# Learning to Read the EARTH and *Sky*

## Explorations Supporting the *NGSS*

GRADES 6–12

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*Bringing the universe into the classroom on a scale that students can investigate and discover*

*Inspiring teachers to reach beyond prepared curricula and explore science with their students*

# INTRODUCTION

In 1997, a group of college students, a pickax, and I (Russ) were scrambling along a rural gravel road in western North Dakota. The brisk wind cut through our thin jackets as the Sun fell behind a bank of clouds on the horizon. After six weeks of lectures in Geology in the National Parks, students at last had a chance to discover geology for themselves. They gathered around the young woman with the pickax, eyes drifting from the soft yellows and browns in the nearby buttes to the deepening hole in the grey rock. About a foot below the surface, the pickax began to dredge up crisp, black imprints of willow leaves. Eyes widened and interest quickened. "How could it be wet enough for willow trees to live here on the dry plains?" "How did they get into the rock?" "How long ago was it?" Suddenly, science became something to figure out, not just something to know.[C1]

And that's exactly what science should be, something to figure out, not just something to know. Telling stories to children does not teach them how to read a book, and telling facts, laws, or principles does not teach students to read the stories written in the earth and sky. *Learning to Read the Earth and Sky* explores the *doing* of earth science—how we read the stories written in the earth by applying the practices of science.

Appropriately, the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) emphasize science as a practice, not as a body of knowledge. Science is not about what we know, or think we know, so much as it is about how we know it. It is the person who *knows how we know* that participates in science. Only that person can reasonably discuss whether our understanding of the world is true or false. Anyone else must either accept or reject an idea based on their faith in the person who told them.

Along with science as practice, the *NGSS* emphasize the Earth as a complex, interacting system. In the natural world, everything is connected. John Muir recognized this interacting connectivity when he said "When we try to pick out anything by itself, we find it hitched to everything else in the Universe" (Muir 1911, p. 110).

So, the *NGSS* encourage both doing science in the classroom—the science and engineering practices—and learning the complex interplay of systems over the whole Earth and space beyond—the disciplinary core ideas (DCIs). The problem is that *you can't bring an all-encompassing supersystem into the classroom even if middle or high school students were able to understand it.* In fact, trying to capture the whole sweep of everything at once is contrary to the historical practice of scientific research—scientists break complex problems into bite-size, solvable chunks. In discussing the solution to a complex, interconnected problem in his book *A Brief History of Time,* Stephen Hawking (1996) notes that "it might be impossible to get close to a full solution by investigating parts of the problem in isolation. Nevertheless, it is certainly the way that we have made progress in the past" (p. 12). *Learning to Read the Earth and Sky* offers ways to break the immensity into small chunks that we can bring into the classroom.

Teachers might be concerned that the all-encompassing DCIs of the *NGSS* cut the link to more familiar big ideas of earth science. For example, the *NGSS* do not specifically identify classic ideas such as telling stories from rocks and strata (the wellspring of nearly everything we know about Earth's past), the movement of cyclones and fronts (the traditional foundation for understanding weather), or the processes that shape planetary surfaces (one of the primary new discoveries of the last half century). Instead, the *NGSS* DCIs emphasize interactions and cycles within Earth and space systems. Thus, for example, one of the components of the *NGSS* DCIs becomes this ESS2.A grade band endpoint for grade 8:

> *The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future. (NRC 2012, p. 181)*

Another component becomes this ESS2.C grade band endpoint for grade 8:

> *Water continually cycles among land, oceans, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. (NRC 2012, p. 185)*

Does this mean that the traditional big ideas are no longer a part of the standards put forth for teaching earth science? No, of course not. They are all in there (along with, no doubt, the kitchen sink). The *NGSS* DCIs are less a limitation on what factual information all students should learn than they are a philosophical proposal that whatever students learn about earth and space processes, they should learn within the context of how that component fits into a bigger picture of a system of interacting subsystems.



