Argument-Driven Inquiry in EARTH AND SPACE SCIENCE

LAB INVESTIGATIONS for GRADES 6–10

Victor Sampson, Ashley Murphy,
Kemper Lipscomb, and Todd L. Hutner

NSTA press
National Science Teachers Association

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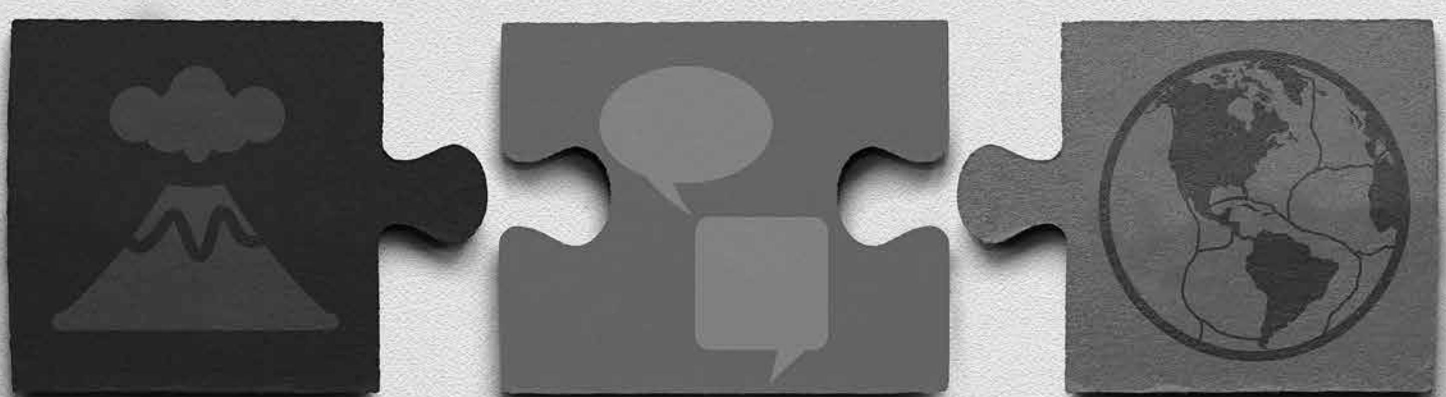

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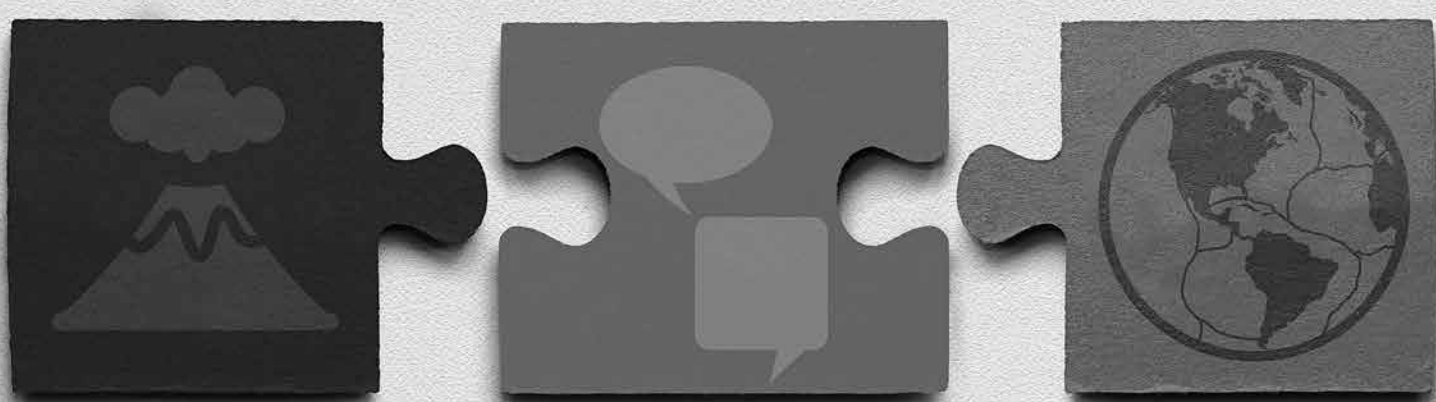

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CONTENTS

SECTION 3

History of Earth

INTRODUCTION LABS

APPLICATION LAB

SECTION 4

Earth's Systems

INTRODUCTION LABS

APPLICATION LABS

SECTION 5

Weather and Climate

INTRODUCTION LABS

APPLICATION LAB

SECTION 6

Human Impact

INTRODUCTION LABS

APPLICATION LABS

SECTION 7

Appendixes

PREFACE

A Framework for K–12 Science Education (NRC 2012; henceforth referred to as the *Framework*) and the *Next Generation Science Standards* (NGSS Lead States 2013; henceforth referred to as the *NGSS*) call for a different way of thinking about why we teach science and what we expect students to know by the time they graduate high school. As to why we teach science, these documents emphasize that schools need to

> ensure by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC 2012, p. 1)

The *Framework* and the *NGSS* are based on the idea that students need to learn science because it helps them understand how the natural world works, because citizens are required to use scientific ideas to inform both individual choices and collective choices as members of a modern democratic society, and because economic opportunity is increasingly tied to the ability to use scientific ideas, processes, and habits of mind. From this perspective, it is important to learn science because it enables people to figure things out or to solve problems.

These two documents also call for a reappraisal of what students need to know and be able to do by time they graduate from high school. Instead of teaching with the goal of helping students remember facts, concepts, and terms, science teachers are now charged with the goal of helping their students become *proficient* in science. To be considered proficient in science, the *Framework* suggests that students need to understand 12 disciplinary core ideas (DCIs) in the Earth and space sciences, be able to use seven crosscutting concepts (CCs) that span the various disciplines of science, and learn how to participate in eight fundamental scientific and engineering practices (SEPs; called science and engineering practices in the *NGSS*).

The DCIs are key organizing principles that have broad explanatory power within a discipline. Scientists use these ideas to explain the natural world. The CCs are ideas that are used across disciplines. These concepts provide a framework or a lens that people can use to explore natural phenomena; thus, these concepts often influence what people focus on or pay attention to when they attempt to understand how something works or why something happens. The SEPs are the different activities that scientists engage in as they attempt to generate new concepts, models, theories, or laws that are both valid and reliable. All three of these dimensions of science are important. Students need to not only know about the DCIs, CCs, and SEPs but also must be able to use all three dimensions at the same time to figure things out or to solve problems. These important DCIs, CCs, and SEPs are summarized in Figure 1.

FIGURE 1

The three dimensions of science in *A Framework for K–12 Science Education* and the *Next Generation Science Standards*

Science and engineering practices	Crosscutting concepts
1. Asking Questions and Defining Problems 2. Developing and Using Models 3. Planning and Carrying Out Investigations 4. Analyzing and Interpreting Data 5. Using Mathematics and Computational Thinking 6. Constructing Explanations and Designing Solutions 7. Engaging in Argument From Evidence 8. Obtaining, Evaluating, and Communicating Information	1. Patterns 2. Cause and Effect: Mechanism and Explanation 3. Scale, Proportion, and Quantity 4. Systems and System Models 5. Energy and Matter: Flows, Cycles, and Conservation 6. Structure and Function 7. Stability and Change
Disciplinary core ideas in the Earth and space sciences	
• ESS1.A: The Universe and Its Stars • ESS1.B: Earth and the Solar System • ESS1.C: The History of Planet Earth • ESS2.A: Earth Materials and Systems • ESS2.B: Plate Tectonics and Large-Scale System Interactions • ESS2.C: The Roles of Water in Earth's Surface Processes • ESS2.D: Weather and Climate • ESS2.E: Biogeology • ESS3.A: Natural Resources • ESS3.B: Natural Hazards • ESS3.C: Human Impacts on Earth Systems • ESS3.D: Global Climate Change	

Source: Adapted from NRC 2012 and NGSS Lead States 2013

To help students become proficient in science in ways described by the National Research Council in the *Framework,* teachers will need to use new instructional approaches that give students an opportunity to use the three dimensions of science to explain natural phenomena or develop novel solutions to problems. This is important because traditional instructional approaches, which were designed to help students "learn about" the concepts, theories, and laws of science rather than learn how to "figure out" how or why things work, were not created to foster the development of science proficiency inside the classroom. To help teachers make this instructional shift, this book provides 23 laboratory investigations designed using an innovative approach to lab instruction called argument-driven inquiry (ADI). This approach promotes and supports three-dimensional instruction inside classrooms because it gives students an opportunity to use DCIs, CCs, and SEPs to construct and critique claims about how things work or why things happen. The lab activities described in this book will also enable students to develop the disciplinary-based literacy skills outlined in the *Common Core State Standards* for English language arts (NGAC and CCSSO 2010) because ADI gives students an opportunity to give presentations to their peers, respond to audience questions and critiques, and then write, evaluate, and revise reports as part of each lab. Use of these labs, as a result, can help teachers align their teaching with current recommendations for improving classroom instruction in science and for making earth and space science more meaningful for students.

