

EARTH SCIENCE PUZZLES

MAKING MEANING FROM DATA

KIM KASTENS
MARGIE TURRIN

NSTA press
National Science Teachers Association

Dear Bill,

That long ago BRF data project was the ground for Per of This Data Puzzle project, and the direct source of the data for Puzzle #5, "Where Did the Water Go?" (p. 123). Best wishes in your continued efforts to help students know more, care more and understand more about the Earth and environment, and Thanks for all your help over the years.

Kim

Dear Bill -

It is so great to finally see this in print isn't it! Black Rock Forest will reach a whole new audience! Many thanks for your unfailing support for collaboration in education projects!

Best Maigie



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KIM KASTENS
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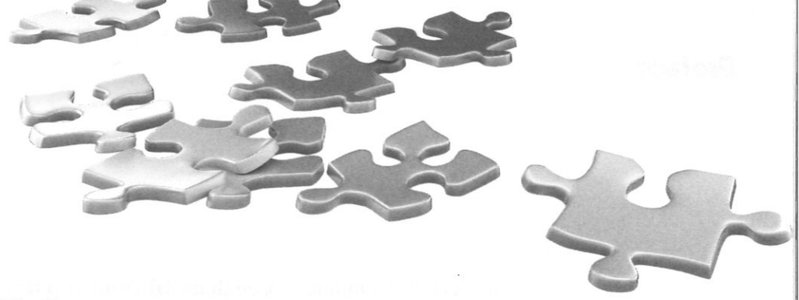


Preface
Why Teach With Data?

Data 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.

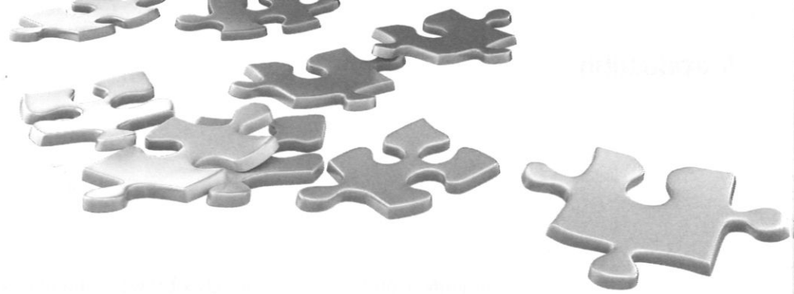
Earth Science Data Puzzles have been developed with the specific goal of overcoming these problems. The major attributes of the puzzles are as follows:

- *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.ldeo.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?

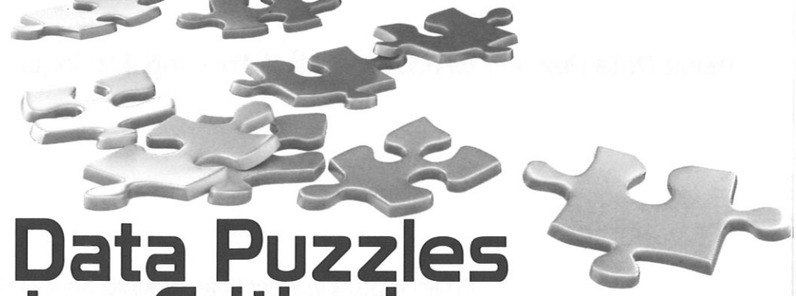
Although we do provide—in the PCK guides—the answers to the questions in each puzzle, we intentionally do not provide scoring rubrics for grading student answers. For our target audience of eighth- through twelfth-grade Earth science students, we think that the most constructive way to use these challenging

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

Critical 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

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.

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

Includes the Critical-Thinking Skills—Ⓢ Spatial, Ⓠ Quantitative, Ⓣ Temporal, and Ⓒ 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.

Ⓒ Ⓠ Ⓢ

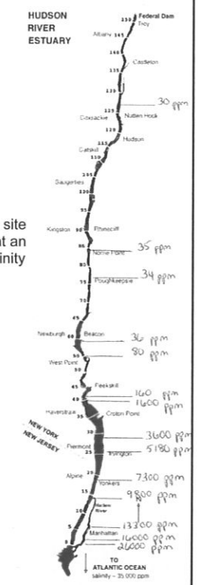
Salinity Data From "A Day in the Life of the Hudson River," Oct. 12

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

Location of the Hudson RiverEstuary



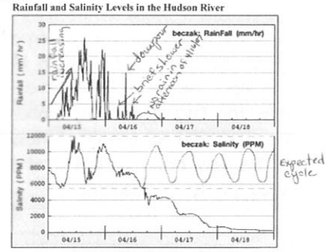
HUDSON RIVER ESTUARY



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 saninity time series.

Ⓒ Ⓣ

Rainfall and Salinity Levels in the Hudson River



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.

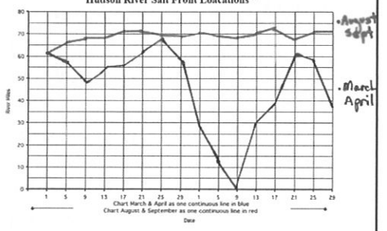
Ⓒ Ⓠ Ⓢ Ⓣ

USGS Salt Front Location * for Hudson Riverin River Miles (RMs)

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	Au	
Mar 25	68		
Mar 29			

* where salinity measures 100 ppm

Hudson River Salt Front Loacations *



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

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
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. The salt front in August and September remained fairly consistent, moving only between RM 62 and RM 73 (approximately Newburgh to Poughkeepsie). 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.	(S)(T) Students interpret the position versus time graph in terms of • *position* (in March and April the salt front is always closer to the ocean—i.e., farther south—than in August and September) • *variability of position* (in August and September, the salt front location is more stable than in March and April)

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.

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.

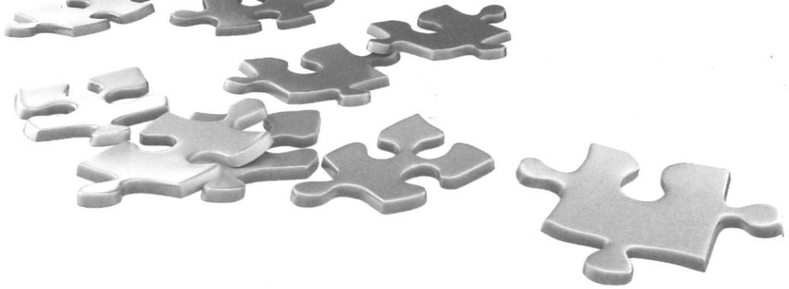
The transition from an elementary or a middle school mode of learning from data to a college-level or adult mode is complicated and multifaceted. High school represents an opportunity to make this transition. Elementary and middle school students typically interpret one data set at a time, whereas college 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.
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- "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.
- "How much heat is released by a seafloor hydrothermal vent?" The late Karen von Damm, marine geochemist, provided data and advice regarding this puzzle. Research scientists with the RIDGE 2000 program—Dan Fornari, Julie Bryce, Marv Lilley, Rachel Haymon, Florencia Prado, and Vicky Ferrini—helped to interpret the data and provided information and insights about the field area. Development of this puzzle was also supported by NSF grant OCE 02-28117.

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Brent Turrin, Rutgers, The State University of New Jersey

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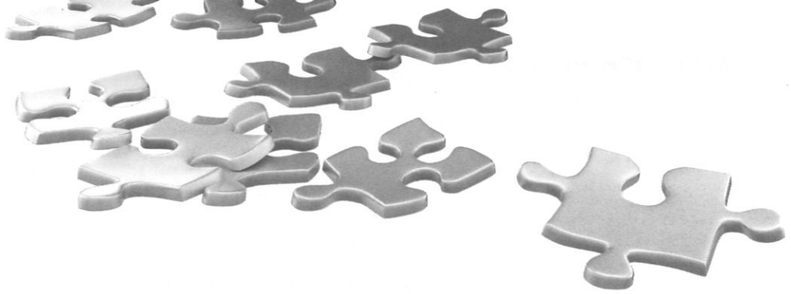

About the Authors

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Topic: Paleoclimate

Data Puzzle 1

Student Pages

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

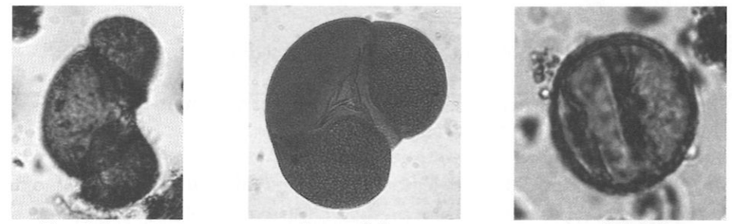
For those who know how to interpret them, pond sediments can provide important records of the past. Information from layer after layer of sediments can be put together to construct a timeline of the history of a pond site. In the early 1990s, a group of scientists and students went to Allamuchy Pond 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 publically available from *www.census.gov.*

Figure 1.2
Grains of Pine, Spruce, and Oak Pollen

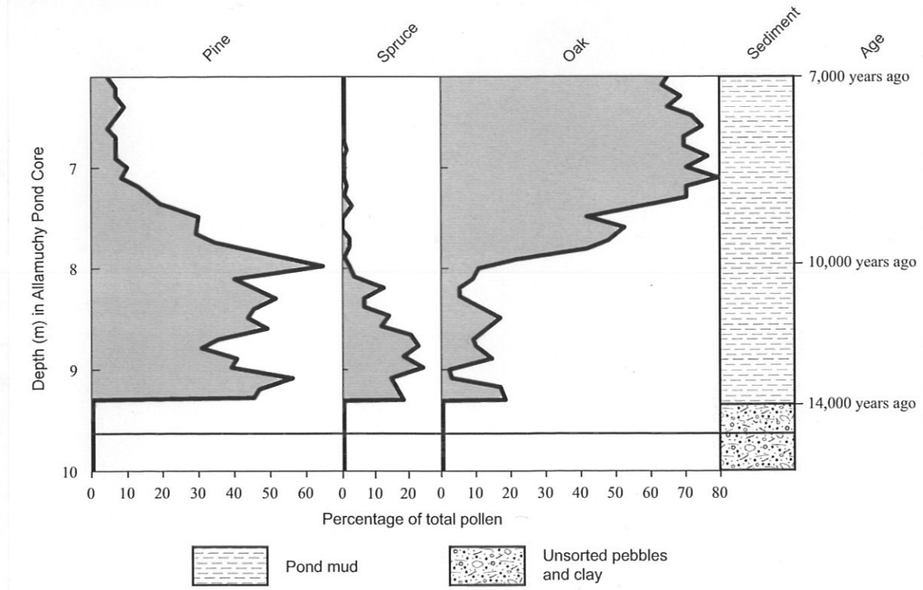


Source: Courtesy of Dorothy Peteet.

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*

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.

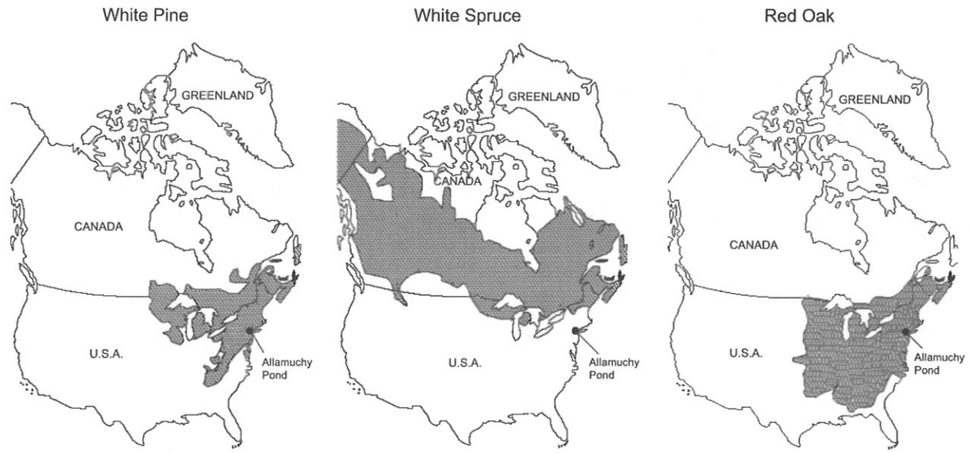
3. According to the data, what were two specific changes that occurred approximately 14,000 years ago?

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*. 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.



Data Puzzle 1

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.

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!

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)

- 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*) 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.

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

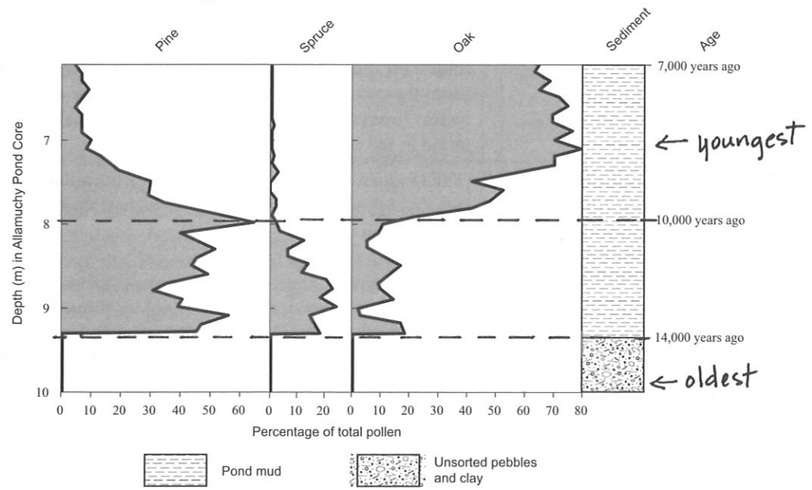
Teaching Note: To solve the puzzle, students must use critical-thinking skills. Each use of critical thinking is described in the right-hand column and is coded as follows: (S) Spatial, (T) Temporal, (Q) Quantitative, and (C) Concept-based. See pages xv–xvii for a discussion of these four types of critical-thinking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

Answer Key	Critical Thinking
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). 1b. Label the oldest sediment and the youngest sediment on the graph. The top of the graph should be labeled "youngest" and the bottom of the graph should be labeled "oldest" as in Figure 1.5.	(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. Or (T)(S) Student may reason out that the younger sediments must be deposited on top of the older layers.

Answer Key	Critical Thinking
2a. According to the data, what types of trees were present in the region between 14,000 and 10,000 years ago? pine, spruce and oak 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? pine and oak, and a very small amount of spruce 2c. Describe the major changes in tree types in the region from 14,000 years ago until 7,000 years ago. 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.	(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. (S)(T) Students interpret the *shape* 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. (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. (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.

Figure 1.5

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*

(continued)

Answer Key	Critical Thinking
3. According to the data, what were two specific changes that occurred approximately 14,000 years ago? • The sediment type changed from pebbles and clay to pond mud. • Pollen of pine, spruce, and oak began appearing in the sediments.	(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. (T)(C) Once again, as in step 2, students use their knowledge that underlying sediments record earlier time intervals than overlying sediments.
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. 4a. Which tree species lives in the coldest locations? spruce 4b. Which tree species lives in the warmest locations? oak	(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. (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. (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.
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? It was colder back then (14,000-10,000 years ago) than it is today.	(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. (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.

Answer Key	Critical Thinking
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. It was colder from 14,000 to 10,000 years ago than from 10,000 to 7,000 years ago. 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.	(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). (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 *evidence from the Allamuchy Pond 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? glaciers and landslides 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. 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.	(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. (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. ***Teaching Note:*** The terms *ice sheet* and *continental glacier* are synonymous in this answer. *Glacier* or *glacial* are the commonly used terms in discussing sediment deposits; *ice sheet* is more commonly used in discussing the Pleistocene ice itself.
8. Why do you think the sediments older than 14,000 years ago have no pine, spruce, or oak pollen? 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.	(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.

(continued)

Answer Key	Critical Thinking Skills for Students
9. Based on your knowledge of Earth history, what event in geologic history do you think is recorded in the Allamuchy Pond sediments? (*Hints:* 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.) **Explain** your answer. 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. • 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. • 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. • 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).	(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. 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.

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 ~3°–4°C (6°–8°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°–4°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.*

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 Paleolimate, 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

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

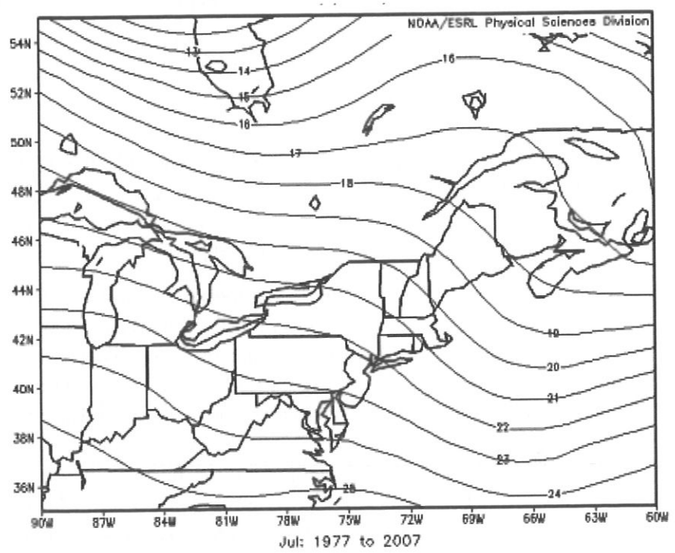
- The paleoclimate lesson plan from the Cary Institute of Ecosystems Studies (see first entry under "Resources") provides a hands-on activity involving pollen-based reconstructions of past climates for the New York/New Jersey area.
- Discuss the three animated *Ice Age* movies (2002, 2006, 2009). What 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*).
- 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. 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*

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

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

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

Exploring Weather and Climate Change Through the Powers of 10
www.ngdc.noaa.gov/paleo/ctl

Glacial advance, retreat, erosion, and deposition animation
www.wwnorton.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

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

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

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*

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

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

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

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

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

Student Pages

How do we decide "weather" or not to proceed with a trip?

