Earth System Science:
The Big Ideas

Like all scientific disciplines, the Earth sciences continually evolve over time. New discoveries fuel new ideas, providing an ever-increasing understanding of the planet. But of the overwhelming number of observations, theories, and principles that form the foundation of Earth system science, what is essential for every American to understand? All too often, curricula are too ambitious and, as a result, may fail to cover topics in any substantial depth. An alternative approach is to build one's curriculum upon a foundation of focused, interconnected ***big ideas****. A well-designed set of big ideas can provide an all-encompassing conceptual framework for any discipline, including Earth system science. Developed alongside scientists and Earth science teachers, presented here is a set of big ideas that illuminates fundamental concepts of the Earth sciences:*

❶ The Earth is a System of Systems

❷ The Flow of Energy Drives the Cycling of Matter

❸ Life influences and is influenced by the environment.

❹ Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.

❺ To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary

These ideas are designed to cover the breadth of any Earth science curriculum, but they also require dissection to build deep understanding. Each idea is essentially bottomless; that is, while a meaningful understanding of these ideas is readily attainable, the details contained within are endless. Each of the ideas can be understood, but the depth of understanding can vary greatly.

Introduction of these ideas also invites discussion of the ***nature of science****. As curricula are designed and implemented, the traditional topics of Earth system science should be complemented with ideas on how we come to know what we know about the natural world.*

Big Idea I:
The Earth is a System of Systems

The Earth is composed of many systems, which cycle and interact in both space and time. It is also part of a multitude of systems, nested in larger systems like the solar system and the universe. Systems are composed of an untold number of interacting parts that follow simple rules, but they can and do evolve. For example:

- Outlining the geologic history of any region demonstrates the concept of the Earth as a system of systems. ***Plate tectonics*** drives the formation of mountains. Subsequent weathering and erosion of the uplifted mountains leads to the formation of deltas in the adjacent shallow seas. And with uplifted continents, shorelines change and the distribution of marine communities are altered.

- The planet's systems are intimately connected: the forces of one system affect other systems nested within it. Systems that drive plate tectonics are obviously linked to the formation of mountains, as plates collide, but they are ultimately linked to and influence much smaller systems. The intense heat and pressure resulting from collisions can lead to the metamorphism of existing strata, or it can melt existing rocks to later form igneous rocks.

- As ***glaciers*** extended down from the north, they cut into river valleys in the central portion of New York. This glacial system shaped the landscape, carving the rivers into lakes and, after the glaciers' retreat, leading to the formation of deeply cut gorges. Had the glaciers never advanced so far south, the erosional forces that led to the formation of the gorges would have never been initiated.

Each of the remaining big ideas operates across multiple systems within the larger Earth system.

Plate tectonics *is a theory based on the observation that the rigid layers of the Earth are composed of multiple plates that move and interact with one another and their boundaries.*

For more information on the glacial features of New York, see the **Glaciers** *chapter in PRI's Teacher-Friendly Guide to the Geology of the Northeastern U.S.*

Big Idea II:
The Flow of Energy Drives the Cycling of Matter

The Earth is an open system. Energy flows and cycles through the system; matter cycles within it. This cycling is largely driven by the interaction of the differential distribution of solar radiation and internal heat: the constant flow of solar radiation powers much of Earth's ocean and atmospheric processes on the surface of the system, while the flow of heat from radioactivity within the Earth drives plate tectonics. For example:

see Rocks, p. 29, for a diagram of the **rock cycle**.

- One of the fundamental processes known to Earth system scientists is the ***rock cycle***. The rock cycle illustrates steps involved in the formation of one type of rock from another. It is a system that has operated since the Earth's origin, and it continues today. The energy that drives weathering and erosion, melting, or an increase in heat or pressure drives the continuation of the rock cycle.

For more information on the **Grenville Mountains** *see the Geologic History chapter in PRI's Teacher-Friendly Guide to the Geology of the Northeastern U.S.*

- The landscape of the Northeast that we see today has been shaped by the geologic forces of the past. Evidence littered throughout the terrain tells a story that began some one billion years ago with the formation of the ***Grenville Mountains***, which resulted from the collision of proto-North America and another continent. The movement of Earth's plates is driven by plate tectonics, illustrating one example of how the flow of energy drives the cycling of matter–the flow of heat from radioactivity within the Earth drives plate tectonics.

- During the most recent ice age, glaciers advanced and retreated many times during the past two million years. One of the great questions in the Earth sciences revolves around the causes of these glacial cycles, with the general consensus pointing toward cyclic variations in the planet's tilt, movement about its axis, and its orbital shape around the sun. These variations lead to changes in the amount of solar radiation that reaches the Earth, which in turn affect global climate.