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INTRODUCTION

The Importance of Helping Students Become Proficient in Science

The current aim of science education in the United States is for *all* students to become proficient in science by the time they finish high school. *Science proficiency*, as defined by Duschl, Schweingruber, and Shouse (2007), consists of four interrelated aspects. First, it requires an individual to know important scientific explanations about the natural world, to be able to use these explanations to solve problems, and to be able to understand new explanations when they are introduced to the individual. Second, it requires an individual to be able to generate and evaluate scientific explanations and scientific arguments. Third, it requires an individual to understand the nature of scientific knowledge and how scientific knowledge develops over time. Finally, and perhaps most important, an individual who is proficient in science should be able to participate in scientific practices (such as planning and carrying out investigations, analyzing and interpreting data, and arguing from evidence) and communicate in a manner that is consistent with the norms of the scientific community. These four aspects of science proficiency include the knowledge and skills that all people need to have to be able to pursue a degree in science, prepare for a science-related career, and participate in a democracy as an informed citizen.

This view of science proficiency serves as the foundation for the *Framework* (NRC 2012) and the *NGSS* (NGSS Lead States 2013). Unfortunately, our educational system was not designed to help students become proficient in science. As noted in the *Framework*,

> K–12 science education in the United States fails to [promote the development of science proficiency], in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done. (p. 1)

Our current science education system, in other words, was not designed to give students an opportunity to learn how to use scientific explanations to solve problems, generate or evaluate scientific explanations and arguments, or participate in the practices of science. Our current system was designed to help students learn facts, vocabulary, and basic process skills because many people think that students need a strong foundation in the basics to be successful later in school or in a future career. This vision of science education defines rigor as covering more topics and learning as the simple acquisition of new ideas or skills.

Our views about what counts as rigor, therefore, must change to promote and support the development of science proficiency. Instead of using the number of different topics covered in a course as a way to measure rigor in our schools, we must start to measure rigor in terms of the number of opportunities students have to use the ideas of science as a way to make sense of the world around them. Students, in other words, should be expected to learn how to use the core ideas of science as conceptual tools to plan and carry out investigations, develop and evaluate explanations, and question how we know what we know. A rigorous course, as result, would be one where students are expected to do science, not just learn about science.

Our views about what learning is and how it happens must also change to promote and support the development of science proficiency. Rather then viewing learning as a simple process where people accumulate more information over time, learning needs to viewed as a personal and social process that involves "people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims" (Driver et al. 1994, p. 8). Learning, from this perspective, requires a person to be exposed to the language, the concepts, and the practices of science that makes science different from other ways of knowing. This process requires input and guidance about "what counts" from people who are familiar with the goals of science, the norms of science, and the ways things are done in science. Thus, learning is dependent on supportive and informative interactions with others.

Over time, people will begin to appropriate and use the language, the concepts, and the practices of science as their own when they see how valuable they are as a way to accomplish their own goals. Learning therefore involves seeing new ideas and ways of doing things, trying out these new ideas and practices, and then adopting them when they are useful. This entire process, however, can only happen if teachers provide students with multiple opportunities to use scientific ideas to solve problems, to generate or evaluate scientific explanations and arguments, and to participate in the practices of science inside the classroom. This is important because students must have a supportive and educative environment to try out new ideas and practices, make mistakes, and refine what they know and what they do before they are able to adopt the language, the concepts, and the practices of science as their own.

A New Approach to Teaching Science

We need to use different instructional approaches to create a supportive and educative environment that will enable students to learn the knowledge and skills they need to become proficient in science. These new instructional approaches will need to give students an opportunity to learn how to "figure out" how things work or why things happen. Rather than simply encouraging students to learn about the facts, concepts, theories, and laws of science, we need to give them more opportunities to develop explanations for natural phenomena and design solutions to problems. This emphasis on "figuring things out" instead of "learning about things" represents a big change in the way we will need to teach science at all grade levels. To figure out how things work or why things happen in a way that is consistent with how science is actually done, students must do more than hands-on activities. Students must learn how to use disciplinary core ideas (DCIs), crosscutting concepts (CCs), and science and engineering practices (SEPs) to develop explanations and solve problems (NGSS Lead States 2013; NRC 2012).

A DCI is a scientific idea that is central to understanding a variety of natural phenomena. An example of a DCI in Earth and Space Sciences is that the solar system consists of the Sun and a collection of objects that are held in orbit around the Sun by its gravitational pull on them. This DCI not only explains the motion of planets around the Sun but can also explain tides, eclipses of the Sun and the Moon, and the motion of the planets in the sky relative to the stars.

CCs are those concepts that are important across the disciplines of science; there are similarities and differences in the treatment of the CCs in each discipline. The CCs can be used as a lens to help people think about what to focus on or pay attention to during an investigation. For example, one of the CCs from the *Framework* is Energy and Matter: Flows, Cycles, and Conservation. This CC is important in many different fields of study, including astronomy, geology, and meteorology. This CC is equally important in physics and biology. Physicists use this CC to study mechanics, thermodynamics, electricity, and magnetism. Biologists use this CC to study cells, growth and development, and ecosystems. It is important to highlight the centrality of this idea, and other CCs, for students as we teach the subject-specific DCIs.

SEPs describe what scientists do to investigate the natural world. The practices outlined in the *Framework* and the *NGSS* explain and extend what is meant by *inquiry* in science and the wide range of activities that scientists engage in as they attempt to generate and validate new ideas. Students engage in practices to build, deepen, and apply their knowledge of DCIs and CCs. The SEPs include familiar aspects of inquiry, such as Asking Questions and Defining Problems, Planning and Carrying Out Investigations, and Analyzing and Interpreting Data. More important, however, the SEPs include other activities that are at the core of doing science: Developing and Using Models, Constructing Explanations and Designing Solutions, Engaging in Argument From Evidence, and Obtaining, Evaluating, and Communicating Information. All of these SEPs are important to learn, because there is no single scientific method that all scientists must follow; scientists engage in different practices, at different times, and in different orders depending on what they are studying and what they are trying to accomplish at that point in time.

This focus on students using DCIs, CCs, and SEPs during a lesson is called *three-dimensional instruction* because students have an opportunity to use all three dimensions of science to understand how something works, to explain why something happens, or to develop a novel solution to a problem. When teachers use three-dimensional instruction inside their classrooms, they encourage students to develop or use conceptual models, design investigations, develop explanations, share and critique ideas, and argue from evidence, all of which allow students to develop the knowledge and skills they need to be proficient in science (NRC 2012). Current research suggests that all students benefit from three-dimensional instruction because it gives all students more voice and choice during a lesson and it makes the learning process inside the classroom more active and inclusive (NRC 2012).

We think the school science laboratory is the perfect place to integrate three-dimensional instruction into the science curriculum. Well-designed lab activities can provide opportunities for students to participate in an extended investigation where they can not only use one or more DCIs to understand how something works, to explain why something happens, or to develop a novel solution to a problem but also use several different CCs and SEPs during the same lesson. A teacher, for example, can give his or her students an opportunity to develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and the seasons. The teacher can then encourage them to use what they know about Earth and the Solar System (a DCI) and their understanding of Patterns and of Scale, Proportion, and Quantity (two different CCs) to plan and carry out an investigation to figure out how Earth, the Sun, and the Moon move relative to each other. During this investigation they must ask questions, analyze and interpret data, use mathematics, develop a model, argue from evidence, and obtain, evaluate, and communicate information (six different SEPs). Using multiple DCIs, CCs, and SEPs at the same time is important because it creates a classroom experience that parallels how science is done. This, in turn, gives all students who participate in a school science lab activity an opportunity to deepen their understanding of what it means to do science and to develop science-related identities. In the following section, we will describe how to promote and support the development of science proficiency during school science labs through three-dimensional instruction.

