



# EARTH SCIENCE PUZZLES

MAKING MEANING FROM DATA

KIM KASTENS  
MARGIE TURRIN

**NSTA**press  
National Science Teachers Association

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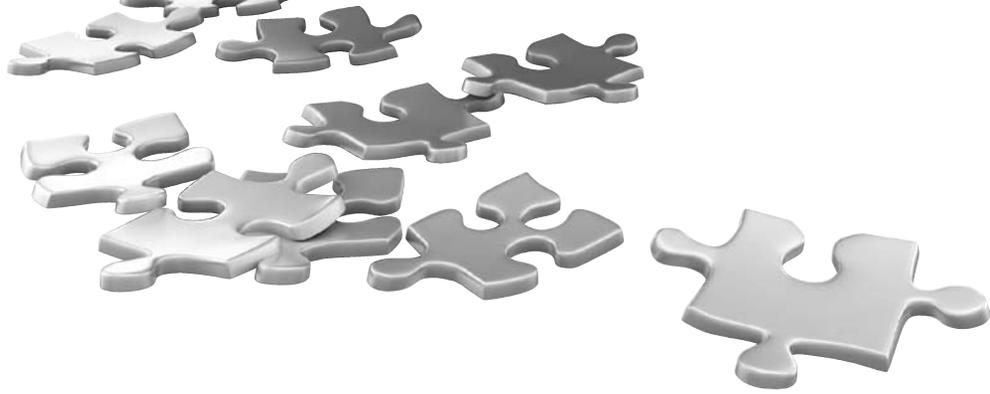
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# Preface

## Why Teach With Data?

**D**ata are the foundation of science. Every insight and every fact in every science textbook is grounded in data. Making meaning from data is a central activity in the life of a scientist. *Science* has been defined as “the use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process” (National Academy of Sciences 2008, p. 10)\*. In science, “evidence” begins with data. If we teach our students only about “the knowledge generated,” and don’t teach them about the “use of evidence to construct ...,” we have only done half our job as science educators.

Data form a strong link from the classroom to real-world phenomena. Data can provide students with evidence for processes that seem counter-intuitive and can reveal relationships among phenomena that initially seem unrelated. Interpreting data draws on higher-order thinking skills that will serve students well regardless of their paths in later life.

The time is ripe to incorporate more data into science teaching practice. In recent years, science-rich institutions, such as universities and government agencies, have made their data treasure troves available to the public via the web. This has opened up the possibility that high school and undergraduate students can learn from the same data sets that scientists ponder.

We (the authors) think that learning from data is an inherently rewarding activity and a habit of mind that is key to the way scientists learn about the world. As such, it deserves a central place in science education. Our experiences in trying to foster the use of data in education have shown us that use of authentic Earth data can be empowering and exhilarating for both students and teachers.

*But*—there are substantive barriers to overcome in teaching and learning with data. It takes a lot of classroom time to extract insights from data, especially when we bear in mind that those same insights could be stated in just few minutes. Teachers may not have sufficient prep time to explore a data set on their own and may hesitate to launch their students on an exploration of a data set that they themselves do not know thoroughly. Most teachers did not learn Earth science through data and may wonder how to guide students’

\*National Academy of Sciences and Institute of Medicine. 2008. *Science, evolution, and creationism*. Washington, DC: National Academies Press.

productive exploration through the labyrinth of a large geoscience data set. In the end, it can be difficult to assess whether students have done a good job analyzing and interpreting complex data.

Earth Science Data Puzzles have been developed with the specific goal of overcoming these problems. The major attributes of the puzzles are as follows:

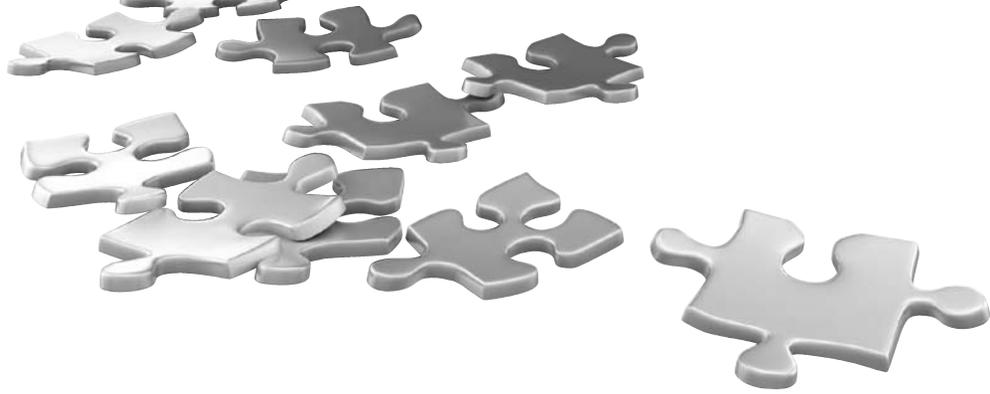
- *Selected Authentic Data.* Each puzzle uses authentic data from the Earth’s lithosphere, hydrosphere, and/or atmosphere. The data are carefully selected in order to illuminate fundamental Earth processes that are typically taught in Earth science classes and are included in the National Science Education Standards: Because the authors have pre-selected insight-rich data snippets, the puzzles are time-efficient, taking approximately one class period to complete.
- *Aha! Insights.* Each puzzle was designed to achieve Aha! Insights—moments when the connection between data and process becomes clear in a rewarding burst of insight and illumination. Aha! moments are the true reward of doing science, the intrinsic thrill that keeps scientists going through thick and thin.
- *Critical Thinking.* Data Puzzles foster the ability to go beyond looking up values in a graph, to thinking deeply about “What does this data mean?” A variety of reasoning processes are called for in the puzzles, including spatial reasoning, temporal reasoning, quantitative reasoning, and reasoning that combines data and concepts (see pp. xv–xvii for a discussion of these four types of reasoning processes).
- *Knowledge Integration.* Data Puzzles require students to combine information from the provided data with their knowledge of Earth processes and to integrate multiple kinds of data, including graphs, tables, maps, images, and narratives. From these intertwining lines of evidence, students must craft coherent claims about the Earth system and support their claims with evidence from data and scientific reasoning.
- *Pedagogical Content Knowledge.* Each puzzle is accompanied by a Pedagogical Content Knowledge Guide. The term *pedagogical content knowledge (PCK)* refers to the knowledge of how to teach something, as opposed to knowledge of the content itself. Our PCK Guides include a step-by-step tour through the reasoning needed to solve each puzzle, a heads-up about common student misconceptions, and other information intended to make the teacher’s job easier and more effective.

For teachers who have little experience using data, Data Puzzles can serve as a bridge from a data-free teaching style to a mode of teaching in which students use authentic data to solve problems and answer questions. For those teachers who are already comfortable with data, Data Puzzles can be used to permeate the curriculum with data-using opportunities that can be slipped into homework problems, exam questions, or in-class activities.

Good luck to you and your students as you explore the Earth through data!

—**Kim Kastens and Margie Turrin**





# Introduction

## How Have Teachers Used Data Puzzles in the Past?

Data Puzzles are designed as in-class exercises for eighth- through twelfth-grade students. As the word *puzzle* implies, they are intended to be challenging, but our pilot testing shows that they are within the grasp of students in this age group with appropriate instruction and scaffolding. Test teachers have found it beneficial to team students in pairs or small groups. Such grouping brings the “self-explanation” effect into play as students explain their ideas to one another. Some of the puzzles have built-in stopping points, at which point the teacher can lead a class discussion and confirm that all students understand a necessary insight or result before moving on to the next section of the puzzle. Advanced Placement Science students may be able to complete the puzzles on their own as homework, although there is still value in having students discuss their reasoning in pairs or small groups.

Our test teachers elected to use Data Puzzles after the relevant topic had already been taught through conventional means, such as diagrams, photographs, and text. When used in this manner, a Data Puzzle serves as a knowledge integration activity—to deepen, broaden, and challenge newly learned concepts and to link concepts with science process skills.

Each of the six puzzles addresses a topic that is typically taught in Earth science at the high school level (paleoclimate, weather forecasting, earthquakes, estuaries, watersheds, and hydrothermal vents). Some of our test teachers also used one or more puzzles in other courses, including chemistry, biology, environmental science, oceanography, and general science. Each puzzle is freestanding, so puzzles can be done in the order that suits the local syllabus. The order of presentation in the book is from least to most quantitatively demanding (see table on p. xix) because the target audience is transitioning from the more qualitative approach to science that is typical of

## Data Puzzles Website

A Data Puzzles website ([www.ideo.columbia.edu/edu/data\\_puzzles](http://www.ideo.columbia.edu/edu/data_puzzles)) offers supplemental and supporting information for using Data Puzzles in your classroom. The website includes items such as color graphics for classroom display, teacher-generated materials such as scaffolding worksheets for some puzzles, detailed alignment of each puzzle with the national science and math education standards, and other background information.

elementary and early-middle school toward the math-based approach found in upper high school and college science courses.

The authors encourage teachers to let students attempt to complete the puzzles without too much teacher support. There is a careful balancing act between, on the one hand, allowing students to struggle just enough so that the Aha! insights come with a rewarding sense of accomplishment and, on the other hand, allowing students to struggle so much that they become frustrated. Teachers know their students best and should watch carefully to provide enough just-in-time help, but not too much, keeping in mind that the later steps in each puzzle build on the earlier steps. The puzzles intentionally do not specify how to solve the problem—for example, students are not told what mathematical formula to use. An important part of the challenge is for students to figure out which of their intellectual “tools” will help them move toward a solution.

### **Why No “Teachers Guide”?**

Each of the student puzzles is accompanied by a rich support document for the teacher. Rather than calling this a “Teachers Guide,” we called it a “Pedagogical Content Knowledge Guide.” Scholars of teaching and learning have found that excellent teachers draw on three distinct bodies of knowledge: content knowledge (e.g., how hurricanes form); general pedagogic knowledge (e.g., assessment strategies); and a specialized body of knowledge about how to effectively teach the understandings and skills characteristic of a specific discipline. This last type of knowledge is called *pedagogical content knowledge* (PCK), and it can be the secret ingredient that makes the difference between an OK teacher and a great teacher.