 

> *Why is it that, in spite of the fact that teaching by pouring in, learning by a passive absorption, are universally condemned, that they are still so intrenched in practice? That education is not an affair of "telling" and being told, but an active and constructive process, is a principle almost as generally violated in practice as conceded in theory. Is not this deplorable situation due to the fact that the doctrine is itself merely told?*
>
> —John Dewey, *Democracy and Education*, 1916

In this first section of *Learning to Read the Earth and Sky*, we offer examples of the practices of science from our own experience, illustrations of the practices of science from history, and encouragement to pursue the practices of science in your own classroom.The *NGSS* science and engineering practices are as follows:

- Asking Questions and Defining Problems
- Developing and Using Models
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Using Mathematics and Computational Thinking
- Constructing Explanations and Designing Solutions
- Engaging in Argument From Evidence
- Obtaining, Evaluating, and Communicating Information

These science and engineering practices are not "steps" in the pursuit of scientific understanding; rather they are overlapping and nested concepts that collectively make up the scientific enterprise. For example, Asking Questions and Defining Problems and Analyzing and Interpreting Data nest within Planning and Carrying Out Investigations; Analyzing and Interpreting Data merges seamlessly with Constructing Explanations and Designing Solutions; and using Mathematics and Computational Thinking is a subset of Analyzing and Interpreting Data as well as Developing and Using Models. All of the previously listed practices underpin Engaging in Argument From Evidence, which shares some of its space with Obtaining, Evaluating, and Communicating Information.

We have chosen a few aspects of these comprehensive practices to examine in this section of the book:

- Chapters 1–3 address experimental and field observations, which include aspects of Asking Questions and Defining Problems, Planning and Carrying Out Investigations, Constructing Explanations and Designing Solutions, and Engaging in Argument From Evidence.
- Chapters 4 and 5 address the interpretation of data through graphs, maps, and cross-sections, which includes aspects of Developing and Using Models; Analyzing and Interpreting Data; Using Mathematics and Computational Thinking; Engaging in Argument From Evidence; and Obtaining, Evaluating, and Communicating Information.
- Chapters 6 and 7 address the creation and use of conceptual and mathematical models, which include aspects of Developing and Using Models, Using Mathematics and Computational Thinking, and Constructing Explanations and Designing Solutions.
- Chapters 8 and 9 address identification of evidence and arguing from evidence, which include aspects of Developing and Using Models; Analyzing and Interpreting Data; Constructing Explanations and Designing Solutions; Engaging in Argument From Evidence; and Obtaining, Evaluating, and Communicating Information.

# PART II

> *Rather than misrepresenting science as a dry catechism of certainties, we should emphasize the excitement of the quest for answers to our questions. The joy is in the chase, for, as Robert Louis Stevenson said, "It is better to travel hopefully than to arrive."*
>
> —Robert H. Dott, Jr., "What Is Unique About Geological Reasoning?" *GSA Today*, October 1998

The important ideas in earth science focus less on what we know than on how we know it. For example, the principle of superposition is less a universal law for how a planet's rock and sediment cycle and change than it is a starting place and methodology for how to read the story written in that rock and sediment. The concepts of geochemical differentiation are less a conclusion of a study than they are a place to begin one. In some sense, how we read the story of the earth and sky is a more fundamental and important idea in earth science than any of the individual stories that we have read, perhaps giving us a response to the following challenge posed by Robert Dott, Jr., in "What Is Unique About Geological Reasoning?"

> *[M]any authors have argued that (geology) has unique modes of reasoning and unique laws of its own. … Each generation of geologists has worried about what, if anything other than the geo-, is unique about our science. Deep time, the fossil record, uniformitarianism, the method of multiple working hypotheses, and historical science are among the special claims. We need to look further for differences, for geology certainly is much more than simply applied physics and chemistry.*

In this section, we consider five key ways that we can read the earth. We read the earth in the rocks (Chapter 10), in the layers of rock (Chapter 11), with seismic waves (Chapter 12), with light (Chapter 13), and in the atoms (Chapter 14). These approaches to inquiry are different from the other sciences, and yet coincide with the key idea of all science—and with the *Next Generation Science Standards*—that science is the process of figuring things out, not the conclusions that are figured out in the end.

