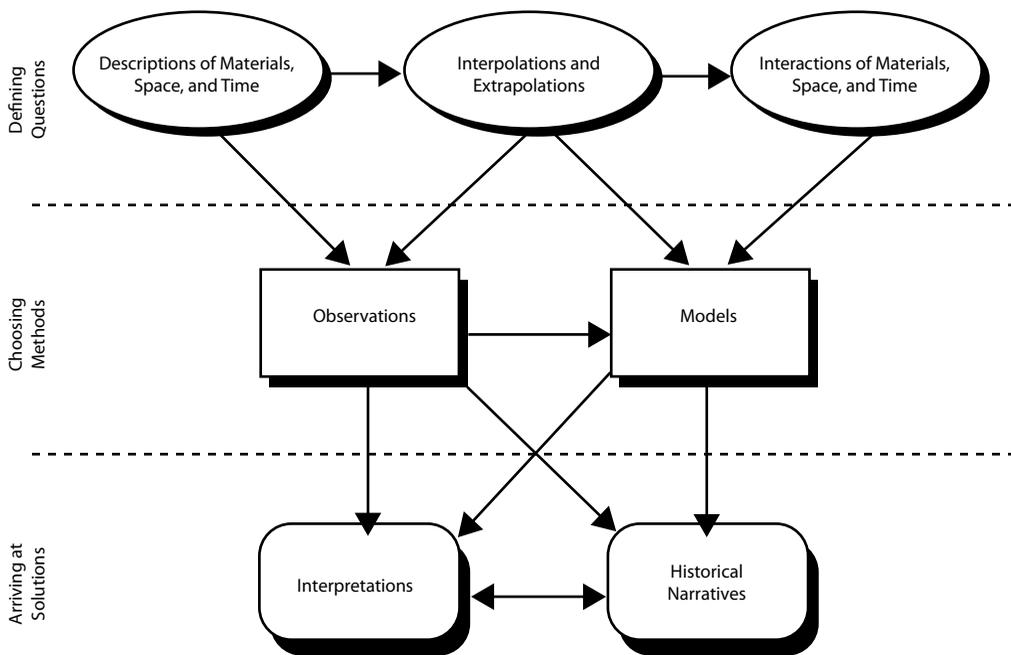
Inquiry experiences in the Earth sciences are often indirect, because direct experimentation, such as is used in the physical sciences, is typically not possible. Because of the natural variability of Earth materials, their broad but often interrupted (or missing) distribution, and the extended time spans required for Earth processes to operate, controlling all of the variables and representing real-world conditions in a laboratory are often difficult. As a result, many teachers avoid inquiry altogether in Earth science classes.

To support inquiry in the Earth sciences it is important to consider the components of inquiry. In this chapter, I describe a model that can guide investigations in the Earth science classroom and addresses these components. Throughout the chapter I use different examples but most are geologic in nature. Given the tendency to emphasize geology content in Earth science courses, these examples may be more familiar to those teaching Earth science than to teachers in other science areas.

Components of Inquiry: A Framework

Inquiries in Earth science should provide experiences with science that allow students to ask questions, collect and analyze data, and discuss their conclusions (see NRC 1996). These three broad components can be simply stated as (a) defining questions, (b) selecting methods, and (c) arriving at solutions (Monk and Dillon 1995). Even though the components are distinct areas, they are linked together by a concept, problem, or event. In terms of Earth science, the question that guides each type of inquiry can be interdisciplinary or it can reside in one specific content area in Earth science. Once the question is identified, then appropriate methods based on observation or model building can be developed. The findings from this step result in creating solutions, which offers new understanding about phenomena. Ultimately, the complexity of the inquiry depends on the topic selected and the amount of time allocated for the inquiry. An overall view of this framework is depicted in Figure 3.1.

FIGURE 3.1. A FRAMEWORK FOR THE COMPONENTS OF INQUIRY



Defining Questions That Make Sense in Earth Science

An issue that 8th-grade Earth science teacher Ms. Spurrier has always struggled with is getting her students to understand the relationship between landforms and the rock structures beneath the land surface. Her students can identify folds and faults on a test without problem, but they cannot transfer this knowledge to mountains, stream drainage patterns, or landslides. During a topographic map reading exercise, one of her students asks her why the river channels on some maps look like the branches in a leaf, while on other maps the pattern looks like steps or ladders. Ms. Spurrier decides that she can structure a student investigation around maps on which she can place known faults and ridges of resistant rock (e.g., sandstone). The question she poses to her students is this: “What do faults and rocks have to do with the course of rivers?”