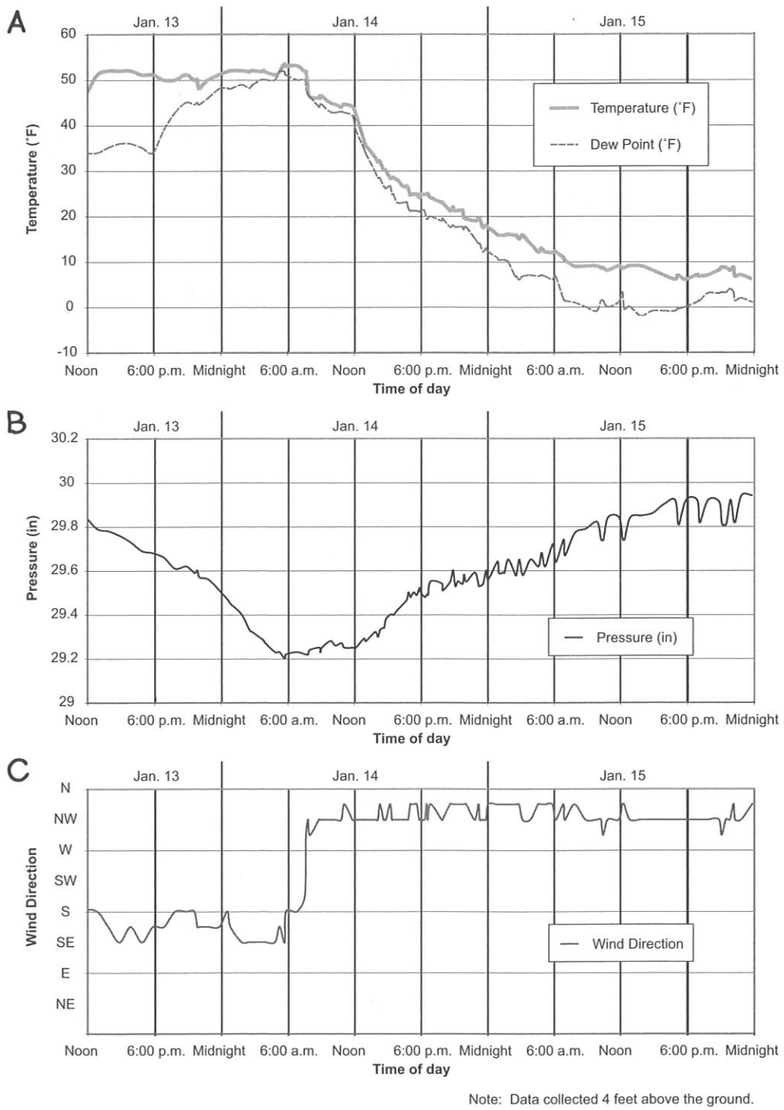
It's January 14, and Binghamton (New York) High School has an outdoor, "weather permitting," field trip scheduled. At 6:00 a.m. the school principal is pacing the floor, trying to decide if today's trip should proceed or be canceled. The temperature is a mild 50°F and the wind is from the south, just like it was all day yesterday, but on his way to work today the principal heard on his car radio that today's forecast was for snow with colder temperatures. Snow seems so unlikely with a temperature of 50°F! Maybe the principal should talk to the Earth science class; perhaps the students in that class could give some insights into the weather system that is in the area. Complete this Data Puzzle to decide what the principal should do.

Directions: Follow steps 1 to 13 below. Use additional sheets of paper as needed and answer in complete sentences.

1. Base your answers to steps 1 to 3 on the data in Figure 2.1. Based on the data, describe how the temperature changed from January 13 through January 15.
2. What happened to the temperature just after the pressure reached its lowest point?
3. Now let's take a look at the wind data. Recall that winds are named for the direction ***from which*** they blow. Use the chart in Figure 2.2 to organize your information about the wind direction.

Figure 2.1

Weather Conditions (Temperature, Pressure, Wind Direction), Jan. 13–Jan. 15, Binghamton, NY



Source: Created by Deena Kramarczyk using data from the Weather Underground website (*www.wunderground.com*).

Note: Data collected 4 feet above the ground.

3a. Complete the compass rose at the top of the chart by adding *S*, *E*, and *W*.

3b. In the blocks of spaces provided in the chart, draw arrows to show the wind direction. (A few arrows are completed for you.)

3c. Which direction was the wind coming from before the pressure drop?

3d. Which direction was the wind coming from after the pressure drop?

4. Considering all of the available temperature, pressure, and wind data, what kind of weather event occurred in Binghamton on January 14? Explain your evidence.

5. Based on the data available at 6:00 a.m. on January 14, what decision do you think the principal should have made about the field trip? Give supporting evidence to back up your opinion. (*Hint*: You might find it easier to answer this question if you cover the three graphs in Figure 2.1 after 6:00 a.m. on the 14th.)

STOP

Discuss steps 1 to 5 with your teacher before moving on to step 6.

Figure 2.2

Wind Direction Changes, Jan. 13–Jan. 15, Binghamton, NY (to be completed by student)



Jan. 13		
Noon	6:00 p.m.	Midnight
↑		

Jan. 14			
6:00 a.m.	Noon	6:00 p.m.	Midnight
	↘		

Jan. 15			
6:00 a.m.	Noon	6:00 p.m.	Midnight
		↘	

6. Recall that *dew point* is the temperature at which water *condenses* (changes from gas to liquid) from an air mass. Compare the graph lines in Figure 2.1 for temperature and dew point. Do temperature and dew point appear to be related? If so, how?

7. When the temperature and dew point are equal or nearly equal, clouds, fog, and precipitation are likely to occur. Do you think there was precipitation in Binghamton on January 13, 14, or 15? If so, when? Explain your answer.

8. There were some snow flurries in Binghamton during this interval of time. When was the most likely time for snow flurries to occur, according to the weather data? Explain your answer.

9. Based on the available data, what type of air mass do you think was sitting over Binghamton on January 15? Describe and name the air mass. Use the terms *maritime, continental, tropical,* and/or *polar* in your answer.

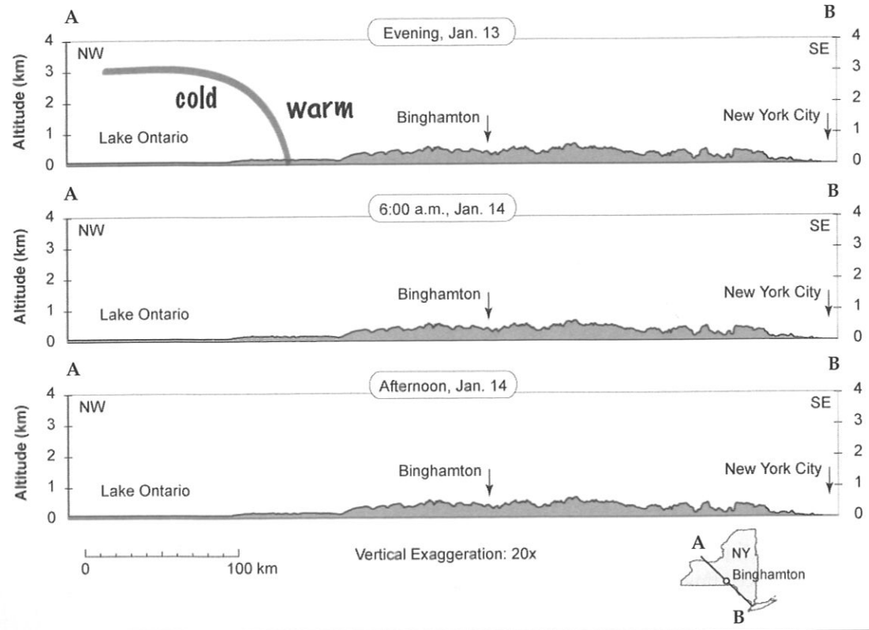
10a. Based on your knowledge of Earth science, describe the direction of movement of most air masses and fronts across North America.

10b. From what geographic region do you think the January 15 air mass originated? Explain your answer.

11. Figure 2.3 is made up of three topographic profiles that you will use as bases to sketch in the advance of the cold air mass. (The first one has been done for you.) The vertical axis shows altitude above sea level and the gray shading indicates the elevation of the land. The location of the geographical area in the figure is shown by a NW/SE trending line labeled A, B on the inset map. Notice that each profile represents a different time on January 13 or January 14. The inset map shows the location of Binghamton, New York, where the weather observations of Figure 2.1 were collected. *Your next step:* On the profiles in Figure 2.3, sketch a representation of the leading edge of the cold air mass.

Figure 2.3

Profiles, Jan. 13–Jan. 14, Binghamton, NY (to be completed by student)



Source: Topography from GeoMapApp (*www.geomapapp.org*), part of the Marine Geoscience Data System (MGDS; *www.marine-geo.org*).

12. Now that you have considered all the data available, what decision do you think the principal should have made? Explain your answer.

13. A student who is monitoring the barometric pressure and wind direction for a different area of the northeastern United States notices that the pressure has been dropping steadily for several hours and that the wind has shifted from northerly to southerly. What prediction can you make about how the temperature will change over the next few hours at that new location? Explain your answer.

Weather
Topic: Forecasting



Data Puzzle 2

Pedagogical Content Knowledge Guide

How do we decide "weather" or not to proceed with a trip?

In this Data Puzzle, students will observe how temperature, dew point, pressure, and wind direction change over time, and they will interpret this suite of related changes as due to the passage of a cold front. They will recognize relationships among the variables and get a sense of cause and effect. They will then use their understanding to predict temperature changes for a different location based on data provided about wind and pressure changes.

This puzzle works well in an Earth science or meteorology course.

Prior Skills Needed

- Basic graph-reading skills
- The ability to visualize Earth phenomena in 3-D, including changes over time

Prior Understandings Needed

- **A front** is the boundary between two air masses. Fronts are characterized by a sudden change in atmospheric properties, including air temperature, humidity, wind direction, precipitation, and air pressure.

Aha! Insights

- People talk about forecasting the weather, but we often don't realize that our weather is someplace else (most often, farther west) before it comes to us.
- Fronts are the leading edge of air masses, so when a front comes through, our weather is about to change because our air mass is about to change.
- "Wiggles" on a graph are directly related to experiences like rain and snow.
- A north wind feels cold and a south wind feels warm.

- **Air masses** can be visualized as large domes of air with similar conditions of temperature and moisture throughout the dome. Air masses move around the Earth bringing weather conditions from their region of origin to wherever they move.
- **Dew point** is the temperature at which moisture would begin to condense out of a given mass of air if that air mass were gradually cooled. Dew point is always less than or equal to the current air temperature. At 100% humidity, dew point and air temperature are equal (the air is saturated and water droplets are likely to form).
- **Prevailing winds** in the United Stated blow primarily from west to east and steer air masses in that direction, but surface conditions can change things locally.
- **Storms** are associated with fronts. Storms form when air masses meet because the density difference between cold and warm air causes the warmer air mass to rise over the colder air mass. As the air mass rises, it cools to the dew point. As the values of temperature and dew point converge, clouds, fog, and precipitation are likely.
- **Winds** are named for the direction from which they come, so a north wind comes from the north.
- **Air masses** are named based on where they come from, and their names are linked to particular weather conditions:
- Scientists use lowercase letters to tell you about the moisture content of air masses: maritime (m) air masses form over water and bring wet, humid weather; continental (c) air masses form over land and bring dry weather.
- Scientists use capital letters to tell you about the temperature of air masses: polar (P) air masses form over areas near the poles and bring cold weather; tropical (T) air masses form over areas near the equator and bring warm weather.

Teacher Preparation

1. Work through the steps in the data puzzle yourself (pp. 21–25). Use Step-by-Step: How to Solve Data Puzzle #2 (pp. 30–38) 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 in this book 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 this puzzle to review with students **before** they work on the puzzle—for example, *air mass, front, cold front, warm front, barometric pressure, prevailing winds, maritime, continental, tropical, polar, dew point, humidity,* and *saturated.*
4. Gather and prepare suggested materials:
   - For each student: ruler, pencil, a copy of Data Puzzle #2 (pp. 21–25)
   - For the class: map of the world
   - Make sure the graphs in Figure 2.1 photocopy well enough that students can see both the horizontal and vertical lines.
5. Plan any pre-puzzle activities (see next section) and extension activities (p. 41). Check the Data Puzzles website (*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

- Have students observe and record daily temperatures and rainfall for your area for a week or two. For the same period of time, cut out daily weather maps from the newspaper or save images from a website. The map should include location of fronts, high and low pressure areas, and precipitation. Surface weather maps can be found at the American Meteorological Society website (see "Resources") or in many daily newspapers.

  Help students notice that fronts track across the United States from west to east over time, bringing changes in the weather with them. If the temperature changes abruptly from one day to the next in your area, discuss possible reasons with your students. Students should notice that cold fronts bring cold weather and tend to come from the north, while warm fronts bring warm weather and tend to come from the south. Help students realize that cold air usually comes down

from Canada or the northern Pacific Ocean and warm air usually moves northward from the southern Pacific Ocean, Mexico, or Gulf of Mexico.

- To demonstrate dew point, set up a glass partially filled with room temperature water and then add ice cubes. Have the students observe the condensation that forms on the outside of the glass as the water and glass are cooled by the ice, thereby cooling the air in contact with the glass.
- Under "Resources," see Learning to Read a Barometer (a discussion of air pressure, isobars, and weather and pressure relationships).

Step-by-Step: How to Solve Data Puzzle #2

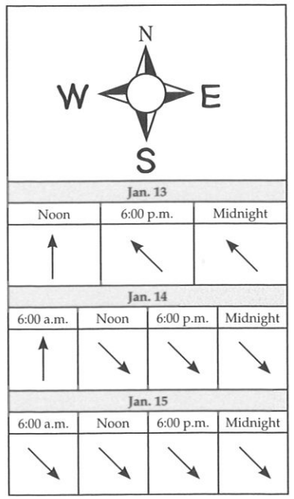
Teaching Note: To solve the puzzle, students must use critical-thinking skills. Each use of critical thinking is described in the right-hand column and is coded as follows: (S) Spatial, (T) Temporal, (Q) Quantitative, and (C) Concept-based. See pages xv–xvii for a discussion of these four types of critical-thinking skills. Decision making is also part of the skill set that students use to solve this Data Puzzle. Decision-making skills are noted where appropriate.

Answer Key	Critical Thinking
1. Base your answers to steps 1 to 3 on the data shown in Figure 2.1. Based on the data, describe how the temperature changed from January 13 through January 15. The temperature was fairly steady on January 13 and into January 14. At approximately 6 a.m. on January 14, however, it began to fall significantly. It continued to fall throughout January 14 and 15. *Teaching Note:* Make sure students realize the temperature was high and steady in the morning and fell throughout the day. The temperature did NOT simply fall at night and rise in the daytime, as is the usual expected day/night pattern.	(T) Students must translate from a time-series graph into a verbal description of the behavior of an Earth attribute over time. Many students are accustomed to reading only individual numerical values off a graph; it may be a new skill to identify and describe *sections* of a line graph. (T) Students must look through the small wiggles in line graphs to identify two time intervals of distinct behavior: • an interval of near-constant temperature from the beginning of the record through 6 a.m. on January 14 • an interval of cooling temperatures from 6 a.m. January 14 through the end of the record. (T)(C) At this point, some alert students may recall that the normal temperature pattern is colder at night and warmer during the day and will notice that the data do not match this pattern.
2. What happened to the temperature just after the pressure reached its lowest point? The pressure reached its lowest point at 6 a.m. on January 14. The temperature began to fall immediately afterward. It dropped from ~53°F to ~25°F in the 12 hours after the pressure reached its lowest point.	(T) Students must translate from a question posed in temporal vocabulary to a time-series graph, equating "after" in the question to rightward on the graph. (S) Students must compare the visual patterns on two different graphs—that is, they must locate the lowest point on the pressure graph and then locate the corresponding point on the temperature graph. (T) Students must translate information from a time-series graph into words and numbers that describe the behavior of air temperature over time. To do so, the student needs to see the graph in its entirety as portraying the *behavior* of air temperature over time, not just as a tool for looking up a particular temperature at a particular time.