How School Science Labs Can Help Foster the Development of Science Proficiency Through Three-Dimensional Instruction

As defined by the NRC (2005, p. 3), "[l]aboratory experiences provide opportunities for students to interact directly with the material world … using the tools, data collection techniques, models, and theories of science." School science laboratory experiences tend to follow a similar format in most U.S. science classrooms (Hofstein and Lunetta 2004; NRC 2005). This format begins with the teacher introducing students to an important concept or principle through direct instruction, usually by giving a lecture about it or by assigning a chapter from a textbook to read. This portion of instruction often takes several class periods. Next, the students will complete a hands-on lab activity. The purpose of the hands-on activity is help students understand a concept or principle that was introduced to the students earlier. To ensure that students "get the right result" during the lab and that the lab actually illustrates, confirms, or verifies the target concept or principle, the teacher usually provides students with a step-by-step procedure to follow and a data table to fill out. Students are then asked to answer a set of analysis questions to ensure that everyone "reaches the right conclusion" based on the data they collected during the lab. The lab experience ends with the teacher going over what the students should have done during the lab, what they should have observed, and what answers they should have given in response to the analysis questions; this review step is done to ensure that the students "learned what they were supposed to have learned" from the hands-on activity and is usually done, once again, through whole-class direct instruction.

Classroom-based research, however, suggests that this type of approach to lab instruction does little to help students learn key concepts. The National Research Council (2005, p. 5), for example, conducted a synthesis of several different studies that examined what students learn from lab instruction and found that "research focused on the goal of student mastery of subject matter indicates that typical laboratory experiences are no more or less effective than other forms of science instruction (such as reading, lectures, or discussion)." This finding is troubling because, as noted earlier, the main goal of this type of lab experience is to help students understand an important concept or principle by giving them a hands-on and concrete experience with it. In addition, this type of lab experience does little to help students learn how to plan and carry out investigations or analyze and interpret data because students have no voice or choice during the activity. Students are expected to simply follow a set of directions rather than having to think about what data they will collect, how they will collect it, and what they will need to do to analyze it once they have it. These types of activities also can lead to misunderstanding about the nature of scientific knowledge and how this knowledge is developed over time due to the emphasis on following procedure and getting the right results. These "cookbook" labs, as a result, do not reflect how science is done at all.

Over the past decade, many teachers have changed their labs to be inquiry-based in order to address the many shortcomings of more traditional cookbook lab activities. Inquiry-based lab experiences that are consistent with the definition of *inquiry* found in the *National Science Education Standards* (NRC 1996) and *Inquiry and the National Science Education Standards* (NRC 2000) share five key features:

1. Students need to answer a scientifically oriented question.
2. Students must collect data or use data collected by someone else.
3. Students formulate an answer to the question based on their analysis of the data.
4. Students connect their answer to some theory, model, or law.
5. Students communicate their answer to the question to someone else.

Teachers tend to use inquiry-based labs as a way to introduce students to new concepts and to give them an opportunity to learn how to collect and analyze data in science (NRC 2012).

Although inquiry-based approaches give students much more voice and choice during a lab, especially when compared with more traditional cookbook approaches, they do not do as much as they could do to promote the development of science proficiency. Teachers tend to use inquiry-based labs as a way to help students learn about a new idea rather than as a way to help students learn how to figure out how things work or why they happen. Students, as a result, rarely have an opportunity to learn how to use DCIs, CCs, and SEPs to develop explanations or solve problems. In addition, inquiry-based approaches rarely give students an opportunity to participate in the full range of scientific practices. Inquiry-based labs tend to be designed so students have many opportunities to learn how to ask questions, plan and carry out investigations, and analyze and interpret data but few opportunities to learn how to participate in the practices that focus on how new ideas are developed, shared, refined, and eventually validated within the scientific community. These important practices include developing and using models, constructing explanations, arguing from evidence, and obtaining, evaluating, and communicating information (Duschl, Schweingruber, and Shouse 2007; NRC 2005). Inquiry-based labs also do not give students an opportunity to improve their science-specific literacy skills. Students, as a result, are rarely expected to read, write, and speak in scientific manner because the focus of these labs is learning about content and how to collect and analyze data in science, not how to propose, critique, and revise ideas.

Changing the focus and nature of inquiry-based labs so they are more consistent with three-dimensional instruction can help address these issues. To implement such a change, teachers will not only have to focus on using DCIs, CCs, and SEPs during a lab but will also need to emphasize "how we know" in the different Earth and space science disciplines (i.e., how new knowledge is generated and validated) equally with "what we know" about plate tectonics, climate, stars, and energy (i.e., the theories, laws, and unifying concepts). We have found that this shift in focus is best accomplished by making the practice of arguing from evidence or scientific argumentation the central feature of all lab activities. We define *scientific argumentation* as the process of proposing, supporting, evaluating, and refining claims based on evidence (Sampson, Grooms, and Walker 2011). The *Framework* (NRC 2012) provides a good description of the role argumentation plays in science:

> Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design. (p. 46)

When teachers make the practice of arguing from evidence the central focus of lab activities students have more opportunities to learn how to construct and support scientific knowledge claims through argument (NRC 2012). Students also have more opportunities to learn how to evaluate the claims and arguments made by others. Students, as a result, learn how to read, write, and speak in a scientific manner because they need to be able to propose and support their claims when they share them and evaluate, challenge, and refine the claims made by others.

We developed the argument-driven inquiry (ADI) instructional model (Sampson and Gleim 2009; Sampson, Grooms, and Walker 2009, 2011) as a way to change the focus and nature of labs so they are consistent with three-dimensional instruction. ADI gives students an opportunity to learn how to use DCIs, CCs, and SEPs to figure out how things work or why things happen. This instructional approach also places scientific argumentation as the central feature of all lab activities. ADI lab investigations, as a result, make lab activities more authentic and educative for students and thus help teachers promote and support the development of science proficiency. This instructional model reflects current theories about how people learn science (NRC 1999, 2005, 2008, 2012) and is also based on what is known about how to engage students in argumentation and other important scientific practices (Erduran and Jimenez-Aleixandre 2008; McNeill and Krajcik 2008; Osborne, Erduran, and Simon 2004; Sampson and Clark 2008; Sampson, Enderle, and Grooms, 2013). We will explain the stages of ADI and how each stage works in Chapter 1.

Organization of This Book

This book is divided into seven sections. Section 1 includes two chapters: the first chapter describes the ADI instructional model, and the second chapter describes the development of the ADI lab investigations and provides an overview of what is included with each investigation. Sections 2–6 contain the 23 lab investigations. Each investigation includes three components:

- Teacher Notes, which provides information about the purpose of the lab and what teachers need to do to guide students through it.
- Lab Handout, which can be photocopied and given to students at the beginning of the lab. It provides the students with a phenomenon to investigate, a guiding question to answer, and an overview of the DCIs and CCs that students can use during the investigation.
- Checkout Questions, which can be photocopied and given to students at the conclusion of the lab activity. The Checkout Questions consist of items that target students' understanding of the DCIs and CCs and the concepts of the nature of scientific knowledge (NOSK) and the nature of scientific inquiry (NOSI) addressed during the lab.

Section 7 consists of five appendixes:

- Appendix 1 contains several standards alignment matrixes that can be used to assist with curriculum or lesson planning.
- Appendix 2 provides an overview of the CCs and the NOSK and NOSI concepts that are a focus of the lab investigations. This information about the CCs and the NOSK and NOSI are included as a reference for teachers.
- Appendix 3 provides several options (in tabular format) for implementing an ADI investigation over multiple 50-minute class periods.
- Appendix 4 provides options for investigation proposals, which students can use as graphic organizers to plan an investigation. The proposals can be photocopied and given to students during the lab.
- Appendix 5 provides two versions of a peer-review guide and teacher scoring rubric (one for middle school and one for high school), which can also be photocopied and given to students.