Inquiries in the Earth sciences are not necessarily about making generalizable statements that go beyond a setting. They can also consist of describing an event that represents a setting and then comparing descriptions to different settings (Ault 1998). Either inquiry form is important in describing natural phenomena. The real challenge in Earth science inquiries is to frame questions in terms of (a) *materials*, such as rocks, minerals, and water, (b) *space*, or where the materials are found or how they are distributed, and (c) *time*, or how materials and their distributions have or will change and evolve. When these three areas are included in an Earth science question, there is a sense that phenomena to be explored are complex, interactive, and uncontrollable and therefore difficult to investigate in a laboratory setting that stresses control.

At the simplest level, meaningful questions in Earth science center on *descriptions*. In the classroom, these questions tend to result in the classification, comparison, or quantification of materials. Space is often added as location, such as where certain minerals can be found, while time can be a matter of suggesting a sequence that is forward or backward in time. These positions, however, are not clearly delineated and can vary with the conceptual orientations of the question.

In moving from descriptions to *interpolations* and *extrapolations*, more questions, including more complex questions, can be asked. Questions of interpolation describe materials that may have been changed or removed by Earth processes, while questions of extrapolations can describe what materials will look like in different conditions. In either orientation, there is reliance on visualizations, such as maps, charts, scales, photographs, and graphs.

Another dimension of questions pertains to *interactions*. Descriptions, interpolations, and extrapolations fall short of providing a full, causal explanation of Earth phenomena. Questions that focus on interactions come even closer to defining Earth phenomena. Yet an increase in complexity makes it harder to find enough data and time to pursue the question meaningfully in the classroom. Ultimately, such questions can serve as a driving course or unit question and be based within a “sphere”: lithosphere, hydrosphere, atmosphere, or cryosphere. Questions bounded by a sphere can ultimately allow students to engage in inquiry that permits a fuller understanding of Earth phenomena.

In the vignette at the beginning of this section, Ms. Spurrier posed an interpolation question structured around an interaction between the orientation of materials and the pattern that streams assume over a larger area. In doing this, her question addressed the important components of materials, space, and time. The inquiry lesson emerging from the student’s question was focused on a specific concept and corresponded to material students were struggling with in class. Ms. Spurrier could have easily discussed this topic during a class period, but she elected to provide a learning opportunity that placed phenomena in the middle of the lesson. This strategy allowed students to construct their knowledge about this topic. Other sample questions are posed in Table 3.1.

Selecting Methods in Earth Science— Observations and Models

Ms. Spurrier and her students cannot help but observe that the day after a heavy rainstorm her classroom is filled with an overpowering stench. Yet the stream that flows next to the building is usually barely flowing at all. The problem only became apparent after the growth of the nearby subdivision. Besides the obvious problem the smell represents, Ms. Spurrier decides that this phenomenon is one that her students can investigate.

As a part setting up the investigation, Ms. Spurrier has her students list factors they believe have caused or are related to the problem. Her students have identified such factors as the amount of rainfall, the frequency of heavy rainfalls, the size of the stream channel, and the number of houses in the subdivision. One student also asks whether the houses are attached to a public sewer line or use septic tanks.

There are obvious public health issues to which Ms. Spurrier does not wish to expose her students, so she structures the inquiry carefully. She selects a time when it hasn’t

TABLE 3.1. SAMPLE EARTH SCIENCE INQUIRY QUESTIONS

<p>Description</p>	<ul style="list-style-type: none"> • What is the maximum elevation of the Sun at noon during the school year? • What is the role of grain size in the settling rates of sediment in a column of water? • What do the minerals that are present in metamorphic rocks tell us about the temperatures and pressures at which the rock formed?
<p>Interpolations and Extrapolations</p>	<ul style="list-style-type: none"> • From the data provided, construct a graph that shows the negative relationship between grain size and rate of cooling for molten rock. • Using temperature data for the past several winters, generate a prediction for next winter. • What does a geologic map of the Moon tell us about its history?
<p>Interactions</p>	<ul style="list-style-type: none"> • How are the deposits left by glaciers and alluvial fans different? • In what ways are grain sorting and grain size related to the environment in which a rock forms? • What would a change in the trade winds do to ocean currents?