(continued)

Answer Key	Critical Thinking
3. Now let's take a look at the wind data. Recall that winds are named for the direction from which they blow. Use the chart in Figure 2.2 to organize your information about the wind direction. 3a. Complete the compass rose at the left end of the chart by adding *S*, *E*, and *W*. See Figure 2.4. 3b. In the blocks of spaces provided in the chart, draw arrows to show the wind direction. (A few arrows are completed for you.) See Figure 2.4. 3c. Which direction was the wind coming from before the pressure drop? south or southeast. 3d. Which direction was the wind coming from after the pressure drop? northwest	(C) Students must know what a compass direction is and must recall or look up which direction is which on a compass rose. (S) Students must first decipher an unfamiliar graph that has wind directions rather than numbers on the vertical axis and read off values for specified times. Then they must translate wind directions from letters ("S," "SE," etc.) to arrows oriented relative to their sketched compass rose. (T) Students need to interpret "before the pressure drop" in step 3c as referring to the time interval from noon on January 13 through 6:00 a.m. on January 14 by referring back to Graph B in Figure 2.1. Similarly, in step 3d, students need to interpret "after the pressure drop" as referring to the time interval from 6:00 a.m. on January 14 through the end of the record. (S) Then they need to find those time intervals on the chart in Figure 2.2 and correctly read the arrows.

Figure 2.4
Answers for Figure 2.2



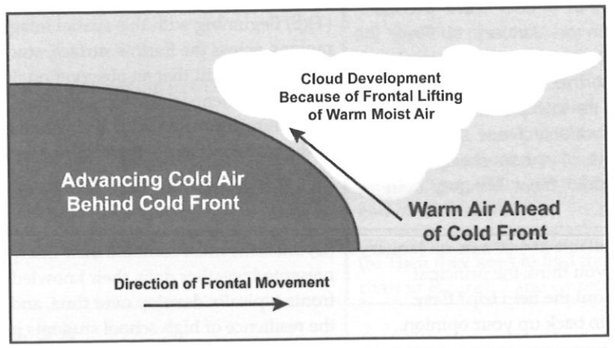
Answer Key	Critical Thinking
4. Considering all of the available temperature, pressure, and wind data, what kind of weather event occurred in Binghamton on January 14? Explain your evidence. *Teaching Note:* If the students are having trouble with this step, put the word *front* on the board as a hint. The temperature, pressure, and wind data together suggest that a cold front passed through Binghamton on January 14. First, the air pressure dropped; then the air temperature got colder. At the same time that the pressure reached its low point, the wind direction shifted suddenly from southerly to northeasterly. All of these changes are consistent with a cold front bringing cold air from the north.	(C) Students recall what they have learned about weather fronts and recognize the symptoms of the passage of a cold front. Students may recall someone in their families or a weather forecaster saying that "a front is coming through" when there is a drastic change in the local weather. (C)(S) Students recall their knowledge of air masses, and they envision two masses of air, one colder than the other, moving together across the locality of observation. (T)(S) Beginning with this spatial image of two air masses moving across the Earth's surface, students make the temporal insight that an observer on the Earth's surface would experience the leading air mass (warm) followed by the trailing air mass (cold) and would experience the passage of the cold front as a temperature drop.
5. Based on the data available at 6:00 a.m. on January 14, what decision do you think the principal should have made about the field trip? Give supporting evidence to back up your opinion. (*Hint:* You might find it easier to answer this question if you cover the three graphs in Figure 2.3 after 6:00 a.m. on Jan. 14.) Answers may vary, but how students defend their decisions is what's key. Answers should state that the falling barometer suggests that a front is coming. Because the weather is now warm for January, it will probably be a cold front, which would be associated with colder temperatures and precipitation. Students may also mention that the narrowing gap between dew point and air temperature suggests precipitation.	(C) Students must combine their interpretation of the presented weather data, their knowledge of how weather fronts typically develop over time, and their knowledge of the resilience of high school students in inclement weather. (Decision Making) Students must confront the difficulties of making decisions about human actions in the face of incomplete information about future environmental conditions.

(continued)

Teaching Note: **Before students move on**, teachers should check to be sure they have identified the weather phenomenon as a cold front (in step 4). At this juncture, it may be helpful to share a cross-section graphic of a cold front because understanding the elements of this kind of graphic will be key in completing step 11. Use Figure 2.5 or a similar image from the students' textbook. Make sure that students (1) understand that this picture is a cross sectional view (aka "profile") of the cold and warm air masses at a cold front and (2) understand the difference between a cross-sectional view and a map view.

Figure 2.5

Cross Section of a Cold Front



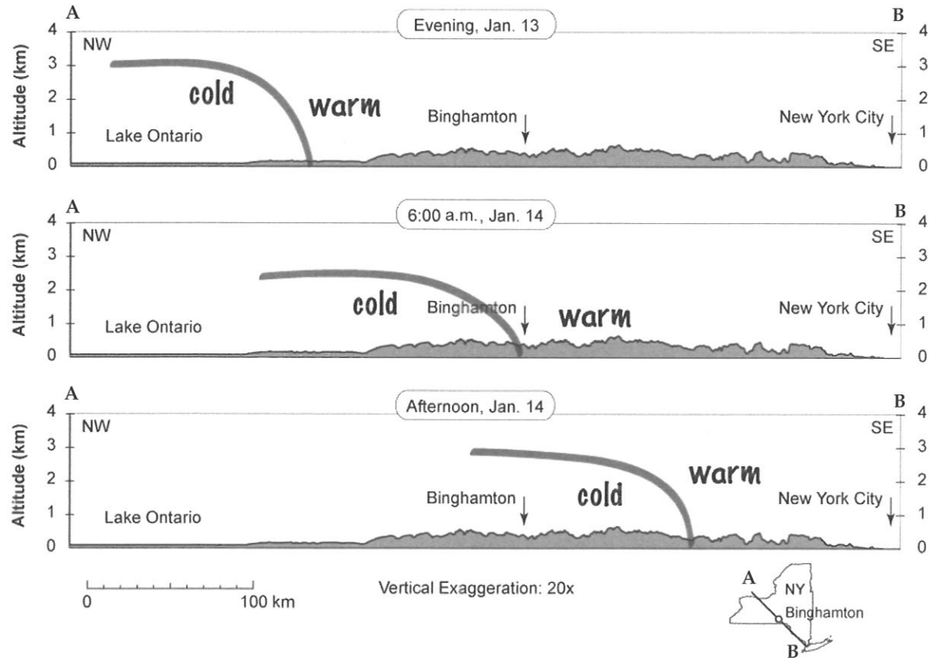
Source: Adapted by Linda Pistolesi from *http://rst.gsfc.nasa.gov/Sec 14_1c.html.*

Answer Key	Critical Thinking
6. Recall that dew point is the temperature at which water condenses (changes from gas to liquid) from an air mass. Compare the graph lines in Figure 2.1 for temperature and dew point. Do temperature and dew point appear to be related? If so, how? Yes, over time the temperature and dew point change together, with the dew point going up when the temperature goes up and down when temperature goes down. The dew point is always less than or equal to the temperature. Sometimes temperature and dew point overlap or touch on the graph.	(T) As in steps 1 and 2, students must translate the graph lines into an understanding of the behavior of environmental attributes over time. In this step, the focus is on comparing and contrasting the behavior of two environmental attributes, temperature and dew point. (S) Students need to "look through" the insignificant wiggles and spot the significant similarities and differences between the behavior of the two lines. (The word *behavior* refers to the way the measured parameter or parameters change over time.)
7. When the temperature and dew point are equal or nearly equal, clouds, fog, and precipitation are likely to occur. Do you think there was precipitation in Binghamton on January 13, 14, or 15? If so, when? Explain your answer. Yes, on January 14 the temperature and dew point were almost the same at around 5:00 a.m. and again at around 8:00 a.m., so there could have been precipitation. (Any answers between 4 a.m. and 2 p.m. are OK if backed up by reasoning about closeness of dew point and air temperature.)	(Q) Students need to decide how close together dew point and temperature need to be to be considered "nearly equal." The amplitude of the small wiggles on the graph (a few degrees) can be taken as an indicator. (T) Students need to read the time-series graph (Figure 2.1, Graph A) correctly, interpolating between marked times, to identify time intervals when temperature and dew point were equal or nearly equal.
8. There were some snow flurries in Binghamton during this interval of time. When was the most likely time for snow flurries to occur, according to the weather data? Explain your answer. Snow requires temperatures below freezing (32°F) and a dew point that is close to the air temperature. There is no time in the weather record that exactly matches these conditions, but the closest conditions occurred in the early afternoon of January 14. That is the most likely time for flurries to have occurred.	(C) Students need to recall that the freezing temperature of water is 32°F and use this information to identify times when the air was cold enough for snow. (T) Then they need to look for times when both (a) air temperature drops below freezing and (b) dew point equals air temperature. *No* times meet these criteria exactly. However, snow flurries were observed, so students must return to the data and find a time interval that most closely matches the two criteria. (C) Students who recall that air temperature generally gets colder with altitude might suggest that the temperature at the high altitude where the snowflakes formed was colder than at the ground where the data were collected.

(continued)

Answer Key	Critical Thinking
9. Based on the available data, what type of air mass do you think was sitting over Binghamton on January 15? Use the terms *maritime, continental, tropical,* and/or *polar* in your answer. Continental polar. The air was very cold even for winter, so the air mass is polar rather than tropical. The air is pretty dry (low dew point), so the air mass is continental rather than maritime.	(C) Students need to recall or look up the terminology for air masses, and combine that knowledge with the air temperature graph (Graph A in Figure 1.2) to determine that the air mass of January 15 was polar rather than tropical. (C) Students need to use their understanding of dew point to recognize that the air mass of January 15 was far below saturated in water vapor and thus was continental rather than maritime.
10a. Based on your knowledge of Earth science, describe the direction of movement of most air masses and fronts across North America. Air masses and fronts typically move from west to east across North America. 10b. From what geographic region do you think the January 15 air mass originated? Explain your answer. The air mass probably originated in the northwest, over Canada, because it is really cold (less than 10°F). Also, because the air mass wasn't very wet, we can infer that it didn't originate over water.	(C) Students need to recall that air masses and fronts move from west to east in North America. (S) Students can combine three pieces of spatial information to infer the air mass's source area: • Air masses usually move from west to east. • The January 15 air mass was very cold, suggesting it came from the north. • The January 15 air mass was dry, suggesting it originated from the continent interior.
11. Figure 2.3 is made up of three topographic profiles that you will use as bases to sketch in the advance of the cold air mass. (The first one has been done for you.) The vertical axis shows altitude above sea level and the gray shading indicates the elevation of the land. The location of the geographical area in the figure is shown by a NW/SE trending line labeled A, B on the inset map. Notice that each profile represents a different time on January 13 or January 14. The inset map shows the location of Binghamton, New York, where the weather observations of Figure 2.1 were collected. *Your next step:* On the profiles in Figure 2.3, sketch a representation of the leading edge of the cold air mass. The important feature to look for in student answers is that they show the front advancing from northwest to southeast over time. The front should be NW (left) of Binghamton in the diagram of the evening of January 13, near Binghamton in the 6:00 a.m. January 14 diagram, and SE (right) of Binghamton in the diagram of the afternoon of January 14. The exact location of the front in the evening and afternoon can vary. Also, the line depicting the boundary between air masses should slope down to the SE. (see Figure 2.6).	(C) Students need to understand what *profile* means and recall what a weather front looks like in profile view. (T)(S) Using information from step 10, students need to realize that the front moved across the landscape over time, causing the observed weather changes, and that the direction of motion was NW to SE. (T) Using information from step 4, students should position the front at Binghamton at 6 a.m. on January 14. (S) Using information from step 10, students need to realize that the under-riding cold, high density air mass must be northwest of the over-riding, warm, low density air mass, and sketch the front dipping toward the southeast. (S)(T) Students need to combine temporal and spatial information to realize that at an earlier time (the evening of January 13) the front would still have been NW of Binghamton; conversely, at a later time (the afternoon of January 14) the front would already be SE of Binghamton.

Figure 2.6
Answers for Figure 2.3



Source: Topography from GeoMapApp (*www.geomapapp.org*), part of the Marine Geoscience Data System (MGDS; *www.marine-geo.org*).

Answer Key	Critical Thinking
12. Now that you have considered all the data available, what decision do you think the principal should have made at 6:00 a.m. on January 14. Explain your answer. Answers may vary to this question. The important thing about the response is that it should draw from the weather information presented on the graphs in Figure 2.1. *Example:* "The students can go on their field trip, but they should bring winter coats because by lunchtime the temperature will be very cold and it might snow."	(Decision Making) Even though the principal and his advisors in the Earth science class had the same data when they answered the question in step 5, they might have reasoned differently, because now they have deeper insights into the workings of the weather system from which the data were drawn.

(continued)

Answer Key	Critical Thinking
13. A student monitoring the barometric pressure and wind direction for a different area of the northeastern United States notices that the pressure has been dropping steadily for several hours and the wind has shifted from northerly to southerly. What prediction can you make about how the temperature will change over the next few hours at that new location? Explain your answer. A shift in wind brings a change in air mass. Because the shift is to a southerly wind, the temperature will likely rise, as a southerly wind will bring in warm air. A warm front is passing.	(C) Students need to recall their understanding of warm fronts and recognize signs of the passage of a warm front from the verbal description (e.g., "drop in barometric pressure" and "drastic change in wind direction"). (C) Students need to understand that a rise or fall in air pressure does *not* necessarily correlate to a rise or fall in air temperature; they should not overgeneralize from the data set of January in Binghamton. Pressure tends to drop with the passage of either a warm front OR a cold front: therefore, the temperature can rise OR fall dramatically following a drop in air pressure. (S) Students need to understand that a southerly wind (in the United States) is a wind from warmer climates and brings a warmer air mass.

Common Student Misconceptions

- *Students may not understand that water vapor is a gas. They may think that water vapor consists of little droplets of water.*

- *Students often do not understand that winds are named for the direction* ***from*** *which they come rather than direction* ***to*** *which they are blowing.*

A northwest wind, for example, is blowing from the NW and toward the SE. This is the opposite from the way ocean currents are named.

- *Students may assume that the temperature will always be warmer in the afternoon than in the morning.*

This is not always the case (as is shown in the data used here). Temperature is dependent on the air mass present, and a colder air mass arriving later in the day will bring in colder temperatures.

- *Students may have difficulties understanding cause and effect during this puzzle.*

A drop in pressure often occurs before temperature rises or falls dramatically, but the pressure change is not the cause of the temperature change. The temperature change results from the arrival of a new air mass.

- *Students often assume that the temperature, pressure, and humidity of an air mass will remain constant.*

In reality all are in flux. If an air mass remains over a region for a long period of time, it will take on the characteristics of that region.

- *Some students equate high humidity with hot air temperature.*

The term *humidity* refers to water content, not to temperature.

Tough Questions (With Answers)

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

Q. What exactly is an air mass?
A. An air mass is an extended section or body of atmosphere that has a fairly uniform temperature and humidity throughout.

Q. Do we always have an air mass?
A. Yes, as an air mass leaves an area it is replaced by another air mass. The boundary between air masses is called a *front* and is an area where the two air masses come into contact.

Q. How big are air masses?
A. Air masses can be a thousand miles across.

Q. Why are there relatively uniform air masses separated by an abrupt front? Why is there not just a gradual gradient from warm to cold as you go north and from moist to dry as you go inland from the coast?
A. In reality the boundary between air masses does have a gradient, changing from warm to cold and/or from moist to dry. When weather maps are drawn, fronts are drawn as lines in the locations where the gradient is the sharpest.

Q. How wide is a front?
A. Fronts vary in width and can be up to 100 miles across in the direction perpendicular to the front. Sometimes the term *frontal zone* is used instead of front to acknowledge that the feature has a substantial width. The width of the frontal zone can be observed from satellite images by the width of the band of clouds.

Q. How long is a front?
A. Weather fronts vary in size and can be more than 1,000 miles long. The length of a front can be determined using satellite images and weather maps that include a distance scale.

Q. What moves air masses around?
A. Air masses are moved by prevailing winds.

Q. Why does it sometimes rain or snow when the temperature and dew point at the surface are NOT the same?
A. The characteristics of the air column from the surface up to the clouds influence the amount and type of precipitation that falls. If the temperature and dew point at higher altitudes are suitable for forming rain or snow, we can get precipitation at the Earth even though the temperature and dew point are not the same at the surface. Meteorologists use equipment called *radiosondes* to measure the characteristics of the air column.

Q: Do all fronts move in the same direction (west to east)?
A. Generally air patterns in the mid-latitudes move from west to east because that is how the prevailing winds run. However, fronts move in different directions at different locations around the world, and local changes in wind patterns can also affect the movement of fronts.

Q: What is the temperature of a cold front—that is, how cold is a cold front?
A. There is no numerical answer to this question. It is a relative measure in that the front brings in colder air than was previously occupying the area.

Q. Can there be cold fronts in the summer when it's not cold?
A. Yes, it's a relative measure. Summer cold fronts bring cooler air than what was previously occupying the area.

Q. Why is there a low-pressure zone at the cold front?
A. Where air masses with different temperatures and/or moisture conditions meet, the air mass with a lower density (higher temperature and/or more moisture) will begin to rise over the higher density air mass. Rising air creates a low pressure at the Earth's surface.

Q. Why is air pressure important to understanding the passage of a front?
A. A drop in air pressure is usually the first sign of the arrival of a front (as in the data set used in this Data Puzzle). This means that a drop in air pressure can be used to forecast a coming change in the weather. Before there were weather satellites and a widespread network of weather-monitoring stations, ship captains, farmers, and others who depended on the weather for their work watched their barometers closely to get advance warning of changes in the weather.