Safety Practices in the Science Laboratory

It is important for all of us to do what we can to make school science laboratory experiences safer for everyone in the classroom. We recommend four important guidelines to follow. First, we need to have proper safety equipment such as, but not limited to, fume hoods, fire extinguishers, eye wash, and showers in the classroom or laboratory. Second, we need to ensure that students use appropriate personal protective equipment (PPE; e.g., sanitized indirectly vented chemical-splash goggles, chemical-resistant aprons, and nonlatex gloves) during all components of lab activities (i.e., setup, hands-on investigation, and takedown). At a minimum, the PPE we provide for students to use must meet the ANSI/ISEA Z87.1D3 standard. Third, we must review and comply with all safety policies and procedures, including but not limited to appropriate chemical management, that have been established by our place of employment. Finally, and perhaps most important, we all need to adopt safety standards and better professional safety practices and enforce them inside the classroom or laboratory.

We provide safety precautions for each investigation and recommend that all teachers follow these safety precautions to provide a safer learning experience inside the classroom. The safety precautions associated with each lab investigation are based, in part, on the use of the recommended materials and instructions, legal safety standards, and better professional safety practices. Selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

We also recommend that you encourage students to read the National Science Teacher Association's document *Safety in the Science Classroom, Laboratory, or Field Sites* before allowing them to work in the laboratory for the first time. This document is available online at *www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf.* Your students and their parent(s) or guardian(s) should then sign the document to acknowledge that they understand the safety procedures that must be followed during a school science laboratory experience.

Remember that a lab includes three parts: (1) setup, which includes setting up the lab and preparing the materials; (2) conducting the actual investigation; and (3) the cleanup, also called the takedown. The safety procedures and PPE we recommend for each investigation apply to all three parts.

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Teacher Notes

Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

Purpose

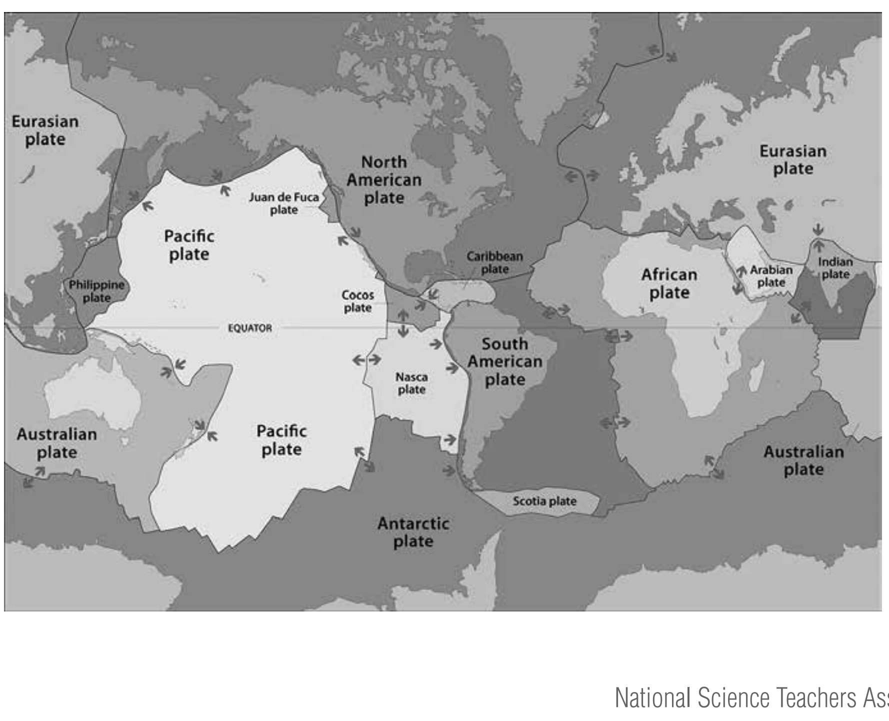
The purpose of this lab is for students to *apply* what they know about the disciplinary core ideas (DCIs) of (a) The History of Planet Earth and (b) Plate Tectonics and Large-Scale System Interactions by having them develop a conceptual model that explains how the Hawaiian archipelago formed over the last 100 million years. In addition, students have an opportunity to learn about the crosscutting concepts (CCs) of (a) Patterns and (b) Systems and System Models. During the explicit and reflective discussion, students will also learn about (a) the use of models as tools for reasoning about natural phenomena and (b) the assumptions made by scientists about order and consistency in nature.

Important Earth and Space Science Content

Scientists use the theory of plate tectonics to explain the origin of many geologic features on Earth. The theory of plate tectonics indicates that the lithosphere is broken into several plates that are constantly moving (see Figure 7.1). The plates are composed of the

FIGURE 7.1

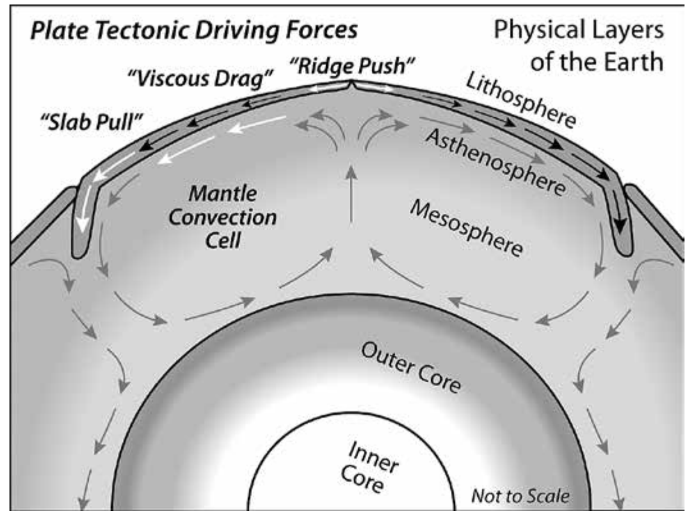
The major tectonic plates



oceanic lithosphere and thicker continental lithosphere. The plates move because they are located on top of giant convection cells in the mantle (see Figure 7.2). These currents bring matter from the hot inner mantle near the outer core up to the cooler surface. The convection cells are driven by the energy that is released when isotopes go through radioactive decay deep within the interior of the Earth. Each of the plates is slowly pushed across Earth's surface in a specific direction by these currents. The plates carry the continents, create or destroy ocean basins, form mountain ranges and plateaus, and produce earthquakes or volcanoes as they move.

FIGURE 7.2

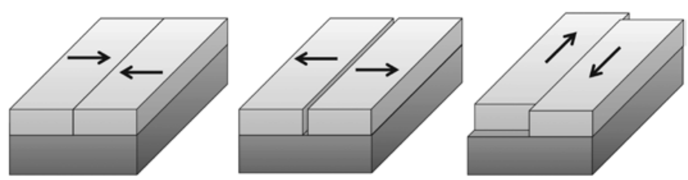
Mechanisms that drive the movement of plates



Most of the continental and ocean floor features that we see are the result of either constructive or destructive geologic processes that occur along different types of plate boundaries. There are three main categories of plate boundaries (see Figure 7.3): *convergent boundaries* result when two plates collide with each other, *divergent boundaries* result when two plates move away from each other, and *transform boundaries* occur when plates slide past each other. The nature of the geologic features that we see at a particular location depends on whether the plates are being pushed together to create mountains or ocean trenches, being pulled apart to form new ocean floor at mid-oceanic ridges and rift valleys on continents, or sliding past each other along surface faults.