rained for several days to have students take careful measurements of the size and depth of the channel and what they see in the channel. She also assigns students to research the factors they have previously identified (see above paragraph). Using these pieces of information, the class constructs a map showing the school grounds, the stream, and the subdivision. Using rainfall data from the local television station, they construct a model that suggests that if the rainfall is over 2 cm then the room will smell awful the next day. All they need is a heavy rain to test their model.

Unlike investigations in physics or chemistry, the methods in Earth science seldom include the direct manipulation of variables, except in the context of simulating an Earth process under laboratory conditions. The same is true for historical investigations as well as for those in the classroom. For the most part, Earth science investigations and inquiries are based on observations about an Earth event, using models to test supported explanations.

Observations in Earth science are more than just verbal descriptions. Were observations limited to measurements of grain size, magnitude of brightness, intensity of the storm, or geometric relations of folds and faults, they would be largely indistinguishable from measurements of force, voltage, pH, or concentration. What separates observations in Earth science from other disciplines is the need to consider a range of scales, whether such scales are in the thickness of the rind on a weathered rock, the magnitude of a flood, or the large-scale map patterns of ocean currents. Such observations are essentially identical, whether the observations are determined by high-tech tools (such as satellite imagery and GIS map layers) or more traditional tools (such as pocket transits and hand lenses or magnifiers).

Manipulating how observations are made, however, usually requires a model of some sort with variables that can be changed. Models are dependent on the overlap or cumulative effect of different factors, as well as on the boundary conditions occurring in the model. For instance, describing an eruption of a volcano requires observations of the temperature of the lava, the amount of different chemical elements, and the amount of gas in the lava. If any of these variables changes, a different eruption will result, which frequently happens within the same volcano over time.

Models of use in explaining Earth phenomena tend to fall into one of four categories, according to Stevens and Collins (1980):

1. Simulation—Duplication in how the materials change when conditions are changed is carried out (e.g., when samples of limestone are immersed in different concentrations of HCl to duplicate how rocks containing CaCO_3 chemically weather).
2. Functional—Measurement is used to make interpolations or extrapolations (e.g., deciding how long a sedimentary layer took to accumulate based on how fast different sediments settle).
3. Cyclical—Connections between specific materials are explored (e.g., the behavior of solid Earth materials over time in the rock cycle).
4. Global/Systems—Interpretation are made based on observations of complex phenomena (e.g., the relationship of rock types to plate margins).

In an instructional sense, it is important to ensure that students know when one type of model or another is appropriate, what model components are or

can be determined in the context of the question of interest, and how various models for an Earth phenomenon can be compared and contrasted. In answering these questions, models can become more or less sophisticated, with students learning through the refinement of the model. (Chapter 1 includes an expanded discussion about models.)

In their investigation of the odor in the classroom, Ms. Spurrier guided her students in an inquiry requiring them to make or collect observations and use them in the context of a functional model. What the students sometimes find in their investigation is that without sufficient observations no single model best fits their data. In Ms. Spurrier’s class, the real cause of the problem turned out to be the subdivision’s water treatment plant, which had failed due to an increased load of influent wastewater without an increase in the processing capacity of the plant. Heavy rainfall caused the plant to overflow. Examples of other inquiry methods are listed in Table 3.2.

TABLE 3.2. SAMPLE EARTH SCIENCE INQUIRY METHODS

Observations	<ul style="list-style-type: none"> • Determining the direction of ocean currents with increasing depth, starting at the surface. • Comparing the angles between the faces of different-size crystals of the same material. • Determining the permeability of different rocks by immersion in water for different amounts of time.
Models	<ul style="list-style-type: none"> • Estimating cloud base altitude, based on temperature, dew point, and adiabatic lapse rates. • Using temperature trend charts for the past 100,000 years to make temperature projections for the next 20,000 years. • Using a stream table with different types of sediment and water flow rates to characterize streams.