Q. Why might you want to measure wind speed? What insights could you draw from wind speed data?
A. Wind carries heat away from the body, causing people to feel colder or cooler when the wind is stronger; this is the concept of "wind chill." In our scenario in this Data Puzzle, the principal would want this information in making his decision because the students were going on an outdoor field trip. Weather maps often include symbols for wind speed.

Q. Why is the dew point always less than or equal to the air temperature?
A. Dew point is defined as the temperature to which a volume of air must be cooled in order to reach saturation, or relative humidity of 100%. As air cools and reaches saturation, water vapor will condense out of the air into liquid water or dew. Dew point will therefore always be less than or equal to air temperature.

Extension Activities

- If your curriculum includes station models or weather maps, have the students sketch the station models for each six-hour increment on the data set in this puzzle (include Temperature, Dew Point, and Wind Direction).
- From maps on the Weather Underground website (*www.wunderground.com*), examine weather maps from January 13, 14, and 15, 2006, showing the motion of the Data Puzzle cold front. Determine how fast the front moved and in what direction.
- Have students convert °F to °C.
- Calculate the relative humidity at selected times in the data.
- Compare and contrast the cold front data in this puzzle with data from a passing warm front—for example, from Minneapolis/St. Paul, on June 25, 2008. (See "Resources" to access data.)
- Show students a recent meteogram from your area by using the American Meteorological Society's (AMS) DataStreme Atmosphere site. Meteograms from select cities around the country are available by clicking on "Surface" on the AMS website (see "Resources"). Have students compare their recalled experience of that day's weather with the data.
- Look at a current surface weather map showing fronts, which can be found on the AMS site. Have the students look at the meteograms for

cities where the fronts are found. Have students look at the different weather variables to see how they are related. Relationships between temperature and dew point and temperature and wind direction are usually the easiest to identify.

- Send students to the Weather Underground website to check the weather on the day of their birth or other special days.

Sources for Data Puzzle #2

The Weather Underground page has the historic weather information used in this Data Puzzle. To manipulate this data yourself, import the page from January 2006 for Binghamton as a comma delimited file into Excel. Graph T, Td, and P, then select the portion of graph you want to use. (*Note:* To select the comma delimited option, you must scroll all the way to the bottom of the page.)
www.wunderground.com/history/airport/KBGM/2006/1/31/MonthlyHistory.html

For weather maps covering the passage of the Data Puzzle cold front (a full data set for January 13, 2006, Binghamton) go to the following site. (You can also step forward into Jan. 14–Jan. 15 from this site.)
www.wunderground.com/history/airport/KBGM/2006/1/13/DailyHistory.html?req_city=Binghamton+Regional-Link&req_state=NY&req_statename=New+York&&theprefset=SHOWMETAR&theprefvalue=0

Topographic data in Figure 2.3 are from GeoMapApp *(www.geomapapp.org)*, part of the Marine Geoscience Data System (MGDS; *www.marine-geo.org)*, to display the Global Multi-Resolution Topography (GMRT) synthesis data set, as set forth in the following paper: Ryan, W. B. F., S. M. Carbotte, J. Coplan, S. O'Hara, A. Melkonian, R. Arko, R. A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky. 2009. Global Multi-Resolution Topography (GMRT) synthesis data set. *Geochemistry. Geophysics. Geosystems* 10: Q03014, doi:10.1029/2008GC002332; Data doi: 10.1594/IEDA.0001000.

Resources

American Meteorological Society (AMS) (surface weather maps and meteograms)
www.ametsoc.org/amsedu/dstreme

Background Information on Warm and Cold Fronts
www.tpub.com/content/administration/14221/css/14221_313.htm
www.tpub.com/content/administration/14221/css/14221_311.htm

Learning to Read a Barometer (Weather Lesson Plans for Teachers)
http://weather.about.com/od/lessonplanshighschool/qt/barometerlesson.htm

Minneapolis/St. Paul, June 25, 2008, Warm Front Passage Data
www.wunderground.com/history/airport/KMSP/2008/6/25/DailyHistory.html?req_city=Minneapolis-Saint+Paul+International&req_state=MN&req_statename=Minnesota

Weather Underground website (includes historical weather data):
www.wunderground.com

What does an earthquake feel like?

Have you ever felt an earthquake? If you are like most people who live in the central or eastern United States, the answer is probably no. But once in a while, an earthquake is felt in this area. Such an earthquake shook the Northeast on August 10, 1884.

Directions: Follow steps 1 to 9 below. You will be working individually on steps 1 to 3, in a small group for steps 4 to 6, and as a class for steps 7 to 9. Use additional sheets of paper as needed and answer questions in complete sentences.

1. Read the newspaper accounts written about the 1884 earthquake provided by your teacher. (Other students will have different newspaper accounts.) How do these accounts differ from modern newspaper stories?
2. Back in the 1800s, there was no network of seismographs for recording earthquakes. Scientists who study historical earthquakes have developed a scale for quantifying the severity of a given earthquake at a given position, based on observations from eyewitness accounts. Read down through the Modified Mercalli (MM) Intensity Scale (pp. 46–47). MM intensity values are reported in roman numerals from I (barely felt) to XII (catastrophic). (See Figures 3.1a and 3.1b for images of two severe earthquakes.)
3. For the towns described in your newspaper accounts (see step 1), estimate the MM intensity of the August 10, 1884, earthquake. Be sure to pay

Figure 3.1a
Damage Characteristic of Earthquake Intensity MM VIII



Image from April 18, 1906 earthquake in San Francisco, California.

"Considerable damage to ordinary substantial buildings."

Source: U.S. Geological Survey (USGS) Photographic Library, San Francisco earthquake 1906. Photo 83, photographer G. K. Gilbert (Gilbert photo 2893).

attention to *negative* evidence (i.e., what is NOT stated in the article). Your answer may be a range rather than an exact value. Use Table 3.2 on page 48 to organize and document what evidence you used to decide on the MM intensity. A sample answer (from the *Trenton[NJ] Evening Times*) has been filled in for you.

4. *Now come together with two or three other students who have independently evaluated the same articles that you did.* Compare your answers and reasoning with those of the other students. Come to a consensus with your group about the MM intensity value for each town that you read about.

5. On your group's copy of the map (Figure 3.2), plot the Modified Mercalli intensity value for each town that your group considered. Write the intensity value in roman numerals next to the name of the town.

6. Contribute your group's MM intensity values to the Master Map, which will combine data from all the student groups. Plot your group's data on the Master Map by coloring in the circles next to the city names on the map. See the suggested color scheme in Table 3.1.

7. As a class, examine the Master Map. Discuss where you think the August 10, 1884, earthquake was located. With this technique, you should be able to identify an approximate position but you will not be able to pinpoint the earthquake exactly. Mark on the Master Map where the class thinks the earthquake was located.

8. If you live in the northeastern United States, mark the location of your own town or city on the map. Read aloud the newspaper account from the city closest to where you live. What other questions do you wish the reporter had asked to give you a fuller sense of the earthquake?

9. As a class, discuss how earthquake science has changed since the development of the Modified Mercalli Intensity Scale.

Figure 3.1b
Damage Characteristic of Earthquake Intensity MM VII



Image from 1886 earthquake in Charleston, South Carolina.

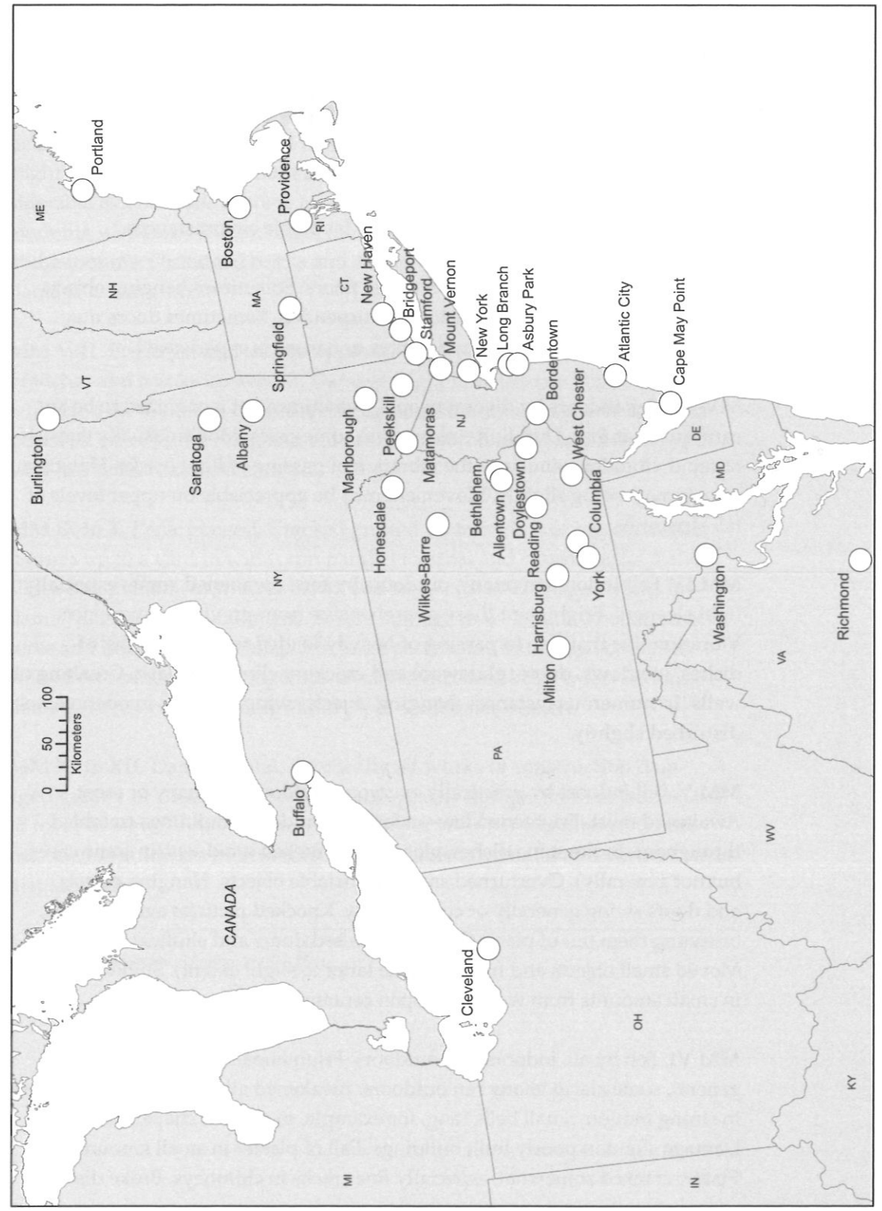
"Cracked chimneys; broke weak chimneys."

Source: U.S. Geological Survey (USGS) Photographic Library, Charleston earthquake 1886. Photo 19, photographer J.K. Hillers (Hillers photo 17).

Table 3.1
Colors to Use With Map in Figure 3.2

MM Intensity	Color
I to II	Purple
III to IV	Blue
V	Green
VI	Yellow
VII	Orange

Figure 3.2
Map of Northeastern United States: Modified Mercalli Intensity Values for Earthquake, August 10, 1884 (to be completed by students)



Modified Mercalli (MM) Intensity Scale

MM I. Not felt, or rarely under especially favorable circumstances.

MM II. Felt indoors, especially on upper floors. Sometimes hanging objects may swing, especially when delicately suspended. Sometimes doors may swing very slowly. Sometimes dizziness or nausea is experienced.

MM III. Felt indoors by several people. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Motion usually consists of rapid vibration, similar to the vibration of passing of light trucks. Hanging objects may swing slightly. Movement may be appreciable on upper levels of tall structures.

MM IV. Felt indoors by many, outdoors by few. Awakened some, especially light sleepers. Frightened those apprehensive from previous experience. Vibration like that due to passing of heavily loaded trucks. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls. In numerous instances, hanging objects swing. Liquids in open vessels disturbed slightly.

MM V. Felt indoors by practically everyone, outdoors by many or most. Awakened most. Frightened few—a few ran outdoors. Buildings trembled throughout. Broke some dishes, glassware. Cracked windows (in some cases, but not generally). Overturned small or unstable objects. Hanging objects and doors swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened or closed doors and shutters abruptly. Moved small objects and furniture (the latter to slight extent). Spilled liquids in small amounts from well-filled open containers.

MM VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all sleepers. Liquid set in strong motion. Small bells rang, for example, in church, chapel, or school. Damage slight in poorly built buildings. Fall of plaster in small amount. Plaster cracked somewhat, especially fine cracks in chimneys. Broke dishes and glassware in considerable quantity; also some windows. Fall of knick-knacks, books, and pictures. Overturned furniture in many instances. Moved moderately heavy furniture.

MM VII. Frightened all. General alarm; all ran outdoors. Some found it difficult to stand. Waves occurred on ponds, lakes, and running water. Damage slight to moderate in well-built ordinary buildings. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amounts; also some stucco. Broke numerous windows. Broke weak chimneys at the roofline. Dislodged bricks and stones. Overturned heavy furniture, with damage to furniture.

MM VIII. Fright general. Alarm approaches panic. Trees shaken strongly—branches and trunks broken off. Damage slight in structures built especially to withstand earthquakes. Considerable damage in ordinary substantial buildings. Fall of walls. Twisting and fall of chimneys, columns, and monuments. Very heavy furniture overturned.

MM IX to X. Panic general. Cracked ground up to widths of several inches; fissures up to a yard in width run parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Damage serious to dams, dikes, and embankments. Severe damage to well-built wooden structures and bridges: some collapse in large part; frame buildings completely shifted off foundations; dangerous cracks in excellent brick walls. Serious damage to reservoirs; underground pipes sometimes broken.

MM XI to XII. Damage total. Practically all works of construction damaged greatly or destroyed. Broad fissures, earth slumps, and landslides; fall of rocks of significant character; slumping of river banks, numerous and extensive. Fault slips in firm rock, with notable horizontal and vertical offset displacements.

Source: Simplified from Wood, H. O., and F. Neumann. 1931. Modified Mercalli Intensity Scale of 1931. *Bulletin of the Seismological Society of America* 21: 277–283.

Table 3.2
Data Recording Table

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
29	NY	Marlborough	*Trenton Evening Times*	"glasses jingled and mirrors shook perceptibly"	IV: "glassware and crockery clink and clash" V: "Moved small objects" V: "Hanging objects…swing generally or considerably"	IV–V

Newspaper Accounts of the August 10, 1884, Earthquake

To the Teacher: The following newspaper accounts are for use by students in steps 1–8 of Data Puzzle #3. Give each student at least three different accounts. Consider printing them on card stock or laminating them for longer use. They have been numbered 1–35 to help you keep track of them; these numbers do not signify position or earthquake intensity. For more information on using these accounts with your class, see pages 69–72 .

1

THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface The Country was Shaken… Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Telegraphic reports afterwards brought the intelligence that the shock was … unnoticed in Richmond [Virginia], and was scarcely felt in Portland [Maine]. In Cleveland [Ohio] it caused a ripple of excitement, but Indiana and Illinois residents read with surprise the news of the disturbance in the neighboring States.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

2

THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface The Country was Shaken… Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Harrisburg [PA], Aug. 10—Large numbers of people in this city were startled this afternoon at 2 o'clock by a violent shock of about five seconds' duration. There was a very perceptible vibration of the earth and houses were shaken in a very lively manner. Some people were almost thrown from their chairs, and … were awakened from sound slumber to see beds and other furniture shaken and to hear … glassware rattle.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

3 THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface
The Country was Shaken... Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Columbia [PA], Aug. 10—[Special.] The citizens of Columbia were gently excited at 2:12 o'clock this afternoon by a most mysterious shock, which, it is believed, came from an earthquake or some other internal disarrangement of the earth. In some parts of the town it was felt more severely than others. On Locust street, more especially at the upper end, the houses shook, while the dishes in cupboards and the windows rattled. The occupants of the houses of Locust and Fifth streets ran out into the street, so violently did their houses sway from side to side. The only damage done was the breaking of several window panes.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

4 THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface
The Country was Shaken... Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Doylestown [PA], Aug. 10—About 2 o'clock this afternoon a rumbling noise as of distant thunder was distinctly heard here, followed by a general vibration of the earth, causing dishes to rattle, furniture to move from its position, doors to unlatch and open. No serious damage has been reported in the vicinity of the town. The earthquake was also felt at other places.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

5 THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface
The Country was Shaken... Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Long Branch [NJ], Aug. 10—The earthquake shock reached Long Branch just as people were sitting down to dinner. The first indication of the phenomenon was a rumbling noise, followed instantly by a trembling as it seemed of all creation. It was all over in half a dozen seconds, but the time was long enough to set all Long Branch in a panic. The cottages and hotels poured forth their inmates. Plazas and lawns were dotted with shaking men, weeping children and fainting women.

The seven hundred guests at the table at the West End made a rush for the doors and shrank back laughing foolishly when the danger was passed, but dainty food went almost untouched after that.... When the first sound was heard and the startled guests were wondering what it all meant the fool somewhere in the crowded room shrieked, "Fire! Fire!" Then there was a wild rush. Instantly women and children fell and strong men ruthlessly stepped over and in some cases on them and forced their way first to the doors....