Traditionally, teachers developed PCK through experience and informal sharing with other teachers. More recently, education research has added to the stock of PCK insights (Appendix A, “Bibliographic Notes,” points the reader to relevant education research literature.) PCK covers such issues as what learning goals are appropriate and achievable for a given audience, prior understandings that students need before they can tackle a specific new topic, alternative concepts that students may have, and what activities or representations are effective for explaining a specific phenomena.

Our PCK Guides are designed to support teachers in their use of specific Data Puzzles and to develop teachers’ PCK for teaching with data more broadly. We recommend that teachers read through the entire PCK Guide before using a puzzle with their students. Each guide includes the following:

- *Aha! Insights:* Each PCK Guide begins with a statement of the insights that the puzzle was designed to bring forth from students. For the purposes of lesson planning, you can think of the Aha! Insights as learning goals or learning performances. When possible, we have quoted or paraphrased the wording from actual students to express Aha! Insights.
- *Prior Skills Needed and Prior Understandings Needed:* Skills and concepts students will need before attempting the selected Data Puzzle.
- *Teacher Preparation:* A heads-up of key vocabulary to review with the students, materials to collect, and other suggestions for teachers to consider before introducing the puzzle to their students.
- *Optional Pre-Puzzle Activities:* Activities that teachers may wish to include in their instruction before the class works on the Data Puzzle.
- *Step-By-Step: How to Solve This Puzzle:* A two-part section for the teacher that includes (a) answers to the questions in the student pages and sketches and graphics completed as the student would be expected to complete them, and (b) the application of critical-thinking skills needed by students to complete each step of the puzzle.
- *Common Student Misconceptions:* Conceptions that have been compiled by examining the work of student testers, tapping into the insights of experienced Earth science teachers, and consulting the research literature on student alternative conceptions. This section can help teachers anticipate, diagnose, and overcome students' difficulties.
- *Tough Questions (With Answers):* Questions that students might ask about the puzzle, the data, or the underlying concepts. Each question includes a suggested response. Teachers can also use these questions to provide additional challenge to students who are finding the main puzzle too easy.
- *Extension Activities:* A range of extra activities that can be done in class or as homework.
- *Sources and Resources:* Links and references to supporting activities, data sources, and background readings.

## Why No Scoring Rubrics?

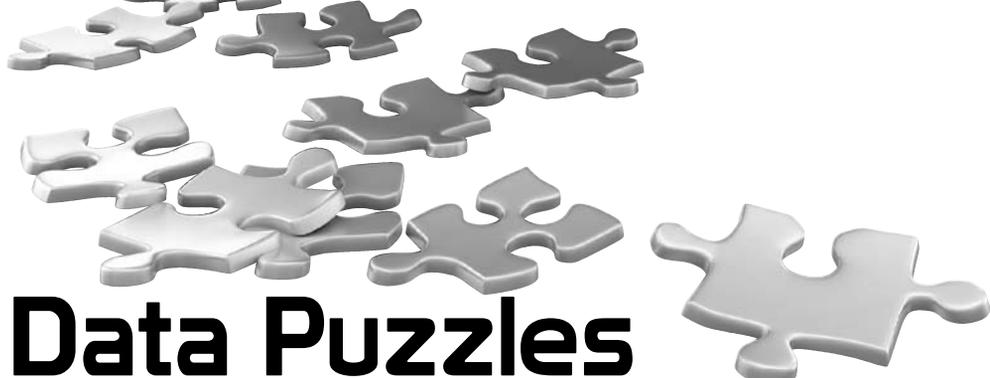
Although we do provide—in the PCK guides—the answers to the questions in each puzzle, we intentionally do not provide scoring rubrics for grading student answers. For our target audience of eighth- through twelfth-grade Earth science students, we think that the most constructive way to use these challenging

puzzles is as an in-class activity, with lots of interaction and discourse. Simultaneously, students may be arguing in their small groups about the meaning of specific wiggles in the data, the teacher may be providing just-in-time clues as student groups develop a need for them, and students may be digging into their class notes or other reference materials. The ideal would be that as many students as possible achieve the Aha! Insights by exerting considerable effort on their own while being supported with exactly the right amount of scaffolding from the teacher to carry them through the puzzle.

In this mode of use, we don't think students should be individually scored on the correctness of each answer because the answers are generated through social construction of knowledge. If a grade is needed for the activity, we recommend that teachers consider not only the written answers but also students' contributions to small-group and whole-class discussion.



Making meaning from data is key to scientific ways of knowing—and yet this appears to be an underrepresented component of science education. The authors hope that these Data Puzzles will challenge students to think broadly and deeply about how the Earth works and about how scientists use data to figure out how the Earth works.



# Using Data Puzzles to Foster Critical Thinking and Inquiry

**C**ritical thinking is thinking that goes beyond recall of information and concepts to which students have been previously exposed. Developing students' ability and willingness to use critical thinking is an important goal of science education at all levels. Data Puzzles are rich in opportunities to use critical-thinking skills because they call on students to reason from the provided data to make inferences about Earth processes.

In this book, we focus on four kinds of critical thinking: spatial reasoning, temporal reasoning, quantitative reasoning, and concept-based reasoning. Spatial reasoning and temporal reasoning are fundamental to Earth science but less common in other sciences. Earth science teachers, therefore, may need to provide extra support for those kinds of reasoning, which may be new to some students. Quantitative reasoning and concept-based reasoning are common across all of the sciences.

In the next section, we describe these four kinds of thinking, using examples from Data Puzzle #4, "Is the Hudson River too salty to drink?" An annotated synopsis of this puzzle on page xvii shows where each type of reasoning is called into play. Note that it is common to combine several types of reasoning to complete a single step of a puzzle.

## **Four Types of Critical Thinking Highlighted in the Data Puzzles**

### **Spatial/Visual Reasoning (S)**

When using spatial reasoning, students make inferences from observations about the location, orientation, shape, configuration, or trajectory of objects or phenomena. In Earth science, this often means extracting insights from maps or from data displayed on maps. A common spatial-thinking approach in Earth science is to look for gradients across space—that is, to look for evidence that some observable property varies systematically onshore/offshore, upstream/downstream, north/south, in rural/urban areas, or with distance from some event. For example, in "Is the Hudson River too salty to drink?" students observe a north/south gradient in the salt concentration of river water and interpret that in terms of the mixing of freshwater from the

## Using Data Puzzles to Foster Critical Thinking and Inquiry

north and salty ocean water from the south. Another common challenge in Earth science is to visually observe a shape or pattern that is similar to—but not identical to—a shape or pattern that has been seen previously. Recognizing fossils or minerals and identifying features in photographs are examples of the “visual” part of spatial/visual reasoning.

### Temporal Reasoning (T)

When using temporal reasoning, students make inferences from observations about the timing, rates, and sequence of Earth events and processes. One common line of temporal reasoning is that the sequence of events constrains causality—in other words, if A happened before B, then A can have caused or influenced B, but B cannot have caused or influenced A. For example, in “Is the Hudson River too salty to drink?” students reason that the heavy rain on April 15 of the data set could have caused the gradual freshening of the river on April 16, 17, and 18.

Another type of temporal reasoning is recognizing cycles or parts of cycles in time series data, including day/night cycles, tidal cycles, seasonal cycles, or glacial/interglacial cycles. For example, in the Hudson River puzzle, the ~12 hr. time interval between salinity peaks is an important clue that salinity is being influenced by tidal processes. Rates of Earth processes tell us about how powerful the process is. For example, in the hydrothermal vents puzzle, the rate at which hot water spews out from the vent constrains how much heat energy is delivered to the ocean from the Earth’s interior.

### Quantitative Reasoning (Q)

Quantitative reasoning makes use of numerical information. Quantitative reasoning would include making a calculation, deciding which mathematical operation is needed, changing numerical values into more useful units, comparing and contrasting numerical values, describing trends or patterns in numerical data, and making inferences about cause and effect from such trends and patterns. For example, in “Is the Hudson too salty to drink?” students use their number sense to grasp the huge difference in saltiness between some sampling localities (26,000 ppm salinity) and others (<100 ppm salinity), and recognize that this huge difference is a significant observation that needs to be explained. *A Note on Units and Scientific Notation:* Some teachers require scientific notation and others do not, so our PCK guides provide answers in both formats. In general, we have used SI units. In a few cases, we used everyday units when we thought this would help students tap into their experiential knowledge and physical intuition (e.g., we used °F in the weather forecasting puzzle and calories in the hydrothermal vent puzzle).

## Concept-based Reasoning (C)

In concept-based reasoning, students must tap into their knowledge of Earth science concepts and apply this knowledge to complete a step of the Data Puzzle. The question cannot be answered by merely reading information off the provided graph, map, or table; students must integrate information from the provided data with prior learning to construct interpretations and explanations. For example, in “Is the Hudson River too salty to drink?” students must draw on their conceptual understanding of tides to interpret the twice daily increase and decrease of salinity on April 15 as a result of the ebb (fall) and flood (rise) of the tidal cycle.

## How to Use the PCK Guides to Foster Critical Thinking

The Pedagogical Content Knowledge Guides that accompany each Data Puzzle spell out the types of critical thinking that students will need to complete each step of the puzzle. The table on page xviii is an excerpt from the two-part “Step-by-Step” section of the PCK Guide for Data Puzzle #4, “Is the Hudson River too salty to drink?” The left-hand side of the table repeats each step of the puzzle from the student pages and is followed by a fully correct answer for that step. The right-hand side of the table shows the critical-thinking processes that students need in order to construct

## Synopsis of Data Puzzle #4, “Is the Hudson River too salty to drink?”

Includes the Critical-Thinking Skills—(S) Spatial, (Q) Quantitative, (T) Temporal, and (C) Concept-based—That Students Need to Solve the Puzzle

Note: Full-size figures can be viewed on pages 93–114.