FIGURE 7.3

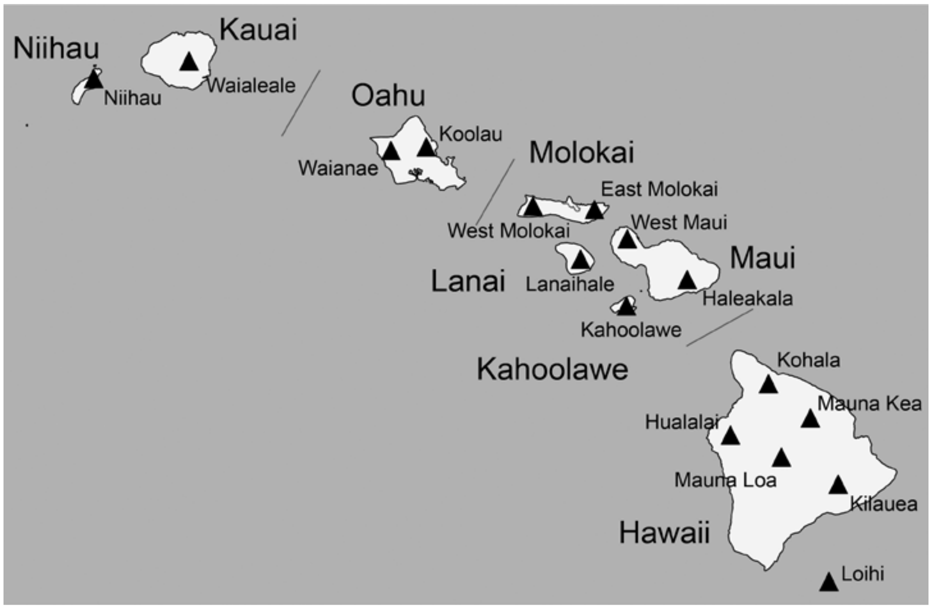
Tectonic plate boundaries



Earth's surface is still being shaped and reshaped because of the movement of plates. One example of this phenomenon is the Hawaiian Islands, an archipelago in the northern part of the Pacific Ocean that consists of eight major islands, several atolls, and numerous smaller islets. It extends from the island of Hawaii over 2,400 km to the Kure Atoll. Each island is made up of one or more volcanoes (see Figure 7.4, p. 170). The island of Hawaii, for instance, is made up of five different volcanoes. Kohala, the oldest volcano on this island, last erupted about 60,000 years ago. It is an extinct volcano because it will never erupt again. Mauna Kea is the next oldest volcano. It is a dormant volcano because the last time it erupted was 3,600 years ago, but it will probably erupt again at some time in the future. The three youngest volcanoes on Hawaii—Hualalai, Mauna Loa, and Kilauea—are active (see *www.nps.gov/havo/faqs.htm* for more information).

FIGURE 7.4

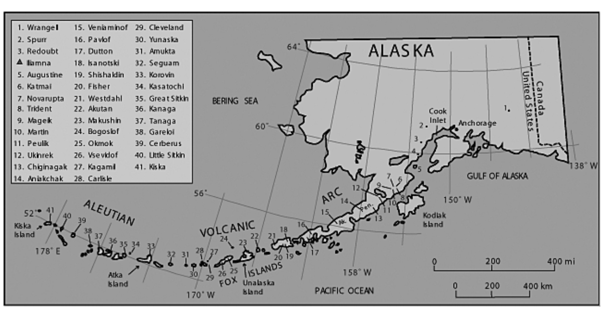
The Hawaiian archipelago and some of its volcanoes (indicated by triangles)



At first glance, these islands look similar to a volcanic island arc, which is a chain of volcanoes that forms above a subducting plate and takes the form of an arc of islands. An example of a volcanic island arc is the Aleutian Islands (see Figure 7.5). The Hawaiian Islands, however, are not located near a plate boundary, so they are not an example of a volcanic island arc. The Hawaiian Islands are a hotspot volcanic chain. A hotspot volcanic chain is created when volcanoes form one after another in the middle of a tectonic plate, as the plate moves over the hotspot, and so the volcanoes increase in age from one end of the chain to the other. In the case of the Hawaiian Islands, the older islands such as Kauai are located in the northwest. These islands are over 4.5 million years old and lush. The big island of Hawaii, in contrast is, about 400,000 years old and much rockier. Volcanic island arcs do not generally exhibit such a simple age pattern like the ones observed with hotspot volcanic chains.

FIGURE 7.5

The Aleutian Islands, an example of a volcanic island arc



Timeline

The instructional time needed to complete this lab investigation is 220–280 minutes. Appendix 3 (p. 573) provides options for implementing this lab investigation over several class periods. Option A (280 minutes) should be used if students are unfamiliar with scientific writing, because this option provides extra instructional time for scaffolding the writing process. You can scaffold the writing process by modeling, providing examples, and providing hints as students write each section of the report. Option B (220 minutes) should be used if students are familiar with scientific writing and have developed the skills needed to write an investigation report on their own. In option B, students complete stage 6 (writing the investigation report) and stage 8 (revising the investigation report) as homework.

Materials and Preparation

The materials needed to implement this investigation are listed in Table 7.1. The *Natural Hazards Viewer* interactive map, which was developed by the National Oceanic and Atmospheric Administration's National Geophysical Data Center, is available at *http://maps.ngdc.noaa.gov/viewers/hazards*. It is free to use and can be accessed using most internet browsers. You should access the website and learn how the interactive map works before beginning the lab investigation. In addition, it is important to check if students can access and use the interactive map from a school computer or tablet, because some schools have set up firewalls and other restrictions on web browsing.

The Ages of Volcanoes in Hawaiian Islands Excel file can be downloaded from the book's Extras page at *www.nsta.org/adi-ess.* It can be loaded onto student computers before the investigation, e-mailed to students, or uploaded to a class website that students can access. It is important that the computers the students will use during this lab have a spreadsheet application such as Microsoft Excel or Apple Numbers loaded on them, or students must have access to an online spreadsheet application such as Google Sheets. In this way, students can analyze the data set using the computational and graphing tools built into the spreadsheet application. It is also important for you to look over the file before the investigation begins so you can learn how the data in the file are organized. This will enable you to give students suggestions on how to analyze the data.

TABLE 7.1

Materials list for Lab 7

Item	Quantity
Computer or tablet with Excel or other spreadsheet application and internet access	1 per group
Ages of Volcanoes in Hawaiian Island Excel file	1 per group
Investigation Proposal A	1 per group
Whiteboard, 2' × 3'*	1 per group
Lab Handout	1 per student
Peer-review guide and instructor scoring rubric	1 per student
Checkout Questions	1 per student

* As an alternative, students can use computer and presentation software such as Microsoft PowerPoint or Apple Keynote to create their arguments.

Safety Precautions

Remind students to follow all normal lab safety rules.

Topics for the Explicit and Reflective Discussion

Reflecting on the Use of Core Ideas and Crosscutting Concepts During the Investigation

Teachers should begin the explicit and reflective discussion by asking students to discuss what they know about the DCIs they used during the investigation. The following are some important concepts related to the DCIs of (a) The History of Planet Earth and (b) Plate Tectonics and Large-Scale System Interactions that students need to be able to develop a conceptual model that explains the formation of the Hawaiian archipelago:

- The lithosphere is broken into several plates that are constantly moving.
- Plate boundaries are found where one plate interacts with another plate.
- Convergent boundaries result when two plates collide with each other.
- Divergent boundaries result when two plates move apart.
- Transform boundaries are formed when two plates slide past each other.

To help students reflect on what they know about these concepts, we recommend showing them two or three images using presentation software that help illustrate these important ideas. You can then ask the students the following questions in order to encourage students to share how they are thinking about these important concepts:

1. What do we see going on in this image?
2. Does anyone have anything else to add?
3. What might be going on that we can't see?
4. What are some things that we are not sure about here?

You can then encourage students to think about how CCs played a role in their investigation. There are at least two CCs that students need to be able to develop a conceptual model that explains the formation of the Hawaiian archipelago: (a) Patterns and (b) Systems and System Models (see Appendix 2 [p. 569] for a brief description of these two CCs). To help students reflect on what they know about these CCs, we recommend asking them the following questions:

1. Why do scientists look for and attempt to explain patterns in nature?
2. What patterns did you identify and use during your investigation? Why was that useful?

3. Why do scientists often define a system and then develop a model of it as part of an investigation?
4. How did you use a model to understand the formation of the Hawaiian Islands? Why was that useful?

You can then encourage students to think about how they used all these different concepts to help answer the guiding question and why it is important to use these ideas to help justify their evidence for their final arguments. Be sure to remind your students to explain why they included the evidence in their arguments and make the assumptions underlying their analysis and interpretation of the data explicit in order to provide an adequate justification of their evidence.

Reflecting on Ways to Design Better Investigations

It is important for students to reflect on the strengths and weaknesses of the investigation they designed during the explicit and reflective discussion. Students should therefore be encouraged to discuss ways to eliminate potential flaws, measurement errors, or sources of uncertainty in their investigations. To help students be more reflective about the design of their investigation and what they can do to make their investigations more rigorous in the future, you can ask the following questions:

1. What were some of the strengths of the way you planned and carried out your investigation? In other words, what made it scientific?
2. What were some of the weaknesses of the way you planned and carried out your investigation? In other words, what made it less scientific?
3. What rules can we make, as a class, to ensure that our next investigation is more scientific?