At one of the hotels a lady who was taking a bath in her room rushed out into the hallway clothed only in a towel. Chairs and beds rocked like hammocks. Henry Haggerty, a guest at the United States Hotel, who was taking a nap, was awakened by the swaying of his bed. The appearance of sky and sea was unchanged during the disturbance, but a woman who was in bathing was thrown off her feet. No serious injury or damage resulted, and after the shock the people were laughing at their own fright.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

6 THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface
The Country was Shaken... Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Asbury Park [NJ], Aug. 10—The earthquake treated the saints of Ocean Groves and the sinners of Asbury Park alike. It scared pretty nearly everybody. There was a loud rumbling sound, quickly followed by a shock which set the cottages and hotels to rocking in the liveliest kind of a manner. People on the beach did not feel it. Houses were quickly emptied of their occupants, the dinner tables were deserted and people with napkins about their necks rushed into the streets with faces as white as chalk. Nobody seemed to know what was the matter for some time. Rumors that boilers in the Sheldon House had blown up caused a stampede in that direction over in the Grove, but there was nothing the matter there.... The streets were filled with excited people, who stood around all the afternoon waiting for another shock and afraid to return to their rooms.

Some of the scenes were ludicrous. Women with babies in their arms rushed into the streets, and some of the big hotels there was the liveliest kind of a panic. The earthquake shock had no effect whatever upon the water. Thousands of people loitered upon the boardwalk hunting for a tidal wave, but beyond some ships out at sea, some gulls hunting for fish and a grand surf they saw nothing.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

7 THE EARTHQUAKE

Undulating Waves Ripple Roughly Over the Ground's Surface
The Country was Shaken... Cracking Walls and Toppling Chimneys

Accounts From Ohio to New England

Stamford [CT], Aug. 10—A very perceptible shock of earthquake was felt at 2:09 P.M. today, shaking buildings and causing considerable excitement. A centre table was overturned in the resident of R.H. Gillespie and a handsome ornament smashed. Pictures fell from the walls and other damage was done. Fifteen years ago a similar shock was felt at night, and forty years ago a still greater one was experienced.

(from an article in *The Easton [PA] Express*, Monday Evening, Aug. 11, 1884)

8 AN EARTHQUAKE SHOCK

Houses Shake and Chimneys Fall in Philadelphia;
The Atlantic Coast Disturbed from Washington, D.C., to Portland, Me.-
No lives Reported lost.

Reading [PA], Aug. 10—At 2:12 this afternoon two distinct shocks of earthquake were felt throughout this city and country, shaking houses, moving furniture and dropping blinds. Considerable excitement prevailed among the people, many running into the street.

(from an article in *The Philadelphia Record*, Monday Morning, Aug. 11, 1884)

9 AN EARTHQUAKE SHOCK

Houses Shake and Chimneys Fall in Philadelphia; The Atlantic Coast Disturbed from Washington, D.C., to Portland, Me.- No lives Reported lost.

Bordentown [NJ], Aug. 10—At precisely eight minutes after 2 o'clock this afternoon the people of this place were thrown into a state of great excitement by an earthquake shock, which lasted fully half a minute. The people were panic-stricken, and rushed pell-mell into the street. Farnsworth Avenue was immediately alive with women and children. The shock was most severely felt at the hilltop, where several children were prostrated. The chimney of Mr. Valentine Woods' house, in Church street, was tumbled into the street. Pans and dishes were thrown off Mr. James Powell's dresser in West Street. Those who were at the riverfront say that the Delaware sent up large waves over the Pennsylvania and Jersey shores.

(from an article in *The Philadelphia Record*, Monday Morning, Aug. 11, 1884)

10 AN EARTHQUAKE SHOCK

Houses Shake and Chimneys Fall in Philadelphia; The Atlantic Coast Disturbed from Washington, D.C., to Portland, Me.- No lives Reported lost.

Peekskill [NY], Aug. 10—At 2:07 P.M. Peekskill experienced two severe shocks of earthquake. The shock caused windows, shutters, and dishes to shake and rattle loudly, persons ran out of their houses wondering and fearful as to the cause of the terrible sensation.

(from an article in *The Philadelphia Record*, Monday Morning, Aug. 11, 1884)

11 AN EARTHQUAKE SHOCK

Houses Shake and Chimneys Fall in Philadelphia; The Atlantic Coast Disturbed from Washington, D.C., to Portland, Me.- No lives Reported lost.

Mount Vernon [NY], Aug. 10—At 10 minutes after 2 o'clock this afternoon, Mount Vernon, Yonkers, New Rochelle, Port Chester, White Plains and other places in Westchester county, had a lively shaking up by an earthquake. The chimneys of a house were shaken down and the brick walls badly shattered.

(from an article in *The Philadelphia Record*, Monday Morning, Aug. 11, 1884)

12 AN EARTHQUAKE SHOCK

Houses Shake and Chimneys Fall in Philadelphia; The Atlantic Coast Disturbed from Washington, D.C., to Portland, Me.- No lives Reported lost.

Washington, D.C., Aug. 10—Commander Sampson, Assistant Superintendent of the Naval Observatory, reports that he observed slight vibrations of the earth around 2 o'clock this afternoon, lasting about sixteen seconds. He was in the second story of his house, adjoining the observatory. The windows of the room rattled and the articles on a marble-top table moved. No phenomena were observed on the lower floors of the house. A few persons have reported this evening that they observed some unusual motion of the earth about 2 o'clock this afternoon, but very few such reports have been made.

(from an article in *The Philadelphia Record*, Monday Morning, Aug. 11, 1884)

13 AN EARTHQUAKE SHAKES US

Bethlehem [PA]—For the first time since the year 1828, so the oldest citizens say, a perceptible shock of an earthquake was felt in the Bethlehems at 2:06 o'clock yesterday afternoon. A rumbling noise, resembling that which is heard when approaching the skating rink, accompanied the shock, which lasted about twelve seconds. Houses were shaken in all sections of the town, and in many instances mantel ornaments were thrown to the floor, window curtains knocked down and doors unlatched. The damage done in Bethlehem was slight. The handsome residence of William Stubblebine, situated at the corner of Church and New streets, was damaged, the southeastern wall being cracked. The residence of Wm. King, on Leibert Street, West Bethlehem, was also damaged. The walls on the inside were cracked to such an extent to resemble a map of Hungary. We are informed that the doorbells of Drs. Wilson and Detwiller were rung by the shock.

The shock of the earthquake yesterday afternoon caused much alarm among our citizens. Women and children ran out of their homes crying and for a time much consternation prevailed. In some residences on Fountain Hill vases, brick-a-brac, &c., were knocked off the mantelpieces. In the First Reformed Church, Fourth Street, the bible was thrown from the pulpit. The shock was most severe in the elevated portions of the town, persons residing on Second Street and in the Third Ward scarcely feeling it.

(from an article in the *Bethlehem [PA] Daily Times*, Aug. 1884)

14 SHAKEN BY AN EARTHQUAKE

A Very Terrible shock of an Earthquake startles York.

Yesterday afternoon, about ten or twelve minutes after two o'clock, **York [PA]** went through a novel experience, in the very sensible feeling of an earthquake shock. The shock lasted, perhaps, from eight to ten seconds, and was felt with more or less effect in the various parts of town.

Many who were taking their Sunday afternoon nap were awakened from their slumbers by the shaking of their beds; and not a few nervous people were badly frightened. Windows rattled, buildings trembled, pictures and looking-glasses trembled on the walls, and for a few moments the town seemed to have a general shaking up.

Few people seemed to have an idea of the cause of the singular sensation. Some thought an explosion had occurred somewhere; to others it appeared as if an unusually heavy team had passed the house shaking the foundations, while others again looked upon it as a token of evil and their forebodings of direful disaster soon to come, made them terrible with fright. In some sections of town it was more perceptible than others and the beds on which people were comfortably resting shook so perceptibly as to awaken the sleepers. In one instance an individual thought some one was under the bed moving it. Many people thought the end of all things was at hand, and there was doubtless more praying than the usual amount of Sunday praying for a little while at least.

(from an article in *the York [PA] Dispatch*, Aug. 1884)

15 NEW YORK AGITATED

Samuel J. Randall's Luncheon Interrupted by the Rumbing Earthquake

Special Dispatch to *The Philadelphia Press*. **New York [City],** Aug. 10—The city and vicinity felt a smart earthquake shock at about five minutes past 2 o'clock this afternoon, or rather two or three distinct shocks, which startled the whole city and set everybody to talking about it.

At the Brevoort House, at Fifth Avenue and Eight Street, the shock was also perceptibly felt. The night clerk, who was still in bed, was awakened by the low rumbling noise, which jarred the furniture in the room sufficiently to break his slumbers. He rushed to the window and found half the windows in the block filled with excited people. Mr. Murant Haistead, of the Cincinnati Commercial-Gazette and the new evening paper was engaged in the writing in an upper room of the same hotel. Mr. Haistead says the vibration was perfectly perceptible but thinks it did not last longer than two or three seconds.

At the New York on Broadway, Mr. Samuel J. Randall, of Pennsylvania, and a few political friends were lunching. Suddenly there was a rattling of glass and a general shaking of dishes, which brought the ex-Speaker to his feet in a jiffy. A South American gentleman in the party recognized the sensation at once. "Why, that is an earthquake!" he exclaimed, and the room was vacant in less time than one can count one.

Two blocks above the Vienna Café was filled with Sunday afternoon strollers, who had stopped for a little refreshment. The shock caused quite a panic among them. The cut glass prisms of the chandelier tinkled like sleigh bells—cups and saucers danced about in the trays in the most festive fashion, while the rumbling in the cellar shook the house from top to bottom and three of the globes on the chandeliers fell to the floor and were shivered a thousand pieces.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

16 Along the Jersey Coast-

The Phenomenon Divides Itself Into Three Sections at Atlantic City.

Special Dispatch to *The Philadelphia Press*. **Atlantic City [NJ],** Aug. 10—There was a series of three mysterious shocks felt here this afternoon at exactly nine minutes after 2 o'clock, which had all the effects of an earthquake. Inquiries were made generally concerning the phenomenon, in the belief that it resulted from an explosion, and the rumor prevailed that the gasworks had blown up.

At the Jackson House alarm was occasioned among the guests, who were seated at their dinner table, when the dishes rattled and the table shook as though it was affected by palsy. At Kuebrie's Hotel and at Joseph A. Harstow's house, on Pennsylvania Avenue, water pitchers were overturned and spilled over the floor. James Beckwith and John Hill Martin, of the Ocean House, were alarmed in their beds while William G. Bartlett's family, on North Carolina Avenue, near Atlantic, ran out of doors in great consternation....

At the Lighthouse the shock startled Major Wolf, the keeper, whilst he was writing, overturning the inkbottle over his Sunday trousers. A hundred such incidents are talked about through the town tonight and everybody was waiting for a tidal wave, which, old watermen say, is always sure to follow an earthquake.

Conductor-Bartlette, of the Camden and Atlantic railroad, says he was thrown from his chair while sitting at home. An unoccupied car on one of the roller coasting roads on Tennessee Avenue is said to have been started by the force of the shock, and to have gone dashing over the circuit.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

17 Rhode Island's Shaken Ground.

Special Dispatch to *The Philadelphia Press*. **Providence [RI],** Aug. 10—The earthquake shock was felt very perceptibly in this city and state and people were temporarily alarmed. It happened at about 7 minutes past 2 o'clock this afternoon and was felt in various parts of the city. Mr. John Kendrick, one of Providence's foremost citizens, was reading in his brick mansion on Westminster Hill, when suddenly the walls and floor of the room shook like a steamship at sea breasting the billows, and the statuary so agitated that Mr. Kendrick was in momentary fear that they would tumble from their pedestals. The duration was perhaps fifteen seconds and then after a quarter of a minute came a second shock of less violence.

In the tall Narragansett and Dorrance Hotels the guests felt the tremor very strongly. Some people who were enjoying Sunday afternoon naps were awakened from their slumber by the shaking of their beds. At Pawtucket, a large town four miles North of here, houses were shaken like reeds and the timbers of wooden buildings creaked like those of a ship in a heavy sea.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

18 West Chester's Bells Rung

How Bottles Rattled and a Chimney Lost Its Terra Cotta Top

Special Dispatch to *The Philadelphia Press*. **West Chester [PA],** Aug. 10—The earthquake was felt very perceptibly in this borough, and lasted for fully a half minute. The quaking were divided into three distinct shocks. In the drug stores of Joseph S. Evans, H.R. Kervey and others the bottles on the shelves rattled quite loudly. The front door bell at the residence of Dr. Edward Jackson was rung. The shock sent people into the streets to find out what had happened, some thinking that duPont's powder mill, at Wilmington, had exploded. The tremulous motion of the earth produced the effect of seasickness with some persons.

Telephone bells were rung, as were other bells in various parts of the town. At the Pennsylvania Railroad station one of the employees stated that he actually noticed the walls of the freight house shaking.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

19 Milton's Up Heaving Pavements

Special Dispatch to *The Philadelphia Press*. **Milton [PA],** Aug. 10—A loud, heavy noise, like the rumbling of a continuous peal of thunder, was heard, and then followed by a terrible trembling of the earth. The shock was very perceptibly felt by those lying in bed. The furniture in some houses trembled…. The pavements were seen to vibrate as if an upheaval was about to occur. Those who have experienced the feelings attendant upon an earthquake say that this of today here is exactly like it. There has been neither rain nor thunder storm here today, and a clear sky has prevailed since early this morning.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

20 A Plum-Picker Shaken From a Tree

Special Dispatch to *The Philadelphia Press*. **Allentown [PA],** Aug. 10—It was about 2:05 o'clock this afternoon, when a distinct shock of earthquake was felt in this city. It continued about fifteen or twenty seconds. Windows rattled, doors shook and chandeliers swung. The first thought was that a dynamite mill had exploded, but the shock lasted too long to hold to that theory. People ran out of their houses in fright, and many who were asleep were awakened by the quaking buildings. A lady on Seventh Street was thrown from a sofa. A man named Shafter, while picking plums, fell off the tree and broke his leg, whether from fright or from the shaking, is not known. The children in Sunday schools were badly frightened.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

21 Pike County Caught in the Wave

Special Dispatch to *The Philadelphia Press*. **Matamoras [PA],** Aug. 10—Two distinct shocks of earthquake were felt in this county this afternoon. Houses were shaken, dishes rattled and buckets of water slopped over. The two shocks were a few seconds apart and lasted about one minute. It was at first thought to be the explosion of a locomotive on the Erie Railway, but this was proven untrue.

(from an article in *The Philadelphia Press*, Aug. 11, 1884)

22 Milton's Up Heaving Pavements

Special Dispatch to *The Philadelphia Press*. **Honesdale [PA],** Aug. 10—A severe shock of earthquake was felt here this afternoon. Dishes rattled on the tables and doors were opened by the shock.

(from an article in *The Philadelphia Press,* Aug. 11, 1884)

23 Saratogians Become Seasick

Special Dispatch to *The Philadelphia Press.* **Saratoga [NY],** Aug. 10—A slight tremor at 2:07 P.M., standard time, was felt at Saratoga. Some people at dinner were affected much as though by seasickness. Curiosity was excited to know the cause, and it was only after a dispatch came from New York and other points announcing an earthquake shock that its meaning was comprehended.

(from an article in *The Philadelphia Press,* Aug. 11, 1884)

24 Ground Vibrates in Wilkes Barre

Wilkes Barre [PA]—There was a perceptible tremor of terra firma about 2:15, and consisted of a series of vibrations, ranging from 2 to 5. The direction was from east to west or from northeast to southwest. It was not felt by everybody, and did not knock down any brick buildings, yet attracted the attention of hundreds of our citizens….

It was thought by the inquirers that a powder mill must have exploded in the vicinity of Wilkes-Barre … a mine blast, or possibly a crash in the mineral spring colliery. Marcus Smith was lying on a sofa reading and was almost thrown off. He thought both gas-o-meters had gone up.

W. W. Brown saw the walls of his residence vibrate. Dick Brundage saw the pictures on the wall begin to rattle. Mrs. Douglass Smith was sitting quietly in a rocking chair, the vibration being strong enough to set her chair rocking. Mrs. M. B. Houpt felt the window shutters and doors rattle….

Editor J. C. Coon felt a north by northeast tremor and pinched himself to see if he wasn't getting paralyzed. Harry Wilbur was napping on a lounge when he jumped up thinking all the mules in the stable were having a kicking picnic. Mrs. Bookseller Butler noticed her sewing machine trying to get up motion.

(from an article in the *Wilkes-Barre [PA] Recorder,* Aug., 11, 1884)

25 Badly Shaken Up

New York Shaken

New York [City], Aug. 11—A few minutes past 2:00 PM yesterday afternoon the city was visited by a genuine shock of earthquake which lasted for a full 15 seconds.

In several uptown bar-rooms glassware was shaken from shelves and broken. The police central building in Mulberry street was shaken from foundation to roof. The shock was very perceptible on the Brooklyn Bridge. All accounts agree that the shock was preceded by a low rumbling noise.

While a congregation of 250 were celebrating the consecration of the Holy Scroll in the B'Nai Drebnine synagogue on the second floor at the old building at Hester and Ludlow St., the building trembled, and several of the window panes broke and fell into the street. The worshippers rushed to the doors in alarm. Stalwart ushers turned them back. They sprang to the windows, and some tried to jump to the ground, a distance of twenty feet, but were held back.