**Step 1:** Working with data collected by school groups, students employ reasoning about variations across space to discover the north-south salinity gradient of the estuary.

(C) Salinity Data from “A Day in the Life of the Hudson River,” Oct. 12

River Mile	Salinity in ppm
0	26000
2	16000
7	13300
14	
18	
25	

(Q) Location of the Hudson River Estuary

**Step 2:** Comparing and describing two time series from a single site on the river, students use temporal reasoning to hypothesize that an event in the rainfall time series resulted in a response in the salinity time series.

(C) Rainfall and Salinity Levels in the Hudson River

(T) Hudson River Salt Front Locations \*

Dates	RM	Dates	RM
Mar 1	62	Aug 1	62
Mar 5	56	Aug 5	66
Mar 9	47	Aug 9	68
Mar 13	55	Aug 13	68
Mar 17	56	Aug 17	
Mar 21	62	Aug 21	
Mar 25	68	Aug 25	
Mar 29		Aug 29	

\* where salinity measures 100 ppm

**Step 3:** Using professionally collected salinity data, students link the concepts of variation over time and space to develop an understanding of the hydrologic processes of the river.

# Using Data Puzzles to Foster Critical Thinking and Inquiry

the correct answer. The thought processes are coded according to the type of thinking, with (S) for spatial/visual reasoning, (T) for temporal reasoning, (Q) for quantitative reasoning, and (C) for concept-based reasoning.

## (Excerpt) Step-by-Step: How to Answer Data Puzzle #4

Answer Key	Critical Thinking
<p>6c. Compare and contrast the salt front location for the two time intervals plotted. Be sure to use river miles and mention specific communities in your response.</p> <p>The salt front in August and September remained fairly consistent, moving only between RM 62 and RM 73 (approximately Newburgh to Poughkeepsie).</p> <p>In March and April the salt front is closer to the ocean. Also, in March and April the location is more variable than for August and September, ranging from RM 68 (north of Newburgh) all the way down to RM 0 at the southern tip of Manhattan.</p>	<p>(S)(T) Students interpret the position versus time graph in terms of</p> <ul style="list-style-type: none"><li>• <i>position</i> (in March and April the salt front is always closer to the ocean—i.e., farther south—than in August and September)</li><li>• <i>variability of position</i> (in August and September, the salt front location is more stable than in March and April)</li></ul>

We suggest three ways to use the critical-thinking information in the right-hand column to strengthen your students' thinking skills.

### 1. Provide Scaffolding

Learning to reason from data is a big step for students, and many teachers find that they need to ease their students into the process gradually. By scanning down through the critical-thinking column of the PCK Guide, teachers can plan where they want to give their students additional clues and where they want to hang tough and insist that the students do the hard thinking themselves. For example, when a step calls for concept-based reasoning, a useful clue might be "take a look at the diagram on page 99 in your textbook." Don't fall into the trap of doing all the hard thinking for the students, leaving them to do just the mechanical steps such as completing a calculation or plotting points onto a graph.

# Using Data Puzzles to Foster Critical Thinking and Inquiry

## 2. Diagnose Difficulties

If you find that many of your students are struggling at a specific point in the puzzle, the comments in the critical-thinking column of the PCK Guide can help you diagnose the problem. If they are stuck on a (C) step, perhaps they haven't fully understood a requisite concept. If they are stuck on a (Q) step, perhaps they know from math class how to carry out a mathematical operation but don't know how to identify situations where that operation is appropriate. If they are stuck on an (S) or (T) step, perhaps they have not encountered these kinds of reasoning in their prior science courses, and you may need to model them by doing a think-aloud as you work through the puzzle with the whole class.

## 3. Target Specific Thinking Skills

Each puzzle has a different balance of types of critical thinking. If you are interested in fostering a specific thinking skill, the "Targeting Specific Critical-Thinking Skills" table below will help you choose the puzzles most suited to your learning goal. In the table, numbers indicate how many instances of each type of reasoning are called for in each puzzle. For example, if you wish to strengthen your students' quantitative reasoning, then "Where did the water go?" or "How much heat is released by a seafloor hydrothermal vent?" would be good choices.

## Targeting Specific Critical-Thinking Skills

Data Puzzle	Instances of Each Type of Critical Thinking			
	Spatial (S)	Temporal (T)	Quantitative (Q)	Concept-Based (C)
#1 How do we know what the climate was like in the past?	10	11	0	8
#2 How do we decide "weather" or not to proceed with a trip?	11	14	1	13
#3 What does an earthquake feel like?	4	2	4	1
#4 Is the Hudson River too salty to drink?	11	11	8	4
#5 Where did the water go?	12	3	15	7
#6 How much heat is released by a seafloor hydrothermal vent?	5	2	26	9

## The Role of Data Puzzles in an Inquiry-Oriented Curriculum

Educators committed to fostering student inquiry may be concerned that Data Puzzles are too structured. After all, we have preselected the data snippets to be examined, declared (in the title of each puzzle) what question shall guide the activity, and choreographed the students' path through the data by means of a step-by-step format.

We share with our inquiry-committed colleagues the ultimate goal that students should be able to tackle open-ended inquiries. Students should be capable of identifying a question, planning an inquiry to address that question, navigating their way through the relevant data, and interpreting subtle or complex data patterns in terms of causal processes. It is our belief that Data Puzzles serve a critical role in helping students develop a tool kit of reasoning skills and data analysis techniques that will enable them to take their science inquiries to a higher level of complexity.

Back in elementary and lower-middle school, students were able to accomplish meaningful inquiries with small, student-collected data sets, interpreted through commonsense lines of reasoning. In college, students may find that they are expected to analyze and interpret large data sets, which they did not see being collected, using multi-step lines of reasoning. In adult life, they may be called on to make data-informed decisions in fields as varied as business, epidemiology, education, and criminal justice.

The transition from an elementary or a middle school mode of learning from data to a college-level or adult mode is complicated and multifaceted. High school represents an opportunity to make this transition. Elementary and middle school students typically interpret one data set at a time, whereas college and adult data interpreters commonly consider interactions among multiple data parameters. One hundred data points would be a large data set at the elementary level, but college and adult data sets are measured in megabytes. Further, when children work with data they collected themselves, they have experiential knowledge of the environment and circumstances represented by the data. As older students or adults, working with professionally collected archival or real-time data, they don't have that personal knowledge of the data's context; instead, they have to build up an understanding of context from the accompanying narrative or metadata. Finally, the process of crafting defensible scientific claims from the evidence contained in data requires a suite of reasoning processes that go far beyond simple common sense, including spatial reasoning, temporal reasoning, and quantitative reasoning. We think the structured approach of Data Puzzles can help high school students prepare for the kinds of complex inquiries they may encounter later in life.

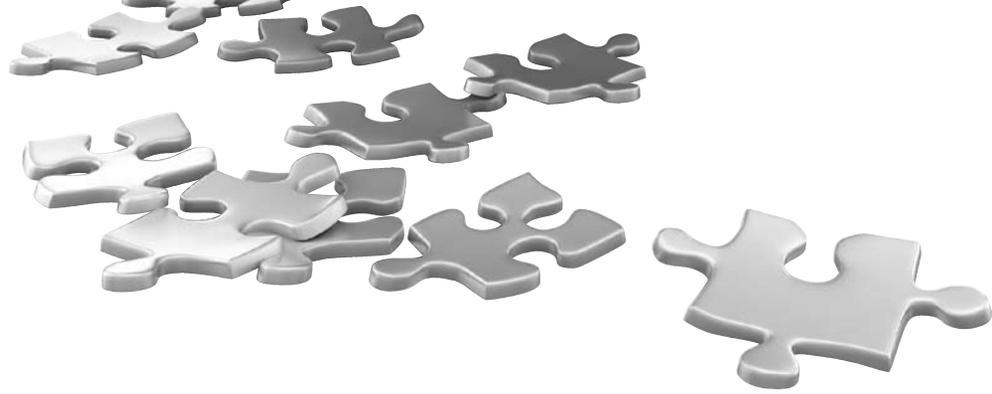
## Using Data Puzzles to Foster Critical Thinking and Inquiry

Perhaps an analogy will help. Inquiry activities in which students generate their own questions and design their own investigations to address those questions can be compared with a game of youth soccer or lacrosse. Players have to cope with a lot going on at once, react to the unexpected, and coordinate many factors toward the goal of winning the game.

Good coaches and physical education teachers spend time developing skills important for success—skills that will enable the players to be independent, to make their own decisions on the field. Data Puzzles are like the drills that help players isolate and practice the skills that will enable them to excel in the game—not simple drills, but challenging drills that the best coaches use, the drills in which players have to combine multiple skills—for example, dribble, pass, pass back, dribble, shoot.

A sports team that doesn't have organized practices, that only plays games, won't improve very quickly. A combination of structured practices that isolate and practice key skills and prepare players to make rapid independent choices on the field, together with games that integrate those skills, produces improvement in youth sports—and we hypothesize that the same is true in youth science.