Reflecting on the Nature of Scientific Knowledge and Scientific Inquiry

This investigation can be used to illustrate two important concepts related to the nature of scientific knowledge and the nature of scientific inquiry: (a) the use of models as tools for reasoning about natural phenomena and (b) the assumptions made by scientists about order and consistency in nature (see Appendix 2 [p. 569] for a brief description of these two concepts). Be sure to review these concepts during and at the end of the explicit and reflective discussion. To help students think about these concepts in relation to what they did during the lab, you can ask the following questions:

1. I asked you to develop a model to explain the formation of the Hawaiian Islands as part of your investigation. Why is it useful to develop models in science?

2. Can you work with your group to come up with a rule that you can use to decide what a model is and what a model is not in science? Be ready to share in a few minutes.
3. Scientists assume that natural laws operate today as they did in the past and that they will continue to do so in the future. Why do you think this assumption is important?
4. Think about what you were trying to do during this investigation. What would you have had to do differently if you could not assume natural laws operate today as they did in the past?

You can also use presentation software or other techniques to encourage your students to think about these concepts. You can show examples and non-examples of scientific models and then ask students to classify each one and explain their thinking. You can also show images of different scientific laws (such as the law of universal gravitation, the law of conservation of mass, or the law of superposition) and ask students if they think these laws have been the same throughout Earth's history. Then ask them to think about what scientists would need to do to be able to study the past if laws are not consistent through time and space.

Remind your students that, to be proficient in science, it is important that they understand what counts as scientific knowledge and how that knowledge develops over time.

Hints for Implementing the Lab

- Learn how to use the *Natural Hazards Viewer* interactive map and the Ages of Volcanoes in Hawaiian Islands Excel file before the lab begins. It is important for you to know how to use the map and what is included in the Excel file, as well as how to analyze the data, so you can help students when they get stuck or confused.
- A group of three students per computer or tablet tends to work well.
- Allow the students to play with the interactive map and the Excel file as part of the tool talk before they begin to design their investigation. This gives students a chance to see what they can and cannot do with the interactive map and with the data in the file.
- Encourage students to analyze the data in the Age of Volcanoes in Hawaiian Islands Excel file by making graphs. The best way to help students to learn how to use Excel (or another spreadsheet application) is to provide "just-in-time" instruction. In other words, wait for students to get stuck and then give a brief mini-lesson on how to use a specific tool in Excel based on what students are trying to do. They will be much more interested in learning about how to use the

tools in Excel if they know it will help solve a problem they are having or will allow them to accomplish one of their goals.

- Students often make mistakes when developing their conceptual models and/or initial arguments, but they should quickly realize these mistakes during the argumentation session. Be sure to allow students to revise their models and arguments at the end of the argumentation session. The explicit and reflective discussion will also give students an opportunity to reflect on and identify ways to improve how they develop and test models. This also offers an opportunity to discuss what scientists do when they realize a mistake is made.
- Students will likely first infer the existence of a plate boundary that has led to the formation of the Hawaiian Islands. Yet, when they use the *Natural Hazards Viewer* interactive map to locate plate boundaries, they will see that there is no plate boundary near Hawaii. This is a good opportunity to help students think about alternate explanations given that they know no boundary exists and that volcanoes are places where magma comes to the surface. This is also a good opportunity to help students think about ways scientists refine models. The model of plate tectonics as originally conceived could not account for the formation of the Hawaiian archipelago. Thus, scientists used new data to refine their model.
- This lab also provides an excellent opportunity to discuss how scientists must make choices about which data to use and how to analyze the data they have. Be sure to use this activity as a concrete example during the explicit and reflective discussion.

Connections to Standards

Table 7.2 highlights how the investigation can be used to address specific (a) performance expectations from the *NGSS* and (b) *Common Core State Standards* in English language arts (*CCSS ELA*).

TABLE 7.2

Lab 7 alignment with standards

***NGSS* performance expectations**	History of Earth • MS-ESS2-2: Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. • MS-ESS2-3: Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions • HS-ESS1-5: Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Reading in Science and Technical Subjects**	Key ideas and details • CCSS.ELA-LITERACY.RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts. • CCSS.ELA-LITERACY.RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. • CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. • CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. • CCSS.ELA-LITERACY.RST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. Craft and structure • CCSS.ELA-LITERACY.RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grade 6–8 texts and topics.* • CCSS.ELA-LITERACY.RST.6-8.5: Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic. • CCSS.ELA-LITERACY.RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. • CCSS.ELA-LITERACY.RST.9-10.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grade 9–10 texts and topics*. • CCSS.ELA-LITERACY.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*). • CCSS.ELA-LITERACY.RST.9-10.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address. Integration of knowledge and ideas • CCSS.ELA-LITERACY.RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Reading in Science and Technical Subjects** (*continued*)	Integration of knowledge and ideas (*continued*) • CCSS.ELA-LITERACY.RST.6-8.8: Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. • CCSS.ELA-LITERACY.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. • CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. • CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. • CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
***CCSS ELA*—Writing in Science and Technical Subjects**	Text types and purposes • CCSS.ELA-LITERACY.WHST.6-10.1: Write arguments focused on *discipline-specific content*. • CCSS.ELA-LITERACY.WHST.6-10.2: Write informative or explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. Production and distribution of writing • CCSS.ELA-LITERACY.WHST.6-10.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. • CCSS.ELA-LITERACY.WHST.6-8.5: With some guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed. • CCSS.ELA-LITERACY.WHST.6-8.6: Use technology, including the internet, to produce and publish writing and present the relationships between information and ideas clearly and efficiently. • CCSS.ELA-LITERACY.WHST.9-10.5: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Writing in Science and Technical Subjects** (*continued*)	Production and distribution of writing (*continued*) • CCSS.ELA-LITERACY.WHST.9-10.6: Use technology, including the internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically. Range of writing • CCSS.ELA-LITERACY.WHST.6-10.10: Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.
***CCSS ELA*—Speaking and Listening**	Comprehension and collaboration • CCSS.ELA-LITERACY.SL.6-8.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6–8 topics, texts, and issues, building on others' ideas and expressing their own clearly. • CCSS.ELA-LITERACY.SL.6-8.2:* Interpret information presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how it contributes to a topic, text, or issue under study. • CCSS.ELA-LITERACY.SL.6-8.3:* Delineate a speaker's argument and specific claims, distinguishing claims that are supported by reasons and evidence from claims that are not. • CCSS.ELA-LITERACY.SL.9-10.1: Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively. • CCSS.ELA-LITERACY.SL.9-10.2: Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. • CCSS.ELA-LITERACY.SL.9-10.3: Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric, identifying any fallacious reasoning or exaggerated or distorted evidence. Presentation of knowledge and ideas • CCSS.ELA-LITERACY.SL.6-8.4:* Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation. • CCSS.ELA-LITERACY.SL.6-8.5:* Include multimedia components (e.g., graphics, images, music, sound) and visual displays in presentations to clarify information.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Speaking and Listening** (*continued*)	Presentation of knowledge and ideas (*continued*) • CCSS.ELA-LITERACY.SL.6-8.6: Adapt speech to a variety of contexts and tasks, demonstrating command of formal English when indicated or appropriate. • CCSS.ELA-LITERACY.SL.9-10.4: Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. • CCSS.ELA-LITERACY.SL.9-10.5: Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. • CCSS.ELA-LITERACY.SL.9-10.6: Adapt speech to a variety of contexts and tasks, demonstrating command of formal English when indicated or appropriate.

* Only the standard for grade 6 is provided because the standards for grades 7 and 8 are similar. Please see *www.corestandards.org/ELA-Literacy/SL* for the exact wording of the standards for grades 7 and 8.