# PART III

> *Not having learned it is not as good as having learned it; having learned it is not as good as having seen it carried out; having seen it is not as good as understanding it; understanding is not as good as doing it. The development of scholarship is to the extreme of doing it, and that is its end and goal. He who carries it out, knows it thoroughly.*
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> —Xunzi (312–230 BC), translated by Homer Dubs in *The Works of Hsüntze*, 1928

The *Next Generation Science Standards* propose that earth science be taught as a practice rather than a body of factual knowledge. That practice is not a fixed set of steps but rather a fluid and dynamic activity that will be somewhat different in each new situation and application. The practice of science in the classroom involves student initiative in asking questions and creating investigations to answer those questions. It connects results of those creative investigations to broad ideas that exceed the limits of the classroom.

This type of learning experience—fluid, flexible, and creative—cannot be captured by a curriculum, regardless of how good the curriculum might be or how well aligned to the standards. Success of this type of learning experience depends on the participation of the teacher. The teacher is needed to connect the spontaneous questions and creative investigations that arise in the classroom to the bigger ideas of science. The teacher is also needed to prompt and guide creative investigations so that students learn from an expert mentor how to focus and pursue their questions. To do this, the teacher needs to depart from set activities whose primary purpose is to reinforce factual learning, and truly explore with students.

This final section of *Learning to Read the Earth and Sky* examines the importance of the teacher in (1) narrating the link between spontaneous and creative explorations of the classroom and the core ideas of the discipline, (2) initiating creative explorations from where you are in place and understanding, and (3) mentoring student explorations as a fellow scholar and practitioner of science.

# AFTERWORD

## SOME THINGS WE'VE LEFT OUT

In *Learning to Read the Earth and Sky,* we emphasize the *doing* of science. We have given less attention to other important aspects of the teacher's job, such as how to link classroom-size investigation to big issues like cost/benefit of extracting natural resources and the human effects on our environment, how to adapt specific activities to different ages or abilities, and how the teacher can engage students in doing science and still give them sufficient factual knowledge to do well on required standardized tests.

Earth science has a long tradition of practical application, such as to problems in natural resource extraction, engineering of landscapes and rivers, and mitigation of human impacts on environment and climate. However, large-scale applied problems might not be the best starting point for classroom investigation, and so they received less attention in this book. Questions that are "too big" tend to generate hypotheses that are not easily testable in the classroom and lead to sociopolitical discussions, which—although an important educational endeavor—do not engage students in doing many of the basic aspects of science. Even when simplified, an investigative foray into the big picture quickly becomes complex enough to require many weeks of class time—as seen in the resources extraction exercise in the "Creating and Using Algorithms" section in Chapter 7 (pp. 130–134).

Nevertheless, students need to put the concepts and practices they learn from doing science into the context of real-world, practical problems to understand the significance of their learning. We hope that teachers, as mentoring scholars, can help students connect the small-scale investigations of this book to the bigger-picture ideas. We have provided some example applications to practical problems in engineering, the environment, and cycles of matter and energy in the earth. For example, when considering flow volume and flow viscosity in Chapter 7, we applied the reasoning challenges to real problems in river management—a story of how humans can have an impact on natural processes. In Chapter 14, we considered how to take big-picture ideas of pollutant migration or ore formation and break them down into classroom-size investigations. In Chapter 15, we considered a variety of ways to connect classroom experience to big ideas.

Likewise, we provide example activities appropriate for a variety of age and ability levels but don't offer multiple versions of each activity tailored to different ages. In keeping