The Italians occupying the row of tenements known as "the Barracks" opposite the Mott street end of the Central office, swarmed into the open air, evidently remembering their earthquake experiences in their own country.

(from an article in the *Trenton [NJ] Evening Times*, Aug. 11, 1884)

26 Badly Shaken Up

A Curious Phenomenon

Bridgeport [CT], Aug. 11—About 2:05 yesterday afternoon people in the city and vicinity were startled by a rumbling sound accompanied by a violent shaking of buildings. At first it was thought a violent explosion at the cartridge factory had occurred.

In some places dishes were thrown from the shelves and broken. At Stratford bricks were shaken from the chimneys, and in one house a man who was lying on a lounge was thrown to the floor.

In the Housatonic River a curious phenomenon occurred. Just as the rumbling began a wave started from either shore, and meeting in the center of the river rolled over and over, presenting a magnificent spectacle.

(from an article in the *Trenton [NJ] Evening Times,* Aug. 11, 1884)

27 Badly Shaken Up

Water Thrown up into the Air

New Haven [CT], Aug. 11—Two severe shocks of an earthquake were felt in this city at about 2:15 o'clock yesterday afternoon. The first was about five seconds in duration and the latter thirty seconds later was much more severe.

Pictures on the walls rattled, mirrors vibrated, and the citizens were much frightened. No serious damage was done however.

In Branford the water in a small brook on the Rose farm was thrown up into the air quite a distance.

(from an article in the *Trenton [NJ] Evening Times*, Aug. 11, 1884)

28 Badly Shaken Up

Two Distinct Shocks

Albany [NY], Aug. 11—At 2:09 o'clock yesterday afternoon a shock of earthquake was experienced in this city, which lasted seven seconds. There were two distinct shocks which shook the houses throughout the city.

Dishes were thrown together on tables, oranges and other fruit thrown to the floor, doors thrown open and blinds closed by the force of the shock. The course of the shock was from east to west apparently.

(from an article in the *Trenton [NJ] Evening Times*, Aug. 11, 1884)

29 Badly Shaken Up

Beasts Strangely Affected

Marlborough [NY], Aug. 11—A few minutes after 2 o'clock yesterday afternoon people along the Hudson river were startled by a dull, rumbling sound, followed by a trembling motion. In the vicinity of Marlborough houses were shaken so much that glasses jingled and mirrors shook perceptibly. Ladies and children were badly frightened, and dogs and beasts of burden were strangely affected.

(from an article in the *Trenton[NJ] Evening Times*, Aug. 11, 1884)

30 Badly Shaken Up

Somebody Told Them

Buffalo [NY], Aug. 11—A shock that was almost imperceptible was felt at 2:30 yesterday afternoon at Black Rock and East Buffalo. It attracted little attention, and no damage was done. So far as can be learned there was no shock in the city. If there was it was too slight to excite any general apprehension.

(from an article in the *Trenton [NJ] Evening Times*, Aug. 11, 1884)

31 Explosion or Earthquake

Cape May Point [NJ], Aug. 10—There is no doubt that the tremor of an explosion or earthquake was felt both here and at Cape May by numbers of persons. They describe quite a shaking of furniture and rattling of window sashes about two o'clock.

(from an article in the *Public Ledger,* Monday, Aug. 11, 1884, Philadelphia, PA)

32 Slight Earthquake Felt

Burlington [VT], Aug. 11—Two slight but very distinct earthquake shocks were felt here yesterday afternoon, the first at 2:30 and the second at 5:30.

(from an article in the *New York Evening Post,* Monday, Aug. 11, 1884)

33 All Shaken Up

Springfield [MA], Aug. 11—The shock was preceded by a deep rumbling sound … in several parts of the city doors were thrown open, bells were rung and pictures swung from the walls. One person reports that he was aroused from a nap by the knocking of a pitcher against the marble sink in his room, and describes the motion like that of swinging in a hammock.

(from an article in the *Boston Globe,* Monday, Aug. 11, 1884)

34 All Shaken Up

Boston [MA], Aug. 11 [Part 1]—Boston has had an earthquake. Not much of one, not enough to shake down any buildings nor throw anybody out of bed…. It was accompanied by swaying chandeliers, rocking tables and furniture, and a rumbling heavy sound like that of a well laden cart going over frozen ground. This lasted about ten seconds and then ceased.

D. J. Saunders was reclining in a room of his house at the South End at the time, reading a paper and inhaling tobacco fumes through the stem of a black "T. D." pipe, when he felt his couch quivering and saw that his pipe was vibrating in an unusual manner.

An old woman was sleeping in the Collins block at Beach street and the jar woke her up. Mr. Nason, night manager of the Western Union Telegraph, was lying down and felt his bed shake for several seconds.

At the Fitchburg depot the restaurant cook and his wife were awakened from a sound sleep. Pictures upon the wall swung to and fro.

(from an article in the *Boston Globe,* Aug. 11, 1884)

35 All Shaken Up

Boston [MA], Aug. 11 [Part 2]—Boston has had an earthquake.

A gentleman in the upper story of the new savings bank on School Street felt the whole building sway and rock like a vessel at sea and thought the chimneys would all fall down.

On Charles St. several persons were aroused from sleep. On Ashburton place and at the offices as well as in many other parts of the city picture frames, books, crockery and other movables were endowed with sudden powers of locomotion. A young man employed at Ricker's pharmacy says "The earthquake made the bottles on the shelves move." None of the bottles was thrown from the shelves.

(from an article in the *Boston Globe,* Aug. 11, 1884)

Topic: Earthquakes

Data Puzzle 3

Pedagogical Content Knowledge Guide

What does an earthquake feel like?

In this Data Puzzle, students examine real newspaper accounts of the August 10, 1884, earthquake in the northeastern United States and gain firsthand experience applying the Modified Mercalli Intensity Scale to the event. Students gain insight into the history of science and how science can reveal patterns of nature by quantifying natural processes.

This puzzle works well in an Earth science or geology class and can also be tied into social studies or the history of science.

Aha! Insights

- So that's what earthquakes feel like. Yes, the Earth really does move! *(for students who have never felt an earthquake)*
- We have earthquakes and active tectonic processes in this region of the United States. I thought they only happened in California and other countries. *(for students in the northeastern United States)*
- Not all earthquakes occur at tectonic plate boundaries.
- The human senses can be tools of science.

Prior Skills Needed

- Be able to analyze a newspaper article
- Be able to discern evidence from the surrounding context
- Have had experience in interpreting maps
- Be able to use Roman numerals I through X

Teacher Preparation

1. Work through the steps in the Data Puzzle yourself (pp. 43–48). Use "Step-by-Step: How to Solve Data Puzzle #3" (pp. 73–76) 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. The 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 in this book 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 this puzzle to review with students **before** they complete the puzzle—for example, *earthquake, tectonic plate boundary, intensity, epicenter, qualitative data,* and *quantitative data.*

4. Plan how your students will collaborate on analyzing the data. We recommend that students begin their analysis individually (steps 1–3), then compare and combine their findings in small groups (steps 4–6), and then come together as a full class (steps 7, 8, and 9). There are 35 newspaper accounts. To get a sense of the variability of the earthquake experience, each student should analyze at least three newspaper accounts and then compare his or her analysis with the analyses of at least two other students in a small group. Do not omit any of the newspaper accounts; the full suite of data points is needed for the pattern to emerge when the data are plotted on the map.

5. Plan how your students will combine their individual findings into one Master Map. Options include the following:

   - Photocopy the blank map (Figure 3.2 on p. 45) onto overhead transparencies (one per group) and have students record their answers onto the map with transparency markers. Superimpose all of the maps, and project them all at the same time.
   - Project the blank map onto a whiteboard or large sheet of white paper and have students record onto the projected map.
   - Pass a page-size blank map from group to group; each group adds its own data (a method most suitable for smaller classes).
   - A method using PowerPoint is included on the Data Puzzle website: *www.ldeo.columbia.edu/edu/data_puzzles.*

6. Gather and prepare materials:

   - colored pencils or markers
   - For each student: a photocopy of Data Puzzle #3, pp. 43–48
   - For each group: blank map (Figure 3.2), extra copies of the blank data recording table (Table 3.2)
   - For each student: at least three newspaper accounts (pp. 49–67). Within a small group, all students should have the same accounts. Consider printing these on card stock or laminating for longer use. The accounts have been numbered 1–35 to help you keep track of them; these numbers do not signify position or earthquake intensity.
   - (optional) World map showing plate boundaries for discussion about the fact that not all earthquakes occur at plate boundaries (See "Resources," U.S. Geological Survey. World Map of Plate Boundaries.)
   - (optional) Historic pictures of earthquake damage (See "Resources," U.S. Geological Survey. Photographic Library of Earthquake Images.)

7. Plan any pre-puzzle activities (see below) and extension activities (p. 90). Check the Data Puzzles website (*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

- As a cross-curriculum activity with the social studies department, have students research the historical time period in which the earthquake took place. Consider research topics such as the following: How were houses and other buildings built in the 1880s? What was the position of women in 1880s society? How were immigrants viewed? What technological innovations were new at the time of the earthquake? How were newspapers reported and edited at that time? Insights from this research will enable students to provide nuanced answers to the question in step 1 of the Data Puzzle ("How do these [historical] accounts differ from modern newspaper stories?"). Some relevant websites are provided on page 92 under "Resources About Historical Context."
- Have students find news accounts of a recent earthquake to compare to the 1884 articles.

Teaching Notes

This Data Puzzle focuses on qualitative data collected through the five senses of human beings (the people who experienced the earthquake and the reporters who wrote the newspaper articles) rather than quantitative data collected by instruments. The puzzle offers a nontextbook-like view of a powerful Earth process. Discussing the differences between qualitative and quantitative types of data deepens students' understanding of the nature of science.

- Use of historic data lends itself to interdisciplinary work with history and social studies teachers. The need for students to closely read the newspaper articles and Mercalli intensity descriptions (pp. 46–47) is a good opportunity for interdisciplinary work with English teachers.
- Although this puzzle works for students in any geographic area, it will have the most impact among students who have never personally experienced an earthquake.
- This is a good activity for fostering discourse and collaboration skills. We recommend that steps 1, 2, and 3 be done individually, steps 4, 5, and 6 be done in small groups, and steps 7, 8, and 9 be done as a full class discussion. An important part of the impact of doing the puzzle is the discussion of the newspaper accounts and the coding selected by the students.
- If you are short on time, consider assigning steps 1, 2, and 3 as homework. Use your valuable in-class time for the questions that need small-group and full-class discussion.

Step-by-Step: How to Solve Data Puzzle #3

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. Decision making is also part of the skill set that students use to solve this Data Puzzle. Decision-making skills are noted where appropriate.

Answer Key	Critical Thinking
1. Read the newspaper accounts of the 1884 earthquake provided by your teacher. (Other student groups have different newspaper accounts.) How do these accounts differ from modern newspaper stories? Answers could include the following: • No photographs • Old-fashioned, more literary vocabulary and vivid descriptions • Specific people mentioned by name or occupation (plum picker, the hotel guest, the politician) • Descriptions lack what we refer to today as political correctness • Portrayal of gender differences • Information transmitted by telegraph • Moral judgments • Newspapers weren't for the masses but for the literate elite • No mention of monetary damages • Few interviews with experts; most interviews with "regular people" • Attempts to provide scientific explanations without knowledge of plate tectonics • No mention of magnitude of the earthquake	(C) Students will need some familiarity with how modern newspapers cover natural disasters, such as earthquakes, storms, and tsunamis. If students don't have this background, the teacher may want to provide, or have students bring in, newspaper clippings about a recent natural disaster to allow a side-by-side comparison. Consider starting with a discussion putting 1884 in context historically. What was happening in history during this time period? *Teaching Note:* After students develop their ideas about how the historical accounts differ from modern newspaper stories of similar events, it works well to have them state their ideas and read aloud their evidence. The descriptive detail and old-fashioned phrasing come alive when read aloud. Because student groups have different readings, it can be helpful to accumulate answers to this question on the board. (T) In Earth science class, temporal thinking usually involves thinking about changes over geological timescales. History and archeology also use temporal thinking, although over shorter timescales. Here, students are using temporal thinking to think about changes over a historical timescale of a bit more than a century (1884–2010, the year this book was written). A learning goal could be for students to recognize that changes in culture (e.g., the role of women), technology (e.g., telegraph versus internet), and scientific understanding (e.g., plate tectonics) have occurred in parallel over the same time span.

(continued)

Answer Key	Critical Thinking
2. Back in the 1800s, there was no network of seismographs for recording earthquakes. Scientists who study historical earthquakes have developed a scale for quantifying the severity of a given earthquake at a given position, based on observations from eyewitness accounts. Read down through the Modified Mercalli (MM) Intensity Scale on pages 46–47. MM intensity values are reported in roman numerals from I (barely felt) to XII (catastrophic).	(Q) An important insight here is that observations made by human senses of sight, hearing, and touch are being turned into numbers, into data. Many data types of importance in Earth science began as observations made with human senses (e.g., air and water temperature, density and hardness of rocks, wind direction and velocity). (Q) An optional math connection: Modified Mercalli intensity values are an example of an "ordinal scale," a kind of scale that shows relative ranking rather than absolute quantity. MM II is stronger than MM I, but there is no implication that it is twice as strong.
3. For the towns described in your newspaper accounts (see step 1), estimate the MM intensity of the August 10, 1884, earthquake. Be sure to pay attention to *negative* evidence (i.e., what is NOT stated). Your answer may be a range rather than an exact value. Use Table 3.2 on page 48 to organize and document what evidence you used to decide on the MM intensity. A sample answer (from the *Trenton [NJ] Evening Times*) has been filled in for you. See Table 3.3 (Data Recording Table With Answers), pp. 77–85. Keep in mind that a Modified Mercalli intensity value is an approximation. When assessing students' performance, focus on how well students support their claims with evidence as well as on their numerical answers.	(Q) In Earth science, it is often the case that measurements or observations are not precise. The best obtainable measurement may be a range, rather than a single exact number. Even a range of values can be useful for understanding the Earth, especially when scientists first begin methodical research of a previously unstudied Earth process. *Teaching Note:* If students are troubled by the concept of translating into a number the feelings they have experienced with their human senses, you might liken this process to walking outside and trying to determine the temperature just from the feeling of the weather.
4. *Now come together with two or three other students who have independently evaluated the same articles that you did.* Compare your answers and reasoning with those of the other students. Come to a consensus with your group about the MM intensity value for each town that you read about. Circulate among the groups. Encourage students to talk about what evidence they used and how they might weigh potentially conflicting evidence.	(Q) This step requires students to re-examine the conversion of felt-experience into quantitative data and think critically about the evidence behind each claim. (They are re-examining the choices they made in step 3.) (Decision Making) Students practice reaching consensus about the interpretation of complex and potentially contradictory Earth data.

Answer Key	Critical Thinking
5. On your group's copy of the map, plot the Modified Mercalli intensity values for each town that your group considered. Write the intensity value in roman numerals next to the name of the town. See Figure 3.3 (map with answers, p. 86).	(S) These data contain two different kinds of information: information about how strong the shaking was and information about where the specified amount of shaking was felt. In this step, students turn their attention from the "how strong" information to the "where" information. Without "where" information, the "how strong" information would not be nearly as valuable for science.
6. Contribute your group's MM intensity values to the Master Map, which will combine data from all the student groups. Plot your group's data on the master map by coloring in the circles next to the city names on the map. See Figure 3.3 (map with answers). For methods to combine maps, see "Teacher Preparation," pages 69–71.	(S) In this step, students experience the process of organizing data spatially. A large amount of diffuse data, gathered from diverse sources by various investigators, can be organized onto a map to convey that information efficiently. In Earth sciences, new patterns and insights often emerge when data are organized spatially.
7. As a class, examine the Master Map. Discuss where you think the August 10, 1884, earthquake was located. With this technique, you should be able to identify an approximate position but you will not be able to pinpoint the earthquake exactly. Mark on the Master Map where the class thinks the earthquake was located. The earthquake was in the general region of New York City; the map in Figure 3.3 shows that the strongest shaking was experienced in northeastern New Jersey, southwestern Connecticut, and southeastern New York State. The shaking was less intense at locations farther away.	(S) In this step, students must scan across a spatial array of information, visually integrate across a lot of details, and extract the overall spatial pattern. The overall spatial pattern is that (a) the strongest shaking (highest MM values) is centered around New York City and (b) the intensity of shaking diminishes radially outward from that center. The use of color facilitates seeing the overall pattern. *Teaching Note:* Students should be trying to interpret the overall map pattern exhibited by the entire data set *considered as a whole*. They should not be simply looking for the single most extreme newspaper account or the individual town with the highest MM intensity. Any single eyewitness account could be influenced by the characteristics of the local geology or the writing style of the newspaper reporter.