Lab Handout

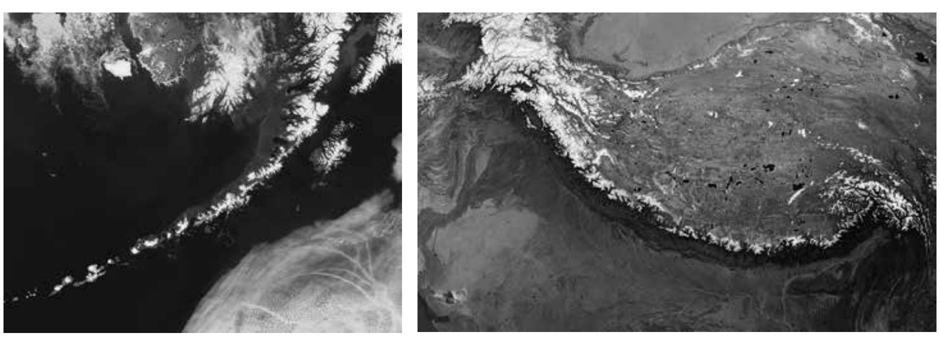
Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

Introduction

Scientists use the theory of plate tectonics to explain current and past movements of the rocks at Earth's surface and the origin of many geologic features such as those shown in Figure L7.1. The theory of plate tectonics indicates that the lithosphere is broken into several plates that are in constant motion. Multiple lines of evidence support this theory. This evidence includes, but is not limited to, the location of earthquakes, chains of volcanoes (see Figure L7.1A), and non-volcanic mountain ranges (see Figure L7.1b) around the globe; how land under massive loads (such as lakes or ice sheets) can bend and even flow; the existence of mid-oceanic ridges; and the age of rocks near these ridges.

FIGURE L7.1

(a) The Aleutian archipelago, a chain of volcanic islands in Alaska; (b) the Himalayas, a nonvolcanic mountain range in Asia separating the plains of the Indian subcontinent from the Tibetan plateau



The plates are composed of oceanic and continental lithosphere. The plates move because they are located on top of giant convection cells in the mantle (see Figure L7.2). These currents bring matter from the hot inner mantle near the outer core up to the cooler surface and return cooler matter back to the inner mantle. The convection cells are driven by the energy that is released when isotopes deep within the interior of the Earth go through radioactive decay. The movement of matter in the mantle produces forces, which include viscous drag, slab pull, and ridge push, that together slowly move each of the plates across Earth's surface in a specific direction. The plates carry the continents, create or destroy ocean basins, form mountain ranges and plateaus, and produce earthquakes or volcanoes as they move.

Many interesting Earth surface features, such as the ones shown in Figure L7.1, are the result of either constructive or destructive geologic processes that occur along plate boundaries. There are three main types of plate boundaries (see Figure L7.3): *convergent boundaries* result when two plates collide with each other, *divergent boundaries* result when two plates move away from each other, and *transform boundaries* occur when plates slide past each other. We can explain many of the geologic features we see on Earth's surface when we understand how plates move and interact with each other over time.

Earth's surface is still being shaped and reshaped because of the movement of plates. One example of this phenomenon is the Hawaiian Islands. The Hawaiian Islands is an archipelago in the northern part of the Pacific Ocean that consists of eight major islands, several atolls, and numerous smaller islets. It extends from the island of Hawaii over 2,400 kilometers to the Kure Atoll. Each island is made up of one or more volcanoes (see Figure L7.4). The island of Hawaii, for instance, is made up of five different volcanoes. Two of the volcanoes found on the island of Hawaii are called Mauna Loa and Kilauea. Mauna Loa is the largest active volcano on Earth, and Kilauea is one of the most productive volcanoes in terms of how much lava erupts from it each year.

The number of islands in the Hawaiian archipelago has slowly increased over the last 100 million years. In this investigation, you will attempt to explain why these islands

FIGURE L7.2

Convection cells in the mantle

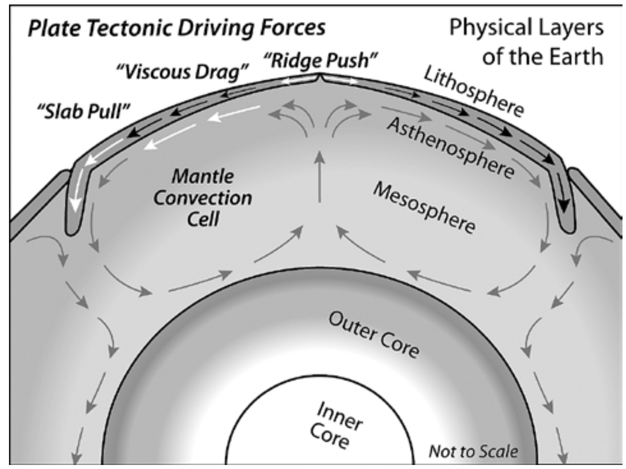


FIGURE L7.3

The three types of plate boundaries

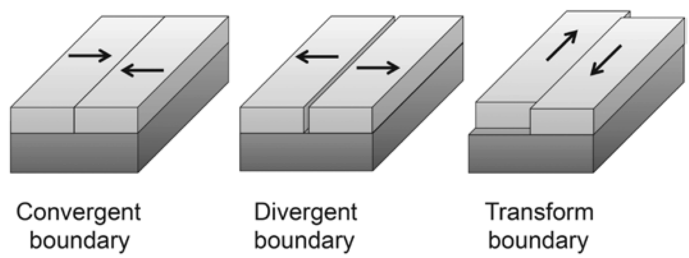
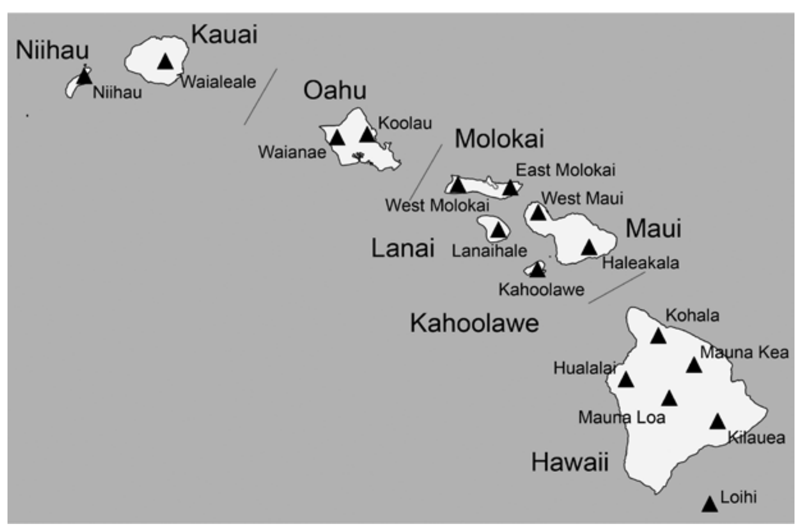


FIGURE L7.4

The Hawaiian archipelago and some of its volcanoes



are in the middle of the Pacific Ocean, why they form a chain instead of some other shape, why some of the islands are bigger than other ones, and why the number of islands in the archipelago has slowly increased over time.

Your Task

Develop a conceptual model that you can use to explain how the Hawaiian archipelago formed over the last 100 million years. Your conceptual model must be based on what we know about patterns, systems and system models, and the movement of Earth's plates over time. You should be able to use your conceptual model to predict when and where you will see a new island appear in the Hawaiian archipelago.

The guiding question of this investigation is, ***How can we explain the growth of the Hawaiian archipelago over the past 100 million years?***

Materials

You will use a computer with Excel or other spreadsheet application during your investigation. You will also use the following resources:

- *Natural Hazards Viewer* online interactive map, available at *http://maps.ngdc.noaa.gov/viewers/hazards*
- Ages of Volcanoes in Hawaiian Islands Excel file; your teacher will tell you how to access the Excel file.

Safety Precautions

Follow all normal lab safety rules.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in the development of your conceptual model is to learn as much as you can about the geologic activity around the Hawaiian archipelago. You can use the *Natural Hazards Viewer* interactive map to determine the location of any plate boundaries around the islands, the location of volcanoes on and around each island, and the occurrence and magnitude of earthquakes in the area. As you use the *Natural Hazards Viewer,* be sure to consider the following questions:

- What are the boundaries and the components of the system you are studying?
- How do the components of this system interact with each other?
- How can you quantitatively describe changes within the system over time?
- What scale or scales should you use to when you take your measurements?

- What is going on at the unobservable level that could cause the things that you observe?

The second step in the development of your conceptual model is to learn more about the characteristics of the volcanoes in the Hawaiian archipelago. You can use the Excel file called Ages of Volcanoes in Hawaiian Islands to determine which volcanoes are active and which are dormant, the distances between the volcanoes, and the age of each volcano. As you analyze the data in this Excel file, be sure to consider the following questions:

- What types of patterns could you look for in your data?
- How could you use mathematics to describe a relationship between two variables?
- What could be causing the pattern that you observe?
- What graphs could you create in Excel to help you make sense of the data?