# Acknowledgments

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The primary authors for each of the puzzles are named in the table of contents. Additional assistance with specific puzzles was provided by the following organizations and colleagues:

- “How do we know what the climate was like in the past?” Dr. Dorothy Peteet, Quaternary paleoecologist and paleoclimatologist, assisted in interpreting this data and developing the puzzle. The NSF Graduate Research Fellowship Program also supported the development of this puzzle.
- “What does an earthquake feel like?” Dr. John Armbruster, seismologist, provided data and advice in developing this puzzle. Holly Chayes and Katherine Cagen assisted with data processing.
- “Is the Hudson River too salty to drink?” This puzzle was created with help from the Beczak Environmental Center and the student and teacher participants of “A Day in the Life of the Hudson River” project.
- “Where did the water go?” Black Rock Forest Consortium constructed the stream station that generated the data used in this Data Puzzle. Americorps member Tanessa Hartwig assisted with data analysis and early development of the activity.
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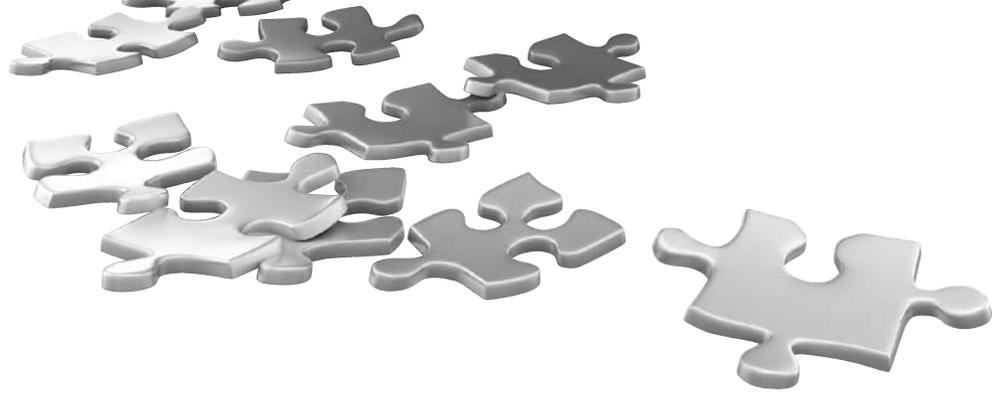
# Acknowledgments

The Data Puzzles and Pedagogical Content Knowledge Guides were refined and tested by a group of science teachers and their students over a period of two years. Our teacher team consisted of the following people:

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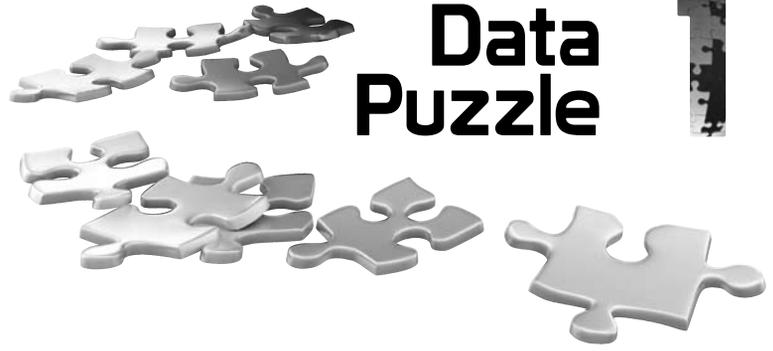
**David McGee** is a postdoctoral researcher in paleoclimatology at the University of Minnesota and Lamont-Doherty Earth Observatory. His research focuses on reconstructing past climate changes recorded in the geochemistry of cave deposits and marine sediments. Prior to pursuing graduate studies in Earth science at Columbia University, he taught Earth science, physical science, and physics at the middle and high school levels in Pittsburgh and New Orleans. During this time, he earned a master's degree in teaching with a focus on environmental education. While a graduate student at Tulane University and Columbia University, Mr. McGee led a variety of science enrichment

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# How do we know what the climate was like in the past?

For those who know how to interpret them, pond sediments can provide important records of the past. Information from layer after layer of sediments can be put together to construct a timeline of the history of a pond site. In the early 1990s, a group of scientists and students went to Allamuchy Pond in northern New Jersey (Warren County) (see Figure 1.1). They collected a 10 m long cylinder of sediments called a *core* by inserting a long metal tube vertically into the bottom of the pond. The recovered sediments included fragments of rocks, mud, and organic material. The scientists removed pollen from each layer of the sediments and studied their samples under a microscope (see Figure 1.2). They identified each type of pollen in order to learn what types of plants were living in the area at different times in the past. They also described the overall type of sediment present in each section of the core. What can you learn about past climate by looking at the pollen record from the bottom of a pond? And how does climate in the early 21st century differ from past climate in that same area?

Figure 1.1

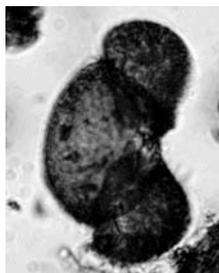
Location of Allamuchy Pond (See\*)



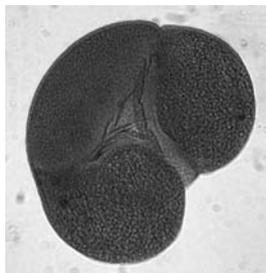
Source: Created by Linda Pistolesi using data publicly available from [www.census.gov](http://www.census.gov).

Figure 1.2

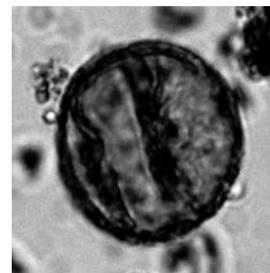
Grains of Pine, Spruce, and Oak Pollen



Pine Pollen



Spruce Pollen



Oak Pollen

Source: Courtesy of Dorothy Peteet.

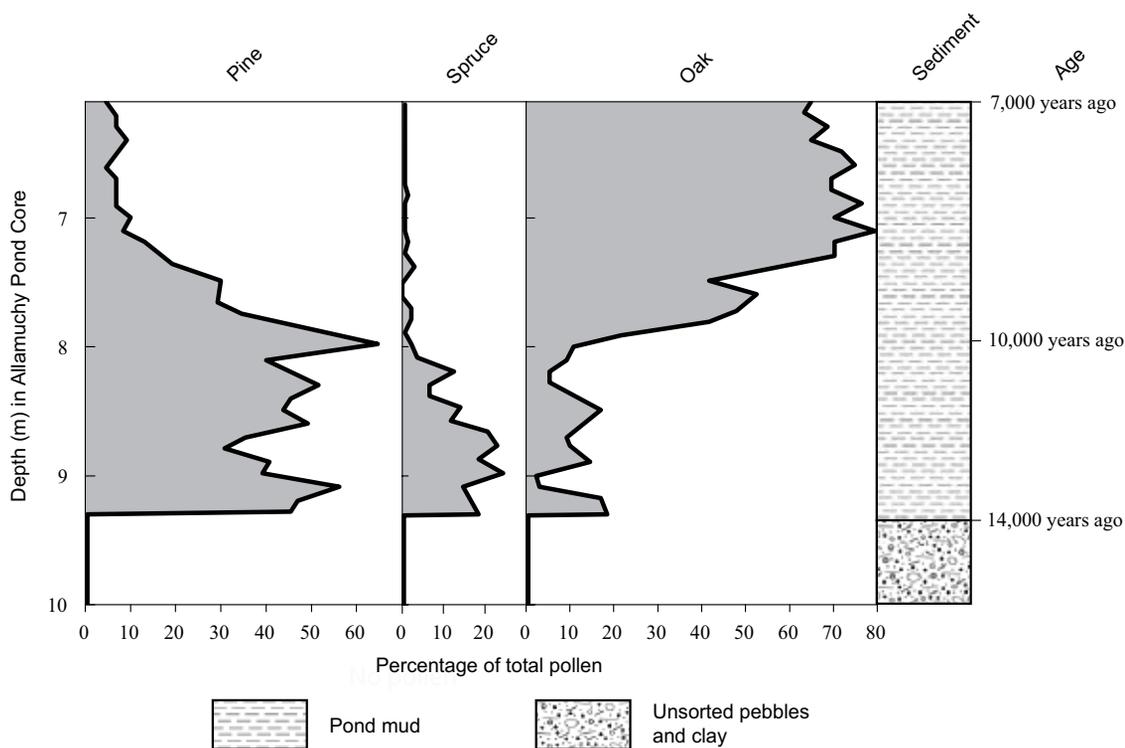
### Student Pages

**Directions:** Follow steps 1 through 9. Use additional sheets of paper as needed and answer in complete sentences.

- 1a. Draw two horizontal lines across the graph in Figure 1.3: one at 14,000 years ago and one at 10,000 years ago. Each line should go all the way from the right-hand axis (Age) to the left-hand axis (Depth).

**Figure 1.3**

### Pollen Data From Allamuchy Pond (to be completed by student)



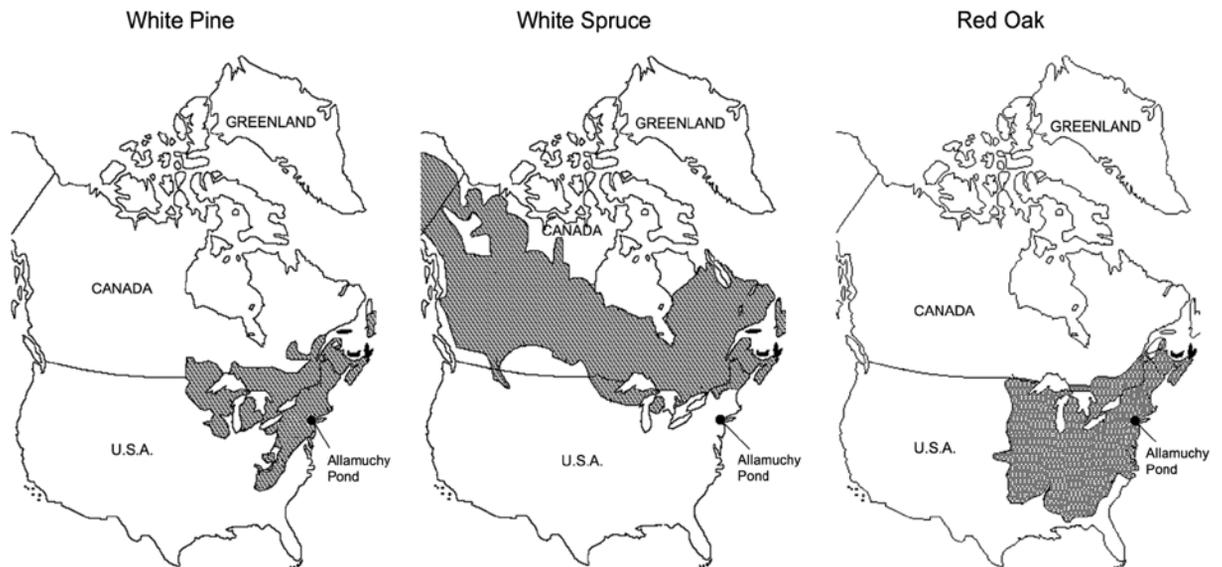
Source: Created by David McGee using data from Peteet, D. M. et al. 1993. Late-Glacial pollen, macrofossils and fish remains in northeastern U.S.A.: The Younger Dryas oscillation. *Quaternary Science Reviews* 12: 597–612. [http://pubs.giss.nasa.gov/docs/1993/1993\\_Peteet\\_etal.pdf](http://pubs.giss.nasa.gov/docs/1993/1993_Peteet_etal.pdf)

- 1b. Label the oldest sediment and the youngest sediment on the graph.
- 2a. According to the data, what types of trees were present in the region between 14,000 and 10,000 years ago?
- 2b. Now look at the data from a more recent interval of time. According to the data, what types of trees were present in the region between 10,000 and 7,000 years ago?