Arriving at Solutions— Interpretive and Historical

Many of Ms. Spurrier’s students travel to the beach on school breaks. The most popular route to the beach is right down the nearby state highway. Being a fan of

the beach herself, Ms. Spurrier knows the route well, and she poses a descriptive question to her students: "Count the number of ridges you pass over or through with white sand in the road cut and the number of short, scrubby pine trees on them." When the students return from break, some students tell her they saw two or three such ridges; others saw four or five. She asks them how these ridges compared with the beach. At first, the students are a little confused. When they discuss the parts of the beach and the areas just behind the beach, however, the lights go on for some of the students. "Those sandy ridges were the beach once, weren't they?" asks one of her students.

Given the wide range of questions tied to Earth phenomena and the methods used to define them, the next step is to decide what answers make sense. Solutions to questions in Earth science span the range from narrow, prescribed answers based on classification to a broad set of answers capturing the complex and dynamic nature of Earth systems. Yet even with the scale of solution that can be generated, it is not enough to offer a solution from a single reference point. For example, one can define a process that describes a phenomenon, such as a river flooding, but until the mechanisms producing that process are defined (such as the size of the floodplain, stream peak discharge, and peak flow duration), the solution remains incomplete.

Interpretations are types of solutions that attempt to reconcile sets of observations, with the goal of testing models. For instance, data sets from the International Ocean Drilling Program have been used in classrooms, enabling students to generate climate and temperature models for the past, based on interpretations of microfossils, sediment thickness, and oxygen isotope ratios. These same interpretations can be used to test models of paleoclimates for different regions during the Ice Age.

Another form of solution is a historical representation, which is a narrative description of the phenomenon or object of inquiry. With detailed descriptions, it is possible to contribute to a set of ideas or a larger problem of interest, or there can be the reconciliation of different descriptions of the same phenomenon by different models. Once these narratives are integrated into a larger set of ideas, they have value as a solution to a larger path of investigation. In the classroom, for example, "expert" groups of students might separately describe the same samples of materials, with each group looking at a different aspect of the materials. Using soil samples borrowed from the local soil conservation service office, one group of students might identify the soil types, another might measure the thicknesses, and a third and fourth group could plot the sample locations on a map and research the type of bedrock

that underlies an area. When the data is pooled, their observations could be used to construct a history of local landform development.

Limits are imposed by the incongruity between geologic time and human time. Ms. Spurrier's students saw a great deal of sand when they went to the beach, but they needed interpretations to see those sandy ridges as past beach terraces. They also needed guidance to see that the ridges are a historical record of sea level changes. Additional solution examples are found in Table 3.3.

TABLE 3.3. SAMPLE EARTH SCIENCE INQUIRY SOLUTIONS

Interpretations	<ul style="list-style-type: none">• A determination of the relative movement along a fault plane from map pattern data.• Description of a paleoenvironment based on rock and fossil types.• An estimate of the past location of a continent, based, for example, on rock type, fossils, and paleomagnetic information.
Historical Representations	<ul style="list-style-type: none">• A block diagram, constructed from fossils, rock types, and layer thickness from different, but nearby, locations.• A determination of the age and timing of storm events, from grain sizes, shell fragments, ripples, etc., drawn from trenches dug in the beach.• A reconstruction of past positions of a continent based on a regional stratigraphic column.

Conclusion

It should be readily apparent that even without the same level of control over the conditions of inquiry enjoyed by other sciences, inquiries in Earth science can be structured in a manner that is reflective of the nature of the various Earth sciences. Earth scientists rarely have the opportunity to either fully describe or fully control the conditions of Earth phenomena in order to study them. As a consequence, Earth science teachers need to see where the flow of learning opportunities lie, helping students see how Earth events unfold in unique combinations of materials over space and time, leading them in

the use of pragmatic models and observations, and arriving at solutions that reflect both the testable interpretations needed for any science and the cumulative contributions of separate inquiries in a more narrowly defined physical area. Only when Earth science instruction is embedded in such a framework will the learning experiences for students advance beyond rote memorization of terminology and events and allow students to embrace the true and engaging complexity of Earth systems.