Once you have learned as much as you can about Hawaiian archipelago system, your group can begin to develop your conceptual model. A conceptual model is an idea or set of ideas that explains what causes a particular phenomenon in nature. People often use words, images, and arrows to describe a conceptual model. Your conceptual model needs to be able to explain the origin of the Hawaiian archipelago. It also needs to be able to explain

- why the islands form a chain and not some other shape,
- why the number of islands has increased over the last 100 million years,
- why some islands are bigger than other ones, and
- what will likely happen to the Hawaiian archipelago over the next 100 million years.

The last step in your investigation will be to generate the evidence you to need to convince others that your model is valid and acceptable. To accomplish this goal, you can attempt to show how using a different version of your model or making a specific change to a portion of your model would make your model inconsistent with what we know about the islands in the Hawaiian archipelago. Scientists often make comparisons between different versions of a model in this manner to show that a model they have developed is valid or acceptable. You can also use the *Natural Hazards Viewer* to identify other chains of volcanoes that are similar to ones found in the Hawaiian archipelago. You can then determine if you are able to use your model to explain the formation of other chains of volcanoes. If you are able to show how your conceptual model explains the formation of the Hawaiian archipelago better than other models or that you can use your conceptual model to explain many different phenomena, then you should be able to convince others that it is valid or acceptable.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, be sure to think about

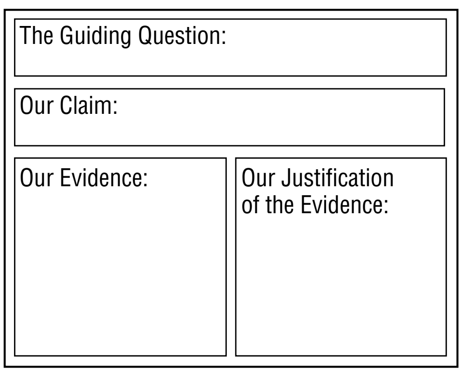
- the use of models as tools for reasoning about natural phenomena in science, and
- the assumptions made by scientists about order and consistency in nature.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L7.5.

FIGURE L7.5

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques of our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer for the following questions:

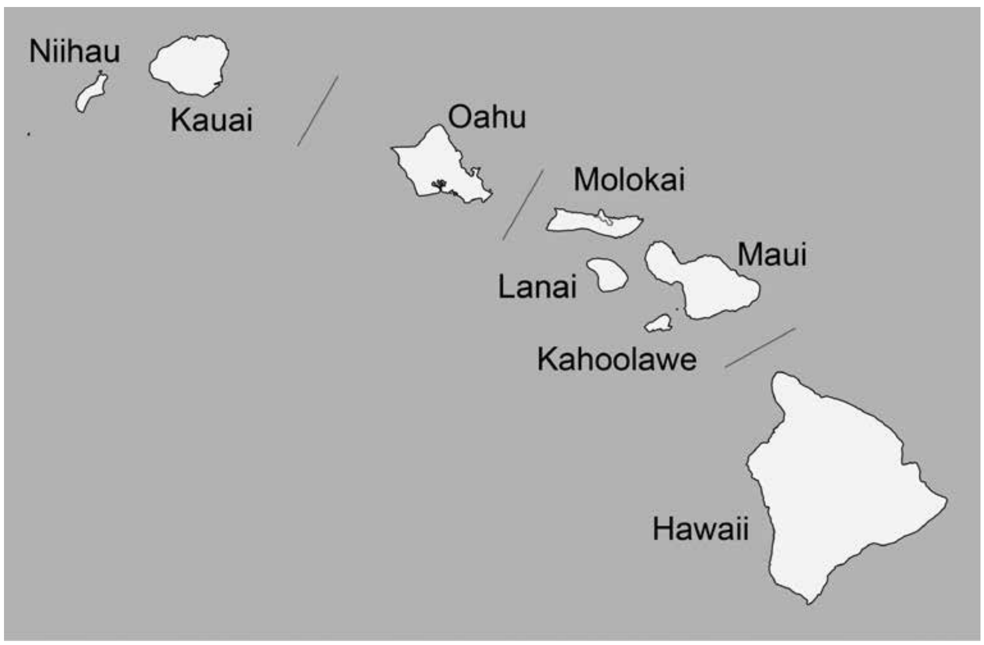
1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. You should write your report using a word processing application (such as Word, Pages, or Google Docs), if possible, to make it easier for you to edit and revise it later. You should embed any diagrams, figures, or tables into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid.

Checkout Questions

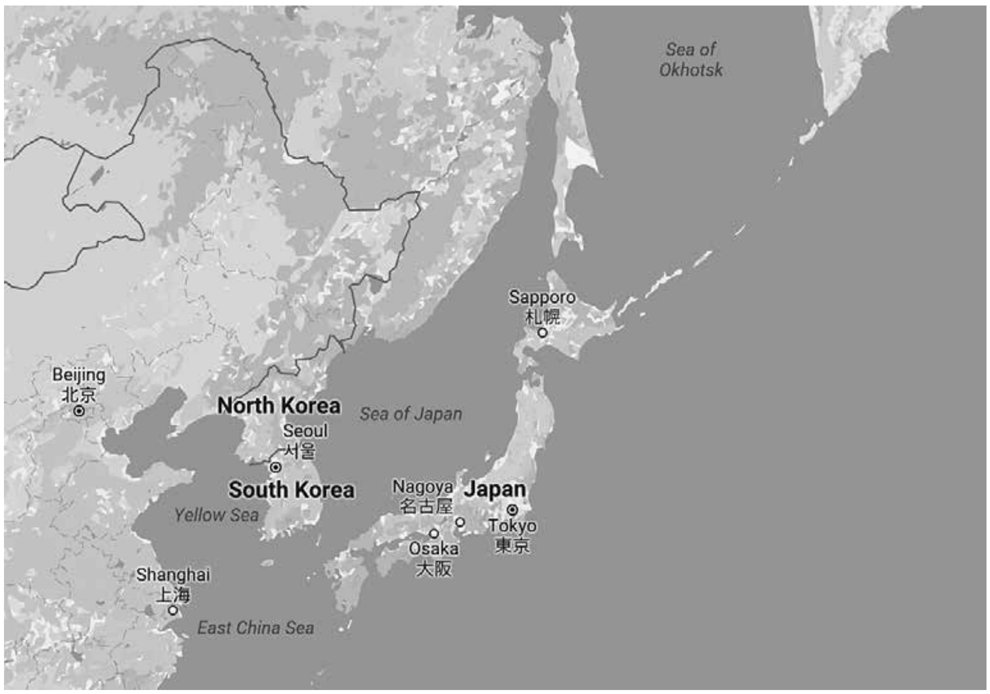
Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

1. Below is a map of the Hawaiian archipelago, shown from above. On the map, draw what you think the archipelago will look like in 100 million years.



Explain your drawing below.

2. Below is a picture of the Japanese archipelago. What information would you need to determine if the Japanese archipelago formed in the same way the Hawaiian archipelago formed?



3. Scientists can change or refine a model when presented with new evidence.

   a. I agree with this statement.

   b. I disagree with this statement.

Explain your answer, using an example from your investigation about the formation of the Hawaiian archipelago.

4. When trying to understand events that happened in the past, scientists assume that natural laws operate today in the same way as they did in the past.

   a. I agree with this statement.

   b. I disagree with this statement.

   Explain your answer, using an example from your investigation about the formation of the Hawaiian archipelago.

5. In science, it is important to define a system under study and then develop a model of the system. Explain why this is important to do, using an example from your investigation about the formation of the Hawaiian archipelago.

6. Scientists often look for patterns as part of their work. Explain why it is important to identify patterns during an investigation, using an example from your investigation about the formation of the Hawaiian archipelago.

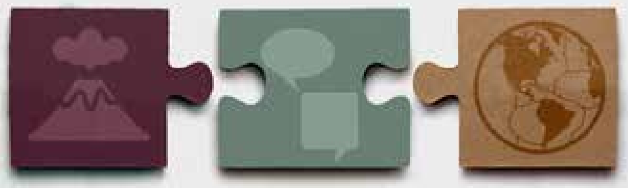
INDEX

Page numbers printed in **boldface** type refer to figures or tables.

D

E

Argument-Driven Inquiry in EARTH AND SPACE SCIENCE



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