- 2c. Describe the major changes in tree types in the region from 14,000 years ago until 7,000 years ago.
- 3. According to the data, what were two specific changes that occurred approximately 14,000 years ago?
- 4. Scientists use the present climates in which trees live to help them understand past climates. Figure 1.4 shows the areas of North America where the three tree types represented in the sediment core are abundant in modern forests.\*
  - 4a. Which tree species lives in the coldest locations?
  - 4b. Which tree species lives in the warmest locations?

**Figure 1.4**

**Present-Day Range Maps for White Pine, White Spruce, and Red Oak\***



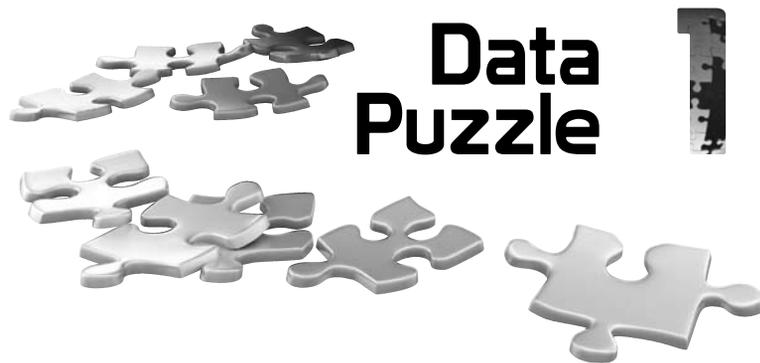
Source: Adapted from [www.eFloras.org](http://www.eFloras.org). Courtesy of the Flora of North America Association.

\*You might wonder why the data shown in Figure 1.3 are for pine, spruce, and oak pollen, while the data in Figure 1.4 are specifically for white pine, white spruce, and red oak trees. That is because the pollen grains are grouped together by genus, while the range maps for trees in Figure 1.4 are for representative individual species within each genus.

### Student Pages

5. Looking at the range maps in Figure 1.4, you can see that there are no spruce trees near Allamuchy Pond. The pollen data in Figure 1.3 show that there were spruce in the area between 14,000 and 10,000 years ago. Based on this observation, how do you think the temperatures in the region of Allamuchy Pond between 14,000 and 10,000 years ago compare with present-day temperatures?
6. Based on your answers to the questions in step 2, which period was colder in the region of Allamuchy Pond: from 14,000 to 10,000 years ago or from 10,000 to 7,000 years ago? Explain your answer using evidence from the data.
- 7a. Which of these processes are most likely to deposit sediments that are an unsorted mix of pebbles and clay (choose two): running water, glaciers, ocean waves, landslides, or wind?
- 7b. Which of the sediment-transport processes do you think deposited the unsorted mix of pebbles and clay at the base of the Allamuchy Pond core? Use your knowledge of Earth science as well as evidence from the core. Explain your answer.
8. Why do you think the sediments older than 14,000 years have no pine, spruce, or oak pollen?
9. Based on your knowledge of Earth history, what event in geologic history do you think is recorded in the Allamuchy Pond sediments? (*Hint: Think about what was happening in North America at this time in geologic history and the changes that you documented in your answers to questions 2c, 3, 5, 6, and 8.*) Explain your answer.

Topic: Paleoclimate



## Pedagogical Content Knowledge Guide

# How do we know what the climate was like in the past?

In this Data Puzzle, students interpret a multi-parameter graph of pollen data from a sediment core collected in the northeastern United States to assess changes that occurred in the tree community over a period of about 7,000 years. By comparing the pollen graph to present-day flora range maps, students infer temperature changes in the region during the time recorded in the core. Then, students interpret changes in sediment lithology recorded across the same time interval. Putting these pieces of information together, students infer that the sediments record the end of the last ice age in the region.

This puzzle is suitable for courses in Earth science, living environment, and environmental science.

### Prior Skills Needed

- Ability to use a graph with two vertical axes and multiple horizontal axes
- Ability to use thematic maps

### Prior Understandings Needed

- Basic familiarity with *sediments* (fragments of rocks and organic materials of different sizes) and *sedimentation* (the natural collection of sediment over time), including the types of sediments associated with different *depositional environments* (such as in a lake or by a glacier)

### Aha! Insights

- The climate of the northeastern United States has changed over time and used to be really different than it is today.
- Changes in climate lead to changes in what plants can live in an area.
- You can learn a lot about Earth's climate history just by studying pond mud!

### Pedagogical Content Knowledge Guide

- An understanding of the geologic principle of superposition—that is, that layers of sediment are deposited over time such that the oldest layer is at the bottom of the core and the youngest is at the top

Students will also need to know the following facts:

- Glaciers leave deposits of unsorted sediments.
- Pollen is produced by plants.
- Pine, spruce, and oak are types of trees.
- Different plants survive and thrive under different climatic conditions.
- In North America, northern climates are generally colder than southern climates. Climates change over time.
- The Earth has had a number of ice ages in the past.

### Teacher Preparation

1. Work through the steps in the data puzzle yourself (pp. 1–4). Use “Step-by-Step: How to Solve Data Puzzle #1” (pp. 8–12) to anticipate which steps may be difficult for students and plan what kinds of clues will help them past the sticky points without giving away the answers. Step-by-Step also shows the critical-thinking skills that students will need to solve each step.
2. Write down your learning goals for this puzzle. The learning goals you select will vary based on the academic needs and skills of your students and the specific focus of your school or your district. You may wish to consult Appendix B, which consists of tables that show the alignment of the Data Puzzles with the National Science Education Standards and the Principles and Standards for School Mathematics. Also refer to your state standards.
3. Select key vocabulary related to the puzzle to review with students **before** they complete the puzzle—for example, *clay* (fine grained sediment), *climate*, *pollen*, *sedimentation*, *sediments*, *superposition*, and *core*.
4. Gather and prepare materials:
  - For each student: ruler, pencil, a copy of Data Puzzle #1 (pp. 1–4)
  - For the class: map of the world



- (optional) Topographic map of North America
  - (optional) Video of a core sample being taken by scientists
  - (optional) Samples or pictures of glacial till (unsorted mixture of pebble, sand, and clay sediments) and pond mud
  - (optional) Magnified pictures of pine, spruce, and oak pollen and photos of adult pine, spruce, and oak trees (See under “Resources,” General Climate and Paleoclimate, Center for Pollen Studies.)
5. Plan any pre-puzzle activities (see next section) and extension activities (p. 16). Check the Data Puzzles website ([www.ldeo.columbia.edu/edu/data\\_puzzles](http://www.ldeo.columbia.edu/edu/data_puzzles)) for background materials, color versions of the graphics, and other supporting materials. Double-check any digital resources to be sure they can be accessed from your classroom.

### Optional Pre-Puzzle Activities

- Direct students to find Allamuchy Pond on Google maps/Google Earth (it can be found by typing in “Allamuchy Pond, NJ”).
- Have students explain their understanding of what pollen is.
- Check the Data Puzzles project website or have students search Google Image for pictures of the different pollen in the puzzle (pine, spruce, and oak). Also see under “Resources,” General Climate and Paleoclimate, Center for Pollen Studies.
- Take a soil core sample from around your school or neighborhood, preferably in a wetland. Identify the oldest and youngest section of your core, and note that the sample represents time. Describe the core length, color, and composition.
- Show a video of either an ocean core sample or a lake core sample being taken by scientists (see under “Resources,” Resources on Methods Used in the Study of Paleoclimate, Description and Animation of Piston Coring).
- Before students work with Figure 1.3, show them a different graph that has either multiple vertical axes or a vertical axis that increases in a downward direction. Walk students through interpreting the graph.

### Pedagogical Content Knowledge Guide

#### Teaching Notes

- The name of the pond in this Data Puzzle is pronounced “AL-a-MOO-chee.”
- The graph in Figure 1.3 differs from graphs that students may be familiar with from other classes in several regards: the independent variable is on the vertical axis, time increases downward on the vertical axis, and there are several data sets on the same graph. This format is standard for graphs of geological data because downward in the Earth corresponds to downward in the diagram. Students may need help reading graphs in this format.
- If students are familiar with the standard symbols used on geological maps and profiles, they may associate the pattern in Figure 1.3 used for “pond mud” with shale. The symbol is used in this figure for clay-rich sediments because they would become shale if they were heated and compressed to form a rock.