Convection *is the rising of less dense material and the sinking of more dense material. Variations in density are commonly caused by temperature or compositional variations.*

- The rock cycle, plate tectonics, and the water cycle are all ***convection*** driven. Without convection, Earth would be extraordinarily different.

Big Idea III:

Life—including human life—influences and is influenced by the environment.

Across its four billion year history, the course of life's evolution has been intimately tied to the Earth's physical environment. Global cooling led to the relatively recent spread of grasslands, which then triggered an evolutionary shift in many herbivorous mammals from browsing to grazing. Conversely, the evolution of life alters the physical environment. Photosynthetic bacteria released free oxygen into the early oceans and atmosphere, making Earth habitable for later types of organisms. Humans, with an interesting population and expanding technology, have altered the landscape, altered the distribution of flora and fauna, and are changing atmospheric chemistry in ways that alter the climate. Earth system processes also affect where and how humans live. For example:

- During the Precambrian, the evolution of photosynthetic organisms led to significant change in the planet's atmosphere. Prior to this event, there was little free oxygen in the atmosphere, but with photosynthesis producing oxygen as a waste product, the very existence of these organisms flooded the seas and atmosphere with free oxygen, changing the planet forever. But life's evolution represents just one of the processes working upon the Earth system.
- With human populations increasing the world over, the emission of greenhouse gases has also increased dramatically. These gases alter the chemical composition of the atmosphere and directly influence the planet's climate. It is generally agreed that the rapid and immense pouring of carbon dioxide into the atmosphere will lead to global warming, which will have incredible impacts throughout the world.
- Around three million years ago, a land bridge formed between North and South America. For the first time in more than 150 million years, the two continents were linked, and the mammals inhabiting both lands migrated across the bridge. Horses, mastodons, cats, and dogs moved south, while opossums, porcupines, ground sloths, and armadillos moved north (to name a few). Today, half the mammal species in South America are descended from North American migrants.

For more infomartion on humans' effect on the environment, visit PRI's Global Change Project online at: **www.priweb.org/globalchange.html**

Big Idea IV :

Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.

Earth processes operating today, everything from local erosion to plate tectonics, are the same as those operating since they arose in Earth history, and these processes are obedient to the laws of chemistry and physics. While the processes that constantly change the planet are essentially fixed, their rates are not. Tipping points are reached that can result in rapid changes cascading through Earth systems. For example:

- Extending from southern Maine up through New Hampshire, the White Mountain Series initially formed deep within the crust as plumes of magma rose from the mantle. As the plate moved over a hot spot, magma pushed upward through the crust to form the string of igneous bodies. It is thought that the Hawaiian Islands may have formed (and are still forming!) in a similar manner.
- Today, the ice sheets of Greenland and Antarctica make up some 95% of all the current glacial ice on Earth. The study of these modern glaciers and their influences on the environment, such as the formation of U-shaped valleys, is key to interpreting glacial deposits of the past, which are thought to have formed under the same processes as those operating today.

Big Idea V :

To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary

The use of models is fundamental to all of the Earth sciences. Maps and models: 1) aid in the understanding of aspects of the Earth system that are too big or small for direct observation, or where observation is not possible; and 2) help make complex systems comprehensible through strategic simplification. When compared to the size and age of the universe, humanity is a speck in space and a blip in time; models assist in the comprehension of time and space at both sub-microscopic and immense scales. For example:

- Much of scientists' understanding of the inner workings of our planet is derived from mathematical modeling. It is not possible to measure directly the movement below Earth's surface, but modeling of ***convection*** currents brings us closer to the true nature of these immense geologic phenomena.

- The observation of natural phenomena today, such as deposition along a stream, is critical for interpreting the geologic record. But for processes that operate on much larger, slower scales, modeling within the lab is required. Understanding the formation of mountain ranges, such as the Acadian and Appalachians, are better understood by examining the effects of stress and strain in the laboratory.

- What is the effect of a two-kilometer thick glacier on the terrain? In addition to changes related to deposition, the shear weight of such an object depresses the continental mass. Understanding this compression—and the rebound that occurs upon the glaciers' retreat—is improved through modeling in the laboratory.

Convection *is the rising of less dense material and the sinking of more dense material. Variations in density are commonly caused by temperature or compositional variations.*

Glaciers *are build-up of snow, firn, and ice—partially or wholly on land—which move down-hill under their own weight.*

In conclusion...

Taken individually, these* big ideas *represent important aspects of Earth system science, but together they are more significant. Keeping these ideas in mind—and considering how these ideas arose through scientific methods and investigation—as one proceeds throughout his or her curriculum can provide a conceptual framework upon which to build an enduring understanding of the discipline.