(continued)

Answer Key	Critical Thinking
8. If you live in the northeastern United States, mark the location of your own town or city on the map. Read aloud the newspaper account from the city closest to where you live. What other questions do you wish the reporter had asked to give you a fuller sense of the earthquake? Students should locate and mark their town or city if they live within the region of the map. *Teaching Note:* Questions that might have been asked by reporters will vary among students. These questions provide a window into which aspects of the earthquake your students wish to know more about.	(S) In this step, students position themselves spatially relative to the data they have been working with and relative to an Earth phenomenon.
9. As a class, discuss how science has changed since the development of the Modified Mercalli Intensity Scale. • Prior to the development of numerical intensity scales, humans could feel and hear earthquakes and could see the destruction caused by earthquakes, but they had no methodical way to compare one earthquake to another or to combine insights from multiple earthquakes. • Development of the intensity scale allowed scientists to compare one earthquake to another, to map the locations of individual earthquakes, and to compile maps to show zones of both abundant and rare earthquake occurrences. Intensity scales were developed and refined in the 1800s. • Later, in the 1900s, scientists developed seismographs, instruments that measure ground motions directly. Seismograph data allow scientists to pinpoint the location of earthquakes precisely, even in regions without human habitations. Seismograph data also allow scientists to quantify how much energy is released in an earthquake.	(T) In this discussion, students will deepen their understanding of the history of observational science. Humanity's ability to observe nature methodically and accurately has increased over historical time. Quantifying a natural phenomenon, turning felt experience into numbers, is a big breakthrough in the study of a natural phenomenon. As in the case of earthquakes, the first numerical data about a given Earth phenomenon are usually fairly imprecise and then gradually scientists figure out how to measure more and more precisely. Along with the ability to observe methodically and accurately has come the ability to interpret the causes and predict the consequences of Earth processes.

Table 3.3
Data Recording Table With Answers (Newspaper Articles Appear on pp. 49–67.)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
26	CT	Bridgeport	*Trenton Evening Times*	"violent shaking of buildings" "dishes were thrown from the shelves and broken" "bricks were shaken from chimneys" "a wave started from either shore, and meeting in the center of the river rolled over and over"	V: "Buildings trembled throughout" VI: "Broke dishes, glassware, in considerable quantity" VII: "Cracked chimneys" VII: "waves on ponds, lakes, and running water"	VI–VII
27	CT	New Haven	*Trenton Evening Times*	"pictures on the walls rattled, mirrors vibrated" "the citizens were much frightened" "no serious damage was done" "the water in a small brook ... was throw up into the air quite a distance."	V: "knocked pictures against walls" V: "Frightened few—a few ran out outdoors VI: "Liquid set in strong motion"	V–VI
7	CT	Stamford	*The Easton Express*	"a centre table was over turned ... and a handsome ornament smashed" "pictures fell from the walls and other damage was done"	VI: "overturned furniture" VI: "fall of knick-knacks, books, pictures"	VI
12		Washington, D.C.	*The Philadelphia Record*	"...observed slight vibrations ... in the second story of his house" "the windows of the room rattled and the articles on a marble-top table moved" "no phenomena were observed on the lower floors of the house"	III: "motion usually rapid vibration; vibration like that due to passing of light trucks" IV: "Rattling of ... windows" V: "Moved small objects" III: "Movement may be appreciable on upper levels of tall structures" *NOT* V: "Buildings trembled throughout"	III–IV

(continued)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
34	MA	Boston	*The Boston Globe* (Part 1)	"not much of one, not enough to shake down any buildings or throw anybody out of bed" "swaying chandeliers" "rocking tables and furniture…. couch quivering and … pipe was vibrating … bed shake for several seconds" "the jar woke her up … cook and wife were awakened…." "Pictures upon the wall swung to and fro"	V: "hanging objects…swing considerably" V: "moved small objects and furniture, the latter to slight extent" V: "awakened most" V: "knocked pictures against walls"	V
35	MA	Boston	*The Boston Globe* (Part 2)	"felt the whole building sway and rock like a vessel at sea" "several persons were aroused from sleep" "picture frames, books, crockery and other movables were endowed with sudden powers of locomotion … bottles on the shelves move"	V: "Buildings trembled throughout" IV: "Awakened some" V: "knocked pictures against walls" V: "moved small objects	V
33	MA	Springfield	*The Boston Globe*	"doors were thrown open" "bells were rung" "pictures swung from the walls" "One person reports that he was aroused from a nap"	V: "Opened or closed doors and shutters, abruptly" VI: "small bells rang" V: "knocked pictures against walls" IV: "awakened some"	V–VI
1	ME	Portland	*The Easton Express*	"scarcely felt"	I: "not felt or except rarely, under especially favorable circumstances	I
6	NJ	Asbury Park	*The Easton Express*	"It scared pretty nearly everybody" "set the cottages and hotels to rocking in the liveliest kind of a manner" "houses were quickly emptied of their occupants" "the earthquake shock had no effect whatever upon the water"	VII: "frightened all—general alarm, all ran outdoors" V: "buildings trembled throughout" *NOT* VII: "waves on ponds, lakes, and running water"	VI

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
16	NJ	Atlantic City	*The Philadelphia Press*	"the dishes rattled" "the table shook as thought it was affected by palsy" "water pitchers were overturned and spilled over the floor" "family … ran out of doors in great consternation" "overturning the ink bottle"	IV: "glassware and crockery clink and crash" V: "moved small objects, furniture" V: "Spilled liquids in small amounts from well-filled open containers" V: "Frightened few—a few ran outdoors" V: "Overturned small … objects"	V
9	NJ	Bordentown	*The Philadelphia Record*	"the people were panic-stricken and rushed pell-mell into the street" "the chimney … was tumbled into the street" "several children were prostrated" "pans and dishes were thrown … off dresser" "the Delaware sent up large waves over the Pennsylvania and Jersey shores"	VII: "frightened all—general alarm, all ran outdoors" VII: "broke weak chimneys at the roofline" VII: "Some found it difficult to stand." VI: "Fall of knick-knacks, books, pictures" VII: "waves on ponds, lakes, and running water"	VII
31	NJ	Cape May Point	*Public Ledger*	"quite a shaking of furniture and rattling of window sashes"	IV: "rattling of dishes, windows, doors" V: "moved small objects, furniture"	IV–V
5	NJ	Long Branch	*The Easton Express*	"all Long Branch in a panic" "The cottages and hotels poured forth their inmates" "was awakened by the swaying of his bed" "Chairs and beds rocked like hammocks" "a woman who was in bathing was thrown off her feet" "the appearance of sky and sea was unchanged during the disturbance"	VII: "frightened all—general alarm, all ran outdoors" VI: "awakened all sleepers" VI: "moved furniture of moderately heavy kind" VII: "Some found it difficult to stand." *NOT* VII: "waves on ponds, lakes, and running water"	VI–VII

(continued)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
10	NY	Peekskill	*The Philadelphia Record*	"the shock caused windows, shutters, and dishes to shake and rattle loudly" "persons ran out of their houses wondering and fearful"	IV: "Rattling of dishes, windows, doors" V: "Frightened few—a few ran out outdoors"	IV–V
28	NY	Albany	*Trenton Evening Times*	"dishes were thrown together on tables" "oranges and other fruit thrown to the floor" "doors thrown open and blinds closed by the force of the shock"	V: "Broke dishes, glassware, to some extent" V: "Overturned small or unstable objects" V: "Opened or closed doors and shutters, abruptly"	V
30	NY	Buffalo	*Trenton Evening Times*	"a shock that was almost imperceptible [felt in outlying areas]" "no shock in the city"	I: "not felt or except rarely, under especially favorable circumstances"	I
29	NY	Marlborough	*Trenton Evening Times*	"houses were shaken" "glasses jingled and mirrors shook perceptibly"	V: "Buildings trembled throughout" IV: "glassware and crockery clink and clash" V: "Hanging objects … swing generally or considerably"	IV–V
11	NY	Mount Vernon	*The Philadelphia Record*	"the chimneys of a house were shaken down and the brick walls badly shattered"	VII: "Broke weak chimneys at the roofline" VII: "Cracked walls….to some extent"	VII

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
15	NY	New York	*The Philadelphia Press*	"the night clerk … was awakened by the low rumbling noise, which jarred the furniture in the room sufficiently to break his slumbers" "there was a rattling of glass and general shaking of dishes" "the shock caused quite a panic among them… ." "the cut glass prisms of the chandelier tinkled … and saucers danced about" "shook the house from top to bottom" "three of the globes of the chandelier fell to the floor"	V: "Awakened most" V: "Moved small objects, furniture" IV: "Glassware and crockery clink and clash" VI: "Frightened many … some alarm" V: "Hanging objects swing generally or considerably" V: "Buildings trembled throughout" VI: "Fall of knick-knacks"	V–VI
25	NY	New York	*Trenton Evening Times*	"glassware was shaken from shelves and broken" "the police building was shaken from foundation to roof" "The Italians … swarmed into the open air, evidently remembering their earthquake experiences in their own country"	VI: "Broke dishes, glassware, in considerable quantity, also some windows." VI: "Fall of knick-knacks" V: "Buildings trembled throughout" V: "Frightened few—a few ran outdoors"	V–VI
23	NY	Saratoga	*The Press*	"some people at dinner were affected much as though by seasickness"	II: "Sometimes dizziness or nausea experienced"	II
1	OH	Cleveland	*The Easton Express*	"caused a ripple of excitement"	I: felt, but no damage or details reported	I–II
20	PA	Allentown	*The Press*	"windows rattled, doors shook, and chandeliers swung" "many who were asleep were awakened by the quaking buildings" "people ran out of their houses in fright"	IV: "Rattling of … windows" V: "Hanging objects … swing generally or considerably" V: "Awakened most" V: "Buildings trembled throughout" V: "Frightened few—a few ran outdoors"	V

(continued)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
13	PA	Bethlehem	*Bethlehem Daily Times*	"Houses were shaken in all sections of the town" "mantel ornaments were thrown to the floor, window curtains knocked down and doors unlatched" "residence … was damaged, the … wall being cracked" "the walls on the inside were cracked to such an extent to resemble a map of Hungary" "the doorbells … were rung by the shock" "women and children ran out of their homes crying"	V: "buildings trembled throughout" VI: "fall of knick-knacks, books, pictures" V: "opened or closed doors and shutters" VI: "cracked plaster somewhat, especially fine cracks in chimneys" VI: "small bells rang" VI: "Frightened many, excitement general, some alarm, many ran outdoors"	V–VI
3	PA	Columbia	*The Easton Express*	"the houses shook" "the dishes in cupboards and the windows rattled" "the occupants … ran out into the street" "the breaking of several window panes"	V: "buildings trembled" IV: "rattling of dishes, windows and doors" V: "a few ran outdoors" V: "cracked windows"	IV–V
4	PA	Doylestown	*The Easton Express*	"general vibration of the earth" "causing dishes to rattle" "furniture to move from its position" "doors to unlatch and open"	IV: "vibration like that due to passing of heavily loaded trucks" IV: "rattling of dishes, windows, doors" V: "moved small objects, furniture" V: "opened or closed doors and shutters"	IV–V

(continued)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
2	PA	Harrisburg	*The Easton Express*	"very perceptible vibration of the earth" "houses were shaken in a very lively manner" "awakened from sound slumber" "bed and other furniture shaken" "glassware rattle"	V: "buildings trembled throughout" V: "awakened most" V: "moved small objects, furniture, the latter to slight extent" IV: "Rattling of dishes; glassware and crockery clink and clash"	IV–V
22	PA	Honesdale	*The Press*	"dishes rattled on the tables" "doors were opened by the shock"	IV: "rattling of dishes, windows, doors" V: "Opened or closed doors…."	IV–V
21	PA	Matamoras	*The Philadelphia Press*	"houses were shaken" "dishes rattled" "buckets of water slopped over"	V: "Buildings trembled throughout" IV: "Rattling of dishes" V: "Spilled liquids in small amounts from well-filled open containers"	IV–V
19	PA	Milton	*The Philadelphia Press*	"terrible trembling of the earth … pavements were seen to vibrate" "the shock was very perceptively felt by those lying in bed" "the furniture in some houses trembled"	III–IV: "Vibration" IV: "felt indoors by many" V: "moved small objects, furniture"	IV–V
8	PA	Reading	*The Philadelphia Record*	"shaking houses" "moving furniture" "excitement prevailed among the people, many running into the street"	V: "buildings trembled throughout" V: "moved … furniture … to slight extent." VI: "Frightened many, excitement general, some alarm, many ran outdoors"	V–VI

(continued)

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
18	PA	West Chester	*The Philadelphia Press*	"the bottles on the shelves rattled quite loudly" "front door bell …was rung" "produced the effect of seasickness" "telephone bells were rung, as were other bells in various parts of the town" "he actually noticed the walls of the freight house shaking"	IV: "Rattling of dishes; glassware … clink and clash" VI: "small bells rang" II: "Sometimes … nausea experienced" V: "Buildings trembled throughout"	V (?)
24	PA	Wilkes-Barre	*Wilkes-Barre Recorder*	"series of vibrations … walls of residence vibrate….vibration strong enough to set [rocking] chair rocking" "it was not felt by everybody … yet attracted the attention of hundreds" "pictures on the wall begin to rattle … the window shutters and doors rattle" "sewing machine trying to get up motion"	III-IV: "Vibrations…." IV: "Felt indoors by many, outdoors by few" IV: "rattling of dishes, windows, doors" V: "Moved small objects, furniture, the latter to slight extent"	IV–V
14	PA	York	*The York Dispatch*	"awakened from their slumbers by the shaking of their beds" "not a few nervous people were badly frightened" "windows rattled, buildings trembled, pictures and looking-glasses trembled on the walls" "beds … shook … perceptibly"	IV: "Awakened some, especially light sleepers" IV: "Frightened those apprehensive from previous experience." IV: "rattling of dishes, windows, doors" V: "Buildings trembled throughout" V: "Moved … furniture … to slight extent."	IV–V

Newspaper Article Number	State	City	Newspaper	Evidence From Newspaper Article	Characteristics From MM Intensity Scale	Mercalli Intensity
17	RI	Providence	*The Philadelphia Press*	"the walls and floor of the room shook like a steamship at sea" "the statuary was so agitated … fear that they would tumble from their pedestals" "some people … were awakened from their slumber by the shaking of their beds" "houses were shaken like reeds"	V: "Buildings trembled throughout" V: "Moved small objects, furniture, the latter to slight extent" V: "Awakened most"	V
1	VA	Richmond	*The Easton Express*	"unnoticed"	I: "not felt"	I
32	VT	Burlington	*New York Evening Post*	"two slight but very distinct earthquake shocks were felt"	I: "not felt, or rarely" II: "felt indoors"	I–II

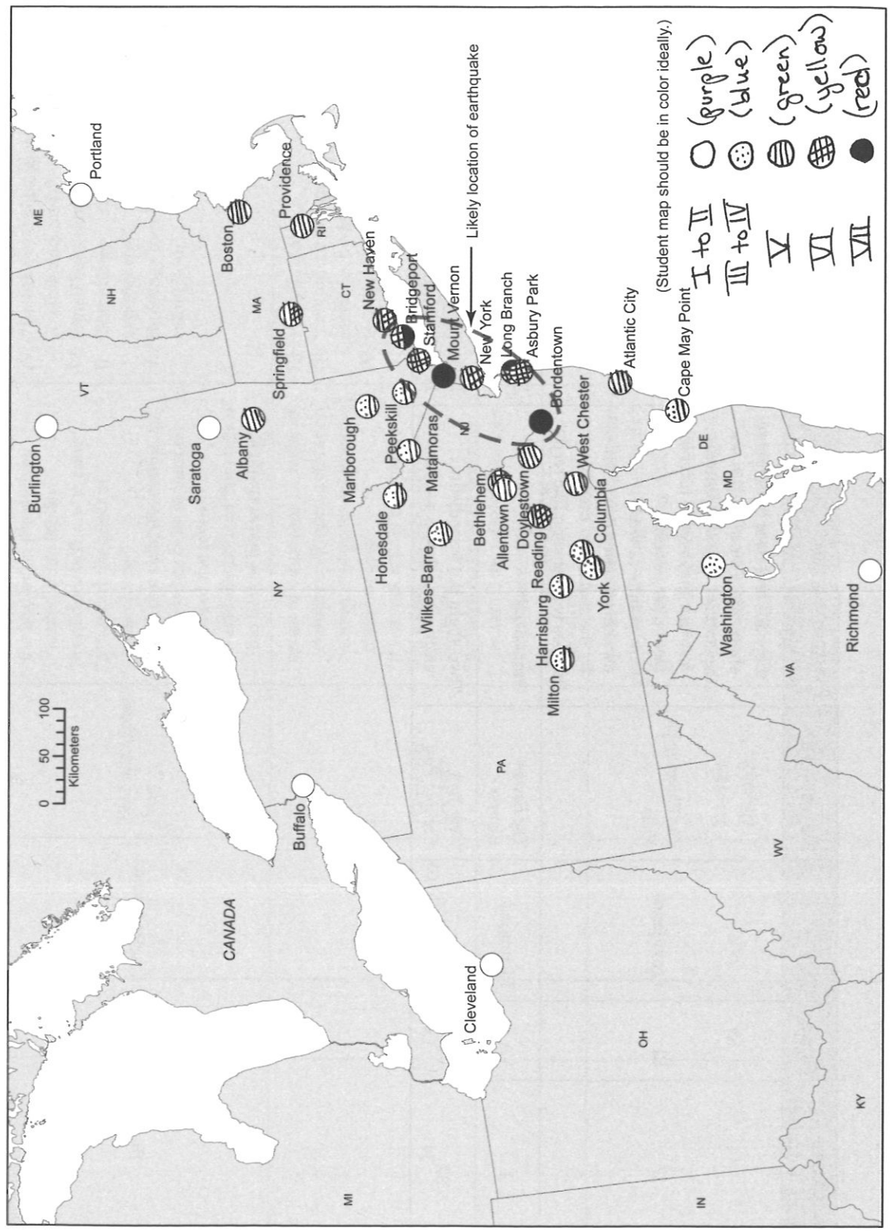


Figure 3.3
Answers for Figure 3.2

Common Student Misconceptions

- *Only scientists can contribute to research.*

Nonscientists can also contribute, as seen in these newspaper articles.