#### Step-by-Step: How to Solve Data Puzzle #1

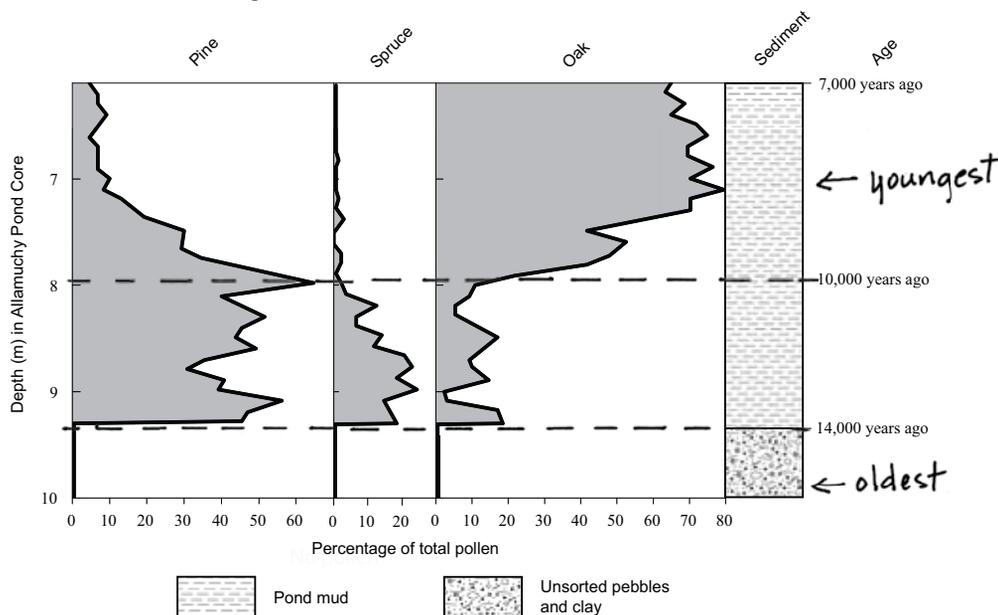
*Teaching Note:* To solve the puzzle, students must use critical-thinking skills. Each use of critical thinking is described in the right-hand column and is coded as follows: (S) Spatial, (T) Temporal, (Q) Quantitative, and (C) Concept-based. See pages xv–xvii for a discussion of these four types of critical-thinking skills.

Answer Key	Critical Thinking
<p>1a. Draw two horizontal lines across the graph: one at 14,000 years ago and one at 10,000 years ago. Each line should go all the way from the right-hand axis (Age) to the left-hand axis (Depth).</p> <p>1b. Label the oldest sediment and the youngest sediment on the graph.</p> <p>The top of the graph should be labeled “youngest” and the bottom of the graph should be labeled “oldest” as in Figure 1.5.</p>	<p>(C) Student may recall learning the principle of superposition—that younger layers of sediment are deposited on top of older layers of sediment—and apply that principle to this sediment core.</p> <p>Or</p> <p>(T)(S) Student may reason out that the younger sediments must be deposited on top of the older layers.</p>

Answer Key	Critical Thinking
<p>2a. According to the data, what types of trees were present in the region between 14,000 and 10,000 years ago?  <b>pine, spruce and oak</b></p> <p>2b. Now look at the data from a more recent interval of time. According to the data, what types of trees were present in the region between 10,000 and 7,000 years ago?  <b>pine and oak, and a very small amount of spruce</b></p> <p>2c. Describe the major changes in tree types in the region from 14,000 years ago until 7,000 years ago.  <b>From 14,000 years ago until 7,000 years ago, pine and spruce were abundant, and there was also some oak. Around 10,000 years ago, a change in the numbers of each species of tree occurred: pine and spruce became less common, while oak became more common. From 10,000 to 7,000 years ago, oak was the dominant species.</b></p>	<p>(T)(C) Students need to make use of their knowledge that in geology, time progresses from larger numbers (14,000 years ago) to smaller numbers (7,000 years ago) and that in sediments, younger sediments are above older sediments.</p> <p>(S)(T) Students interpret the <i>shape</i> of the three pollen curves, which is a different skill from the commonly practiced skill of reading numbers off a graph. They need to look through the minor wiggles to see the major trends in the data.</p> <p>(S) Students recognize a spatial pattern: that all three pollen curves show rapid changes in pollen abundance during the same time interval, around 10,000 years ago.</p> <p>(T) Students need to integrate data from all three pollen curves to assemble a chronological narrative, in order of advancing time, with a beginning, middle, and end.</p>

Figure I.5

Answers for Figure 1.3



Source: Created by David McGee using data from Peteet, D. M. et al. 1993. Late-Glacial pollen, macrofossils and fish remains in northeastern U.S.A.: The Younger Dryas oscillation. *Quaternary Science Reviews* 12: 597-612. [http://pubs.giss.nasa.gov/docs/1993/1993\\_Peteet\\_etal.pdf](http://pubs.giss.nasa.gov/docs/1993/1993_Peteet_etal.pdf)

### Pedagogical Content Knowledge Guide

(continued)

Answer Key	Critical Thinking
<p>3. According to the data, what were two specific changes that occurred approximately 14,000 years ago?</p> <ul style="list-style-type: none"> <li>• <b>The sediment type changed from pebbles and clay to pond mud.</b></li> <li>• <b>Pollen of pine, spruce, and oak began appearing in the sediments.</b></li> </ul>	<p>(S)(T) Students need to read spatial representations (pollen graphs and sediment record) in terms of changes over time, coping with the fact that at the resolution of the data the changes appear to have occurred instantaneously.</p> <p>(T)(C) Once again, as in step 2, students use their knowledge that underlying sediments record earlier time intervals than overlying sediments.</p>
<p>4. Scientists use the present climates in which trees live to help them understand past climates. The range maps in Figure 1.4 show the areas of North America where the three tree types represented in the sediment core are abundant in modern forests.</p> <p>4a. Which tree species lives in the coldest locations?</p> <p><b>spruce</b></p> <p>4b. Which tree species lives in the warmest locations?</p> <p><b>oak</b></p>	<p>(C)(S) Students need to recognize that the field area is in the Northern Hemisphere, recall that in the Northern Hemisphere the climate cools as you move north, and recognize from the shape of the continents that north is toward the top of the maps.</p> <p>(S) Students must notice that on the range maps spruce is found farthest north, oak extends farthest south, and pine is found at intermediate latitudes.</p> <p>(S) Students must combine previously known information with provided information to reason that spruce occurs farthest north (from the range charts), that as you move north the climate cools (from prior knowledge), and therefore that spruce is found in the coldest locations. Likewise, oak extends the farthest south (from the range charts). As you move south, the climate warms (from prior knowledge), and therefore oak is found in the warmest locations.</p>
<p>5. Looking at the present-day range maps in Figure 1.4, you can see that there are no spruce near Allamuchy Pond. The pollen data show that there were spruce in the area between 14,000 and 10,000 years ago. Based on this observation, how do you think the temperatures in the region of Allamuchy Pond between 14,000 and 10,000 years ago compare with present-day temperatures?</p> <p><b>It was colder back then (14,000-10,000 years ago) than it is today.</b></p>	<p>(T)(C) Students need to apply their knowledge that the climate of the Earth was different in the past than it is in the present.</p> <p>(S)(T) Drawing on their insights from question 4, students must reason that spruce is found in colder climates, spruce was in the area 14,000–10,000 years ago, and therefore the climate was colder 14,000–10,000 years ago than it is today.</p>

Answer Key	Critical Thinking
<p>6. Based on your answers to the questions in step 2, which period was colder in the region of Allamuchy Pond: from 14,000 to 10,000 years ago or from 10,000 to 7,000 years ago? Explain your answer using evidence from the data.</p> <p><b>It was colder from 14,000 to 10,000 years ago than from 10,000 to 7,000 years ago.</b></p> <p><b>From 14,000 to 10,000 years ago, pine and spruce pollen were abundant, according to the pollen data in Figure 1.3. These are trees that thrive in medium to cold climates, as we see in the range maps in Figure 1.4. From 10,000 to 7,000 years ago, oak was abundant, according to the pollen data. Oak lives in warmer climates, according to the range map.</b></p>	<p>(S)(T) Students need to combine their understanding of changes through time (pollen data in Figure 1.3) with their understanding of variation across space (range maps in Figure 1.4).</p> <p>(C) Students may have recognized that this time interval of 14,000 to 7,000 years spans the Pleistocene/Holocene transition and the waning of the last ice age. However, they should NOT explain their answer only in generalities; they were asked to explain their answer using <i>evidence from the Allamuchy Pond data</i>.</p>
<p>7a. Which of these processes are most likely to deposit sediments that are an unsorted mix of pebbles and clay (choose two): running water, glaciers, ocean waves, landslides, or wind?</p> <p><b>glaciers and landslides</b></p> <p>7b. Which of these sediment-transport processes do you think deposited the unsorted mix of pebbles and clay at the base of the Allamuchy Pond core? Use your knowledge of Earth science as well as evidence from the core. Explain your answer.</p> <p><b>A glacier. It's possible that an unsorted mix of pebbles and clay was deposited by either a glacier or a landslide. A continental glacier was most likely, however, because the time was during the Pleistocene ice age and the position is far enough north to have been at the edge of the ice sheet.</b></p>	<p>(C) Students need to recall that running water, ocean waves, and wind tend to deposit sediments that are well sorted in grain size, whereas landslides and glaciers can deposit a mixture of coarse and fine sediments.</p> <p>(C) By now, students may be connecting the age of the sediments with their knowledge of geological history; they recognize that the bottom of the core records conditions during the last ice age, when northern North America was covered by an ice sheet.</p> <p><i>Teaching Note:</i> The terms <i>ice sheet</i> and <i>continental glacier</i> are synonymous in this answer. <i>Glacier</i> or <i>glacial</i> are the commonly used terms in discussing sediment deposits; <i>ice sheet</i> is more commonly used in discussing the Pleistocene ice itself.</p>
<p>8. Why do you think the sediments older than 14,000 years ago have no pine, spruce, or oak pollen?</p> <p><b>The area was covered by a continental ice sheet or at the edge of an ice sheet. No trees could grow in such a cold climate and such poor soil.</b></p>	<p>(C)(T) Again, students need to combine their knowledge of geological history at the global and continental scale with the evidence from the local core.</p>

### Pedagogical Content Knowledge Guide

(continued)

Answer Key	Critical Thinking Skills for Students
<p>9. Based on your knowledge of Earth history, what event in geologic history do you think is recorded in the Allamuchy Pond sediments? (<i>Hints:</i> Think about what was happening in North America at this time in geologic history and the changes that you documented in questions 2c, 3, 5, 6, and 8.) <b>Explain</b> your answer.</p> <p><b>An interpretation of the Allamuchy Pond sediments that is consistent with all of the available data is that the sediments record the transition from glacial to interglacial conditions at the end of the Pleistocene and beginning of the Holocene.</b></p> <ul style="list-style-type: none"> <li>• Before 14,000 years ago, the region of Allamuchy Pond was under an ice sheet or at the edge of an ice sheet. Evidence is the unsorted mix of pebble and clay.</li> <li>• By 14,000 years ago, the climate was warming and the ice sheet had melted back, uncovering this region. Evidence is the transition from the unsorted mix of pebbles and clay to pond mud with cold-climate tree pollen.</li> <li>• By 10,000 years ago, the climate in this region had warmed even more. Evidence is the transition from cold-loving trees (pine and spruce) to warmer climate trees (oak and some pine).</li> </ul>	<p>(C, T, S) This final question gives students one more opportunity to integrate all of the information and insights they have assembled in the preceding questions.</p> <p>Note that knowledge of Earth history plus evidence from the local core is sufficient to assemble an interpretation that is logical and internally consistent. But it is not absolutely, positively, 100% guaranteed to be the truth about what actually happened at this site at this time. This level of uncertainty is typical when geologists try to unravel the sequence of events of the past at a given site. All interpretations are tentative, subject to revision as further data are collected.</p>

### Common Student Misconceptions

- *Students may not understand that the oldest pollen and sediment are plotted at the bottom of the graph in Figure 1.3 and thus they may answer all the questions backward with respect to time.*

If students make this mistake in step 1b, they probably lack this aspect of temporal understanding. One possible reason for the mistake is that the first-deposited sediments (at the bottom of the core) are associated with the largest numbers for both depth and age; students may expect that numbers should increase in size with time as they would in an AD timeline. Providing an analogy to years BC encountered in history classes may help students.



- *Students may conclude there were no trees on Earth before 14,000 years ago.*

It may help to ask students where the three tree types in this puzzle would have existed prior to 14,000 years ago (answer: south of this location).

- *Students may think that these dramatic pollen changes imply a much larger temperature change than there really was.*

Comparison of these data to the modern ranges of these trees suggests that there was a  $\sim 3^{\circ}\text{--}4^{\circ}\text{C}$  ( $6^{\circ}\text{--}8^{\circ}\text{F}$ ) difference in average summertime temperatures between 14,000 years ago and today (see Extension Activity #7, p. 17). This may be a good opportunity to point out to students that even seemingly small changes in average temperature have large effects on ecosystems. Making this point will help students put into perspective the  $3^{\circ}\text{--}4^{\circ}\text{C}$  annual temperature increase that is forecast for the coming century.

- *Students may also think there was no sedimentation or pollen preservation after 7,000 years ago.*

Considerable time and expense is required to extract and analyze pollen records. Therefore, scientists often focus on specific questions they would like to answer or on specific sections of the core to analyze. See also the answer under “Tough Questions (With Answers),” page 14, to the question “Why does the pollen data start 6 m below the surface?”

- *Students may think that the pollen abundance data tell us the precise makeup of the forest surrounding the pond.*

These data tell us generally how abundant these trees were at different times in the past, but they should not be translated directly into the composition of the surrounding forest (i.e., just because the pollen at 14,000 years ago is 45% pine doesn’t mean that the forest was 45% pine trees). For one thing, different types of tree pollen travel different distances. Pine pollen travels especially far, so the forest between 10,000 and 14,000 years ago might not have been quite as pine-dominated as is suggested by the pollen data. However, we can still say that pine became less abundant relative to oak after 10,000 years ago.

- *Some students may not understand that a warming of the climate can cause changes in the ranges of trees.*
- *Some students may not recall that glaciers create poorly sorted deposits of sediments.*

### Pedagogical Content Knowledge Guide

#### Tough Questions (With Answers)

These are questions that your students may ask you or that you could ask them to provide additional challenge.

*Q. What is “pond mud”?*

A. The “pond mud” in these cores, which is referred to by researchers as gyttja (yut’ ya), is dark, organic-rich, partly fluid sediment.

*Q. Why don’t the pollen percentages in Figure 1.3 add up to 100%?*

A. We chose to present three abundant genera; however, the core contains pollen from roughly a dozen additional tree species. If reported, these would account for the difference. The full data are presented in Peteet et al. 1993 (see “Source for Data Puzzle #1” on p. 18).

*Q. Why does the pollen data start 6 m below the surface?*

A. The top 6 m of the core were not studied by the researchers (Peteet et al. 1993; see “Source” at the end of this guide) because they were primarily interested in the first several thousand years after the retreat of the ice sheets.

*Q. How is pollen separated from pond mud for identification and analysis?*

A. Preparing samples for pollen counting is a difficult process. First, most of the rest of the sediment is dissolved using a variety of acids (often hydrofluoric, hydrochloric, and sulfuric acids). Other steps help decompose the organic material. The sediment is screened to collect the pollen size fraction, between 7 and 150 microns. The pollen is mounted on slides in oil and stained to allow easier identification. Researchers then identify and count at least 300 grains from each sample.

*Q. If white pine generally marks moderate climates, why does its modern range extend so far south?*

A. The white pine forests to the south are largely at higher elevations, where it is cooler. Note that the range follows the spine of the Appalachians.

*Q. If tree ranges are determined by temperature, why aren’t the red oak and white pine species found farther west?*

A. There are a number of factors that influence the range of flora, including red oak and white pine. Temperature range, precipitation amounts, soil type, topography, and competition are all important. Generally it is too dry in much of the Midwest for red oak and white pine. For specific information on these and other tree species, go to Plant Ranges and Responses to Climate Change under “Resources.”



*Q. Why does the pine spike in abundance just before it drops at around 10,000 years before present?*

- A. The scientists who collected these data hypothesize that pine initially took advantage of the available niche space created by the decline of spruce. As temperatures continued to increase, the pine wasn't able to compete with oak, so pine declined while oak increased in abundance.

*Q. How were the ages of the sediments determined, and why is there no date at the bottom of the core?*

- A. The dates on the graph were determined by radiocarbon (aka carbon-14) dating, a common scientific procedure for determining the age of organic materials (see "Resources," Resources on Methods Used in the Study of Paleoclimate, for further explanation). The dates represent individual sampling depths within the core and were determined from identified seeds, cone scales, and/or needles contained in the core with the pollen. Each analysis is time-consuming and costly, which limits the number of analyses completed. The unsorted pebble and clay unit at the bottom of the core is glacial till, made up of rocks that eroded from beneath the moving ice sheet. In this environment, plant parts suitable for dating are not usually preserved.

*Q. Why does the age axis increase in uneven increments?*

- A. Changes in sediment accumulation rates and compaction of sediments near the bottom of the core cause the relationship between age and depth in the core not to be constant.

*Q. If the unsorted pebble and clay unit is a glacial till and the mud is a pond deposit, why is the transition from glacial sediments to pond sediments so abrupt in Figure 1.3? Wouldn't it have taken some time for the ice sheet to melt back and for organic-rich sediments to start accumulating in the pond?*

- A. The actual transition is slightly more complicated than is shown in the simplified diagram (Figure 1.3); the bottom of the pond mud section is much more clay-rich than higher up in the section, reflecting slower organic sedimentation and increased runoff from newly deglaciated land around the pond when it first formed. Still, even in a more detailed diagram than this one, the change from glacial sediments to pond sediments would appear to be fairly abrupt at this scale. This impression results from the fact that at the average sedimentation rate of the bottom section of the core (10,000 to 14,000 years ago), 100 years is represented by only 4 cm of sediment. A century is likely enough time for the beginnings of a forest to develop, but

### Pedagogical Content Knowledge Guide

this length of time, though long in terms of a human lifetime, appears to be nearly instantaneous in most sedimentary records.

*Q. When pond mud solidifies, what rock will it become? How about the mix of pebbles and clay?*

A. The pond mud is composed primarily of clay and organic matter, which compacts and cements to become shale. A mixture of pebbles and clay becomes conglomerate.

### Extension Activities

- The paleoclimate lesson plan from the Cary Institute of Ecosystems Studies (see first entry under “Resources”) provides a hands-on activity involving pollen-based reconstructions of past climates for the New York/New Jersey area.
- Discuss the three animated *Ice Age* movies (2002, 2006, 2009). What was good science, and what was entertainment?
- Ask students to suggest what sorts of additional evidence they would collect to test their hypotheses from the final question in the puzzle. Conduct research into additional evidence for climate change during this period using the General Climate and Paleoclimate section under “Resources.”
- Explore the reasons why the ranges for red oak and white pine don’t extend into the western United States. Have students suggest other factors besides latitude that might influence which species live in certain areas. Compare graphs of average monthly rainfall and temperature from locations at the same latitude and elevation in the western and eastern United States (available at the NOAA U.S. climate site: [www.cdc.noaa.gov/USclimate](http://www.cdc.noaa.gov/USclimate)).
- The Data Puzzle explored the impact on trees of climate change over thousands of years. To explore how climate change in recent decades has affected plants and animals, compare graphs showing changes in flowering and birthing times (and possibly migration times) for more recent years. How would a rise in average temperature impact flowering/birthing timing of various species? (See under “Resources,” Plant Ranges and Responses to Climate Change, the changing phenology site.)
- If improving quantitative skills is one of your teaching goals, have students calculate approximate accumulation rates for the two sections of the core (7,000–10,000 and 10,000–14,000 years ago) (*Answer: Approximately 0.6 and 0.4 m/1,000 yr., respectively*). Discuss the possible

reasons for the differing accumulation rates. (*Answer: Two possibilities are changes in the rate of sediment input and sediment compaction deeper in the core.*)

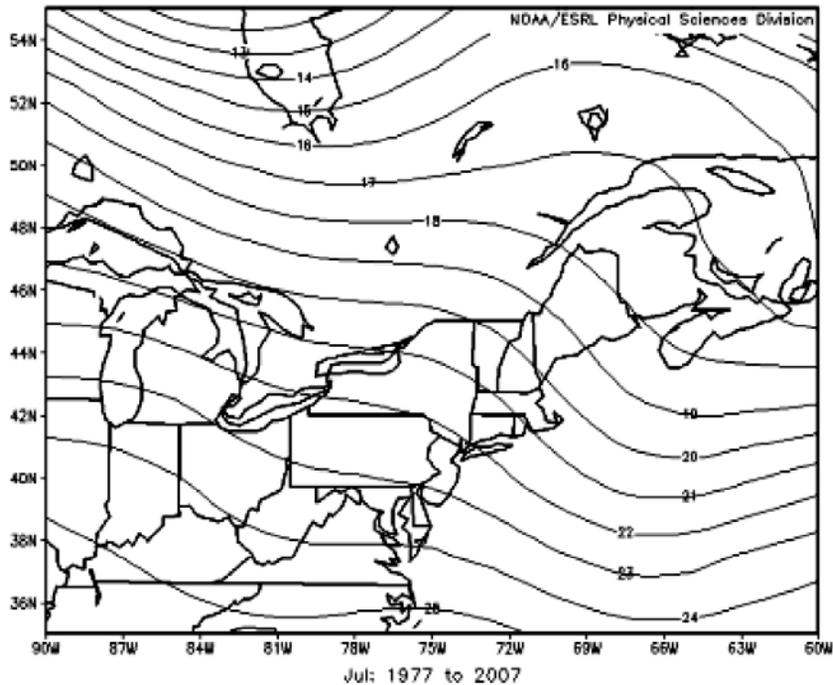
- We can use the modern climate and tree range maps to obtain a quantitative estimate of how much colder it was near Allamuchy Pond between 10,000 and 14,000 years ago. (Your students will need a map of North America to complete this activity.)

First, have students use the range maps and the pollen data to identify the areas of North America where the trees today are like the trees near Allamuchy Pond before 10,000 years ago. (*Answer will include some combination of Maine, southern Quebec and Ontario, northern Michigan, Wisconsin, New Hampshire and/or Vermont.*)

Second, explain to students that these tree species are most sensitive to summer temperatures. That is, the ranges of these trees are determined more strongly by summer temperatures than by factors like rainfall or winter temperatures. The map in Figure 1.6, page 18, uses isotherms to show average July temperatures in northeast North America for 30 years (1977–2007). Have the students compare the July temperature near Allamuchy Pond to the July temperature in the area you identified in the first part of this extension activity; approximately how much colder was the July temperature between 10,000 and 14,000 years ago than it is now? (*Answer: The average July temperature near Allamuchy Pond is approximately 22° to 23°C on the isotherm map (Figure 1.6). The average July temperature in New Hampshire and Vermont is approximately 20°C, and in Maine it is approximately 18°C. Therefore the average July temperature at Allamuchy Pond was 2° to 5°C cooler than at present.*)

**Figure 1.6**

### Isotherm Map Showing Average July Temperatures in Northeast North America (1977–2007)



Source: National Oceanic and Atmospheric Administration (NOAA), ESRL (Earth Systems Research Laboratory), Physical Sciences Division, Boulder, Colorado, from its website: [www.esrl.noaa.gov/psd](http://www.esrl.noaa.gov/psd). Data set source: Kalnay, E., M. Kanamitsu, R. Kistler, and W. Collins. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society* 77: 437–470.

### Source for Data Puzzle #1

D. M. Peteet, R. A. Daniels, L. E. Heusser, J. S. Vogel, J. R. Southon, and D. E. Nelson. 1993. Late-Glacial pollen, macrofossils and fish remains in northeastern U.S.A.: The Younger Dryas oscillation. *Quaternary Science Reviews* 12: 597–612. [http://pubs.giss.nasa.gov/docs/1993/1993\\_Peteet\\_etal.pdf](http://pubs.giss.nasa.gov/docs/1993/1993_Peteet_etal.pdf)

### Resources

#### New Jersey/New York Regional Climate and Paleoclimate

Cary Institute of Ecosystem Studies. Changing Hudson Program. Paleoclimate of the Hudson Valley (A standards-based lesson on pollen as a key to understanding past climate)  
[www.ecostudies.org/chp\\_land\\_use.html](http://www.ecostudies.org/chp_land_use.html)

Glacial Sediment and the Ice Age in New Jersey (A very nice two-page informative description of glacial extent and glacial deposits in New Jersey from the New Jersey Geological Survey. As the inset map shows, Allamuchy Pond is in Warren County, northwestern New Jersey.)  
[www.state.nj.us/dep/njgs/enviroed/infocirc/glacial.pdf](http://www.state.nj.us/dep/njgs/enviroed/infocirc/glacial.pdf)

## General Climate and Paleoclimate

Center for Pollen Studies, College of Saint Benedict, St. John's University  
[www.csbsju.edu/pollen/images/pollensummarysheets/images\\_new\\_summaries.htm](http://www.csbsju.edu/pollen/images/pollensummarysheets/images_new_summaries.htm)

Exploring Weather and Climate Change Through the Powers of 10  
[www.ngdc.noaa.gov/paleo/ctl](http://www.ngdc.noaa.gov/paleo/ctl)

Glacial advance, retreat, erosion, and deposition animation  
[www.wvnorton.com/college/geo/oceansci/animations.asp#ch8](http://www.wvnorton.com/college/geo/oceansci/animations.asp#ch8)

Ice Age Temperature Changes (Proxy record of past temperatures from Antarctica)  
[http://en.wikipedia.org/wiki/Image:Ice\\_Age\\_Temperature.png](http://en.wikipedia.org/wiki/Image:Ice_Age_Temperature.png)

NOAA (National Oceanic and Atmospheric Administration). Paleoclimatology site (Good background information about paleoclimate studies, with links to data and graphs)  
[www.ncdc.noaa.gov/paleo/primer.html](http://www.ncdc.noaa.gov/paleo/primer.html)

NOAA (National Oceanic and Atmospheric Administration). US average monthly rainfall and temperature graphs to use for comparison of tree ranges  
[www.cdc.noaa.gov/USclimate](http://www.cdc.noaa.gov/USclimate)

Skostad, E. 2001. Myriad ways to reconstruct past climate. *Science* 292 (5517): 658–659.  
 Also at [www.sciencemag.org/cgi/content/full/292/5517/658](http://www.sciencemag.org/cgi/content/full/292/5517/658)

## Plant Ranges and Responses to Climate Change

Changing phenology (flowering/leafing/birthing times) with modern climate change:  
 Earth's Before and After Pics  
<http://discovermagazine.com/2006/nov/climate-change-vegetation>

Climate Change (BBC Weather Centre)  
[www.bbc.co.uk/climate/evidence/phenology.shtml](http://www.bbc.co.uk/climate/evidence/phenology.shtml)

Miller-Rushing, A. J., R. B. Primack, D. Primack, and S. Mukunda. 2006. Photographs and herbarium specimens as tools to document phenological changes in response to global warming. *American Journal of Botany* 93 (11): 1667–1674.  
 This paper examines changes in plant bloom time in relation to changes in climate. By examining photographs and records from a herbarium, the authors find that plants in the Boston area are flowering earlier in the spring than they did 100 years ago, likely due to the significant increase in spring temperatures that Boston has experienced over the same period. The bloom images in this paper may be a useful teaching resource or the paper can be a way to dig a little deeper into the overall topic of the connection between plant data and climatic conditions.  
[www.amjbot.org/cgi/reprint/93/11/1667](http://www.amjbot.org/cgi/reprint/93/11/1667)

U.S. Department of Agriculture Natural Resources Conservation Service. PLANTS Database (species ranges and fact sheets).  
<http://plants.usda.gov/index.html>

### Pedagogical Content Knowledge Guide

#### Resources on Methods Used in the Study of Paleoclimate

Carbon-14 dating: Earth surface processes: U.S. Geological Survey website

<http://esp.cr.usgs.gov/info/lacs/radiocarbon.htm>

Carbon-14 dating tutorial

[www.howstuffworks.com/carbon-14.htm](http://www.howstuffworks.com/carbon-14.htm)

Description and animation of piston coring (used in some lakes and in the ocean, though not in shallow settings like Allamuchy Pond; animation link is at the bottom of the page)

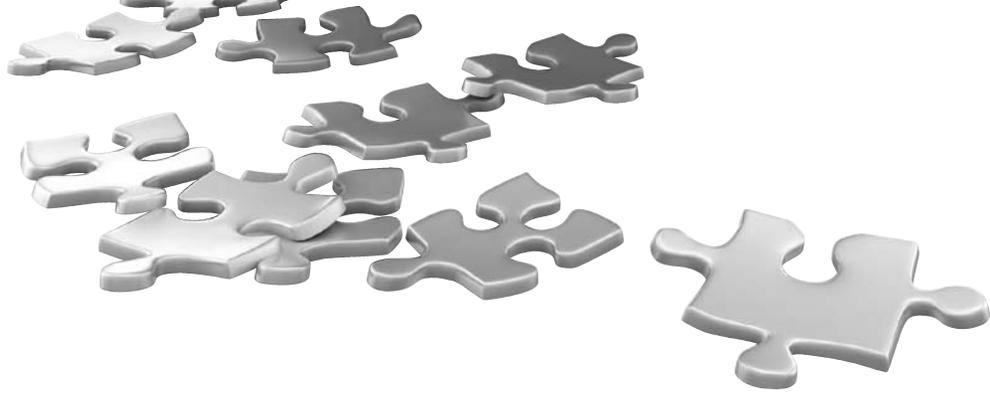
[www.mnhn.fr/mnhn/geo/Collection\\_Marine/moyens\\_mer/Engins\\_de\\_prelevements\\_eng.htm](http://www.mnhn.fr/mnhn/geo/Collection_Marine/moyens_mer/Engins_de_prelevements_eng.htm)

Description (rather technical) and photos of coring apparatus similar to that used in the study of paleoclimate

<http://lrc.geo.umn.edu/livingstone-bolivia.pdf>

Video of coring a larger lake in Scotland

[www.geos.ed.ac.uk/homes/aruther2/sediment.html](http://www.geos.ed.ac.uk/homes/aruther2/sediment.html)



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