- *Earthquakes only occur at plate boundaries.*

As evidenced in this puzzle, earthquakes are NOT restricted to plate boundaries.

- *Earthquake magnitude and intensity are the same thing.*

Magnitude measures the energy released at the source of the earthquake and is determined from measurements on seismographs. Intensity measures the strength of shaking produced by the earthquake at a certain location. Thus intensity varies from place to place, while magnitude is a constant for a given earthquake. Traditionally, intensity is determined from observations of the shaking's effects on people, human structures, and the natural environment.

- *The larger the structure the more damage it will have in an earthquake.*

Buildings of all sizes were affected by the 1884 event. In modern cities, larger buildings are usually built with earthquake-resistant construction techniques, and so smaller buildings or older buildings may have more damage than large buildings.

Tough Questions (With Answers)

These are questions that your students may ask you, or that you could ask them. Many additional questions with answers are on the U.S. Geological Survey Earthquake FAQs page (see "Resources").

Q. Who was Mercalli and when did he do his work?

A. Giuseppe Mercalli was an Italian volcanologist, who lived from 1850 to 1915. His work built on an earlier 10-step intensity scale called the Rossi-Forel scale. Between 1884 and 1906 Mercalli modified his intensity scale several times to include additional kinds of observations. After Mercalli's death, the scale was revised several more times by other seismologists until it reached its current form, called the "Modified" Mercalli Intensity Scale.

Q. Are these real newspaper articles?

A. The accounts about the earthquake are taken from real newspaper articles. Some portions have been omitted to make the reading passages shorter and to provide observations that are internally consistent.

Q: Most articles say the earthquake was on August 10, but one article, published on August 11, refers to events of "this afternoon." Which date is correct?

A: The earthquake was on August 10. Note that many of the articles have a "dateline" at the beginning of the article, stating the date and place of the origin of the article. In the following example, the dateline is in boldface type: "**Columbia [PA], Aug. 10 [Special]**—The citizens of Columbia were gently excited at 2:12 o'clock this afternoon by a most mysterious shock…." This article was published on August 11, but the newspaper editor kept the original dateline of August 10 on the article. Back in those days, news traveled much more slowly than it does today, and newspapers often published accounts of events that had happened a day or even several days earlier. In the 21st century, with the electronic transmission of news, we are accustomed to having access to news within hours or even minutes of an event.

Q. Why do several newspaper articles have the same headline?

A. Some of the original newspaper articles reported eyewitness accounts from several towns or cities. In such cases, we split up the newspaper articles so that each reading covered only one locality, but we kept the original newspaper headline and subheads for all the readings.

Q. Why did some locations close together seem to experience effects of the earthquake differently?

A. There are two possible reasons:

1. *Actual heterogeneities in the Earth.* The nature of the bedrock and soil influence the intensity felt in a particular locality. For example, buildings on soft squishy ground sway more than building on solid rock, even if both buildings are the same distance from the epicenter.

2. *Imperfections in the data.* The job of a newspaper reporter is to report what is newsworthy, and thus he or she might tend to write about the most extreme situation rather than the most typical situation. For example, the destruction of one chimney might make it into the paper even if many other chimneys remained intact and the fallen chimney was unstable to begin with. Seismologists studying historical earthquakes try to account for this aspect of the data by reading multiple accounts if possible and by paying careful attention to what was *not* said as well as what was said.

Q. Why do we care about the MM Intensity Scale now that we can measure ground motion with seismographs and calculate magnitude with computers?

A. The MM Intensity Scale is still used to create "shake maps" that show how

intense the ground shaking was around a specific earthquake and to predict how much shaking could occur in different locations around a possible future earthquake. This is useful because intensity varies with position. Shake maps for recent earthquakes can be viewed at the U.S. Geological Survey ShakeMap website (see "Resources").

Q. Why would there be an earthquake in New York?

A. Earthquakes can occur anywhere as strain builds up inside the rocks of the Earth's crust. There are zones where earthquakes are more frequent; we call these *plate boundaries.* There are also zones where earthquakes are less frequent; we call these *plate interiors.* Every place, however, is a candidate for an earthquake sooner or later.

Q. What was the magnitude of the earthquake in the puzzle? And how was this magnitude determined, since there were no seismographs at the time?

A. The U.S. Geological Survey has estimated the magnitude of the August 10, 1884 event as 5.5. The first step in estimating the magnitude of a historic but pre-instrumental earthquake is to assemble eyewitness accounts, assign MM intensity values, and map the intensity values (just as students did in this puzzle). Then, the spatial distribution of MM intensities is compared to the spatial distribution observed for more recent earthquakes, for which both magnitudes and intensities are known.

Q. Isn't the Mercalli scale fairly subjective?

A. Yes, Mercalli intensity values derived from damage reports and eye-witness accounts have an element of judgment in them. But they are still valid observations of an Earth phenomenon. It is common in the history of science that the first methodical observations of a phenomenon are qualitative (subjective). If qualitative data seem to be revealing interesting patterns or trends, then scientists may try to develop instrumentation (e.g., seismographs) to gather quantitative data.

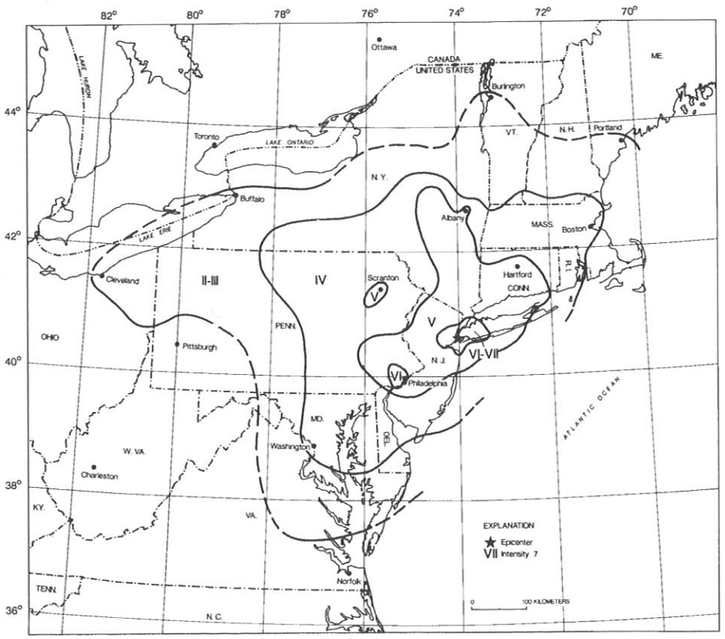
Q. How long do earthquakes "last"?

A. Some of the newspaper accounts of the 1884 earthquake contain eyewitness impressions of how long the shaking lasted, in the range of 5 to 20 seconds. How long earthquake shaking can be felt by a human observer depends on how long it took for the earthquake to actually break the crustal rock and on how the earthquake waves traveled through the Earth. The duration of felt-shaking varies from place to place, even from the same earthquake. More detail can be found at the U.S. Geological Survey Earthquake FAQs site (see "Resources").

Extension Activities

- Write an imaginary newspaper article for your local newspaper, describing the effects from the 1884 earthquake.
- Make a plan for how your family could prepare for an intensity VII earthquake.
- Discuss other situations or examples of scientists turning processes or phenomena that people experience with their senses into numbers. Student responses could include *feeling*—temperature (thermometer); *hearing*—sound (decibels); *taste*—salinity (ppt); *sight*—color (frequency); *hearing*—pitch (frequency); *sight, kinesthetics*—size and distance (units of length, area, volume); *feeling of muscles as you pick something up*—weight (density).

Figure 3.4
Isoseismal Map of 1884 Earthquake



1884 08 10 19:07 UTC Magnitude 5.5 Intensity VII

Source: Stover, C. W., and J. L. Coffman. 1993. Seismicity of the United States, 1568–1989 (rev.). U.S. Geological Survey Professional Paper 1527. Washington, DC: U. S. Government Printing Office. Courtesy of the USGS.

- Figure 3.4 is a map from a professional paper showing the intensity of the 1884 earthquake. Compare this map with the responses of your students.
- Explore the U.S. Geological Survey's Did You Feel It? website, where students can report an earthquake (see "Resources").
- Research the similarities and differences between earthquake magnitude and intensity.
- Research seismographs: When were they invented? When was the global network of seismographs established? Where are there seismographs? Where is there a seismograph near our school?
- Research other historical earthquakes—for example, the 1811–1812 New Madrid quakes (in Arkansas and Missouri), the 1906 San Francisco quake, or the 1886 Charleston earthquake. Compare and contrast these events and their human impact with the 1884 northeastern event.
- Research recent earthquake activity. Find a recent earthquake that seems to have been approximately as destructive as the 1884 event. What was its magnitude?
- Research your local building codes to see if there is any mention of earthquake standards.
- Discuss emergency preparedness, and compare what it was like in 1884 versus what it is like in the present day.

Sources for Data Puzzle #3

Historical newspaper accounts courtesy of seismologist John Armbruster, Lamont-Doherty Earth Observatory.

Modified Mercalli (MM) Intensity Scale
http://earthquakescanada.nrcan.gc.ca/gen_info/scales/mercalli_e.php

U.S. Geological Survey, Historic Earthquakes. Map of Aug. 10, 1884, earthquake with Mercalli intensities.
http://earthquake.usgs.gov/regional/states/events/1884_08_10_iso.php

Resources

General Information

"Turning Nature into Numbers": Reflections by the author of Data Puzzle #3 (Kim Kastens) on the process by which Earth scientists quantify aspects of nature so

as to capture and record information in a form that is more permanent and more standardized than the output of the human senses.
http://serc.carleton.edu/earthandmind/posts/realitytonumber.html

Resources About Historical Context

History of Journalism in the United States
www.writesite.org/html/tracing.html
Timeline of Science, Technology, and Invention, 1867–1899
http://inventors.about.com/od/timelines/a/Nineteenth_3.htm
U.S. Family Life, 1880–1920
www.americancenturies.mass.edu/turns/theme.jsp?x=3&y=1
U.S. Immigrants, 1880–1920
www.americancenturies.mass.edu/turns/theme.jsp?x=3&y=3

Resources About Earthquakes

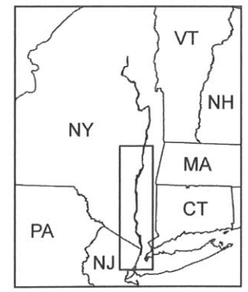
How to Get a Seismograph for Your School.
www.iris.washington.edu/about/ENO/AS1_apply_2003.pdf
Incorporated Research Institutions for Seismology, Interactive Map of Recent Seismic Activity.
www.iris.edu/seismon
U.S. Geological Survey. Did you feel it? Reporting an Unknown Event.
http://earthquake.usgs.gov/eqcenter/dyfi.php
U.S. Geological Survey. Earthquake FAQs.
http://earthquake.usgs.gov/learn/faq/?showAll=yes
http://earthquake.usgs.gov/learn/faq/?categoryID=2&faqID=114
U.S. Geological Survey. Earthquake Preparedness Program. (A site to guide students in preparing for an earthquake.)
http://quake.wr.usgs.gov/prepare
U.S. Geological Survey. Photographic Library of Earthquake Images.
http://libraryphoto.cr.usgs.gov/earth.htm
U.S Geological Survey. Recent Earthquakes.
http://earthquake.usgs.gov/eqcenter/recenteqsww
U.S. Geological Survey. ShakeMaps.
http://earthquake.usgs.gov/earthquakes/shakemap
U.S. Geological Survey. World Map of Plate Boundaries.
http://pubs.usgs.gov/gip/dynamic/slabs.html
Use the Accelerometer in Your Laptop as a Seismograph.
www.indiana.edu/~pepp/manuals/Scream3.pdf

Is the Hudson River too salty to drink?

To answer the question "Is the Hudson River Too Salty to Drink?" you would need to know about estuaries. There are many important estuaries in North America, including the Hudson River, the Mississippi River, Chesapeake Bay, Puget Sound, and San Francisco Bay. An estuary is a place where salt water from an ocean mixes with freshwater from inland rivers and streams. This mixing creates a "brackish," or partially salty, mix. The ocean tides and currents are also important, as their twice-daily cycle assists with mixing the salty water and the freshwater.

The Hudson River (located in New Jersey and New York State; see Figure 4.1) flows a total of 315 miles, but only the southern 153 miles (Figure 4.2, p. 94) are considered the estuary. Located along the length of the map in Figure 4.2 are numbers that represent "river miles" (indicated by the white lines on the map). A river mile measures distance as if you were traveling on the river, starting with zero at the southern tip of Manhattan and measuring northward along the river.

Figure 4.1
Location of the Hudson River Estuary



Source: Created by Linda Pistolesi using data publicly available from *www.census.gov.*

Directions: Follow steps 1–7 below. Use additional sheets of paper as needed and answer in complete sentences.

1. Table 4.1 (p. 94) contains surface salinity readings collected by school groups during the annual "A Day in the Life of the Hudson River." The salinity is recorded in parts per million (ppm). Ocean water is about 35,000 ppm, and distilled water is 0 ppm. Write the salinity readings from the different river miles onto the map.

2a. How does the salinity in the data vary with distance from the Atlantic Ocean?

Figure 4.2

Hudson River Estuary (to be completed by student)



2b. What might be the cause of this variation in salinity?

3. Native Americans call this river *Muhheakantuck* (the river that flows both ways). Referring back to the opening paragraph, can you explain why they gave the river that name?

4. We have talked about the tides. Figure 4.3 displays data collected in April of a recent year by instruments at the Beczak Environmental Education Center in Yonkers, located at river mile 18. Notice the rise and fall of salinity levels twice a day on 4/15 and 4/16. Salinity in the river fluctuates rhythmically with the tidal cycle. Trace your pencil along the observed rise and fall of salinity. Predict what the salinity will be like on 4/17 and 4/18 and show your prediction by completing the salinity line on the graph with your pencil.

Table 4.1

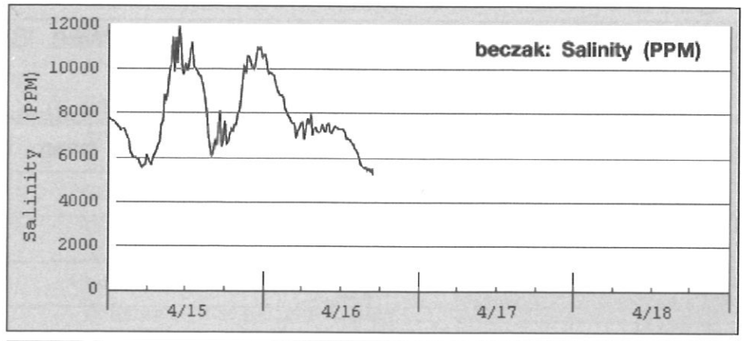
Salinity Data From "A Day in the Life of the Hudson River," Oct. 12

River Mile	Salinity in ppm
0	26000
2	16000
7	13300
14	9800
18	7300
25	5180
28	3600
39.5	1600
41	160
55	80
59	36
76	34
84.5	35
127	30

Source: Created by Steve Stanne, Hudson River Estuary Program, New York State Department of Environmental Conservation (NYSDEC).

Figure 4.3

Salinity Levels in the Hudson River at River Mile 18, Apr. 15-Apr. 18 (to be completed by student)



Source: Created by Margie Turrin with data from Beczak Environmental Education Center (*www.beczak.org*).

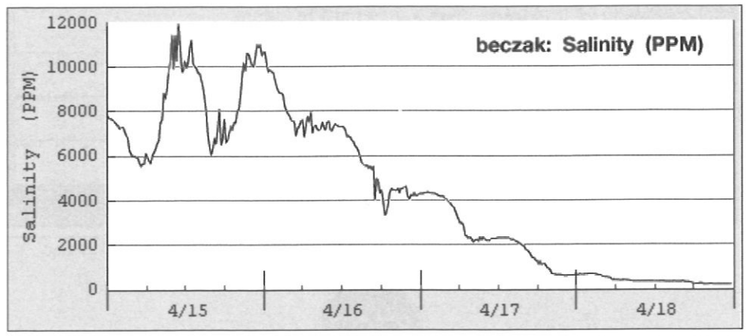
STOP

Discuss steps 1–4 with your teacher before moving on.

5a. Now let's look at the actual data (Figure 4.4). This graph shows what really happened to the salinity on 4/17 and 4/18. Compare what you predicted with what actually occurred.

Figure 4.4

Salinity Levels in the Hudson River at River Mile 18, Apr. 15-Apr. 18 (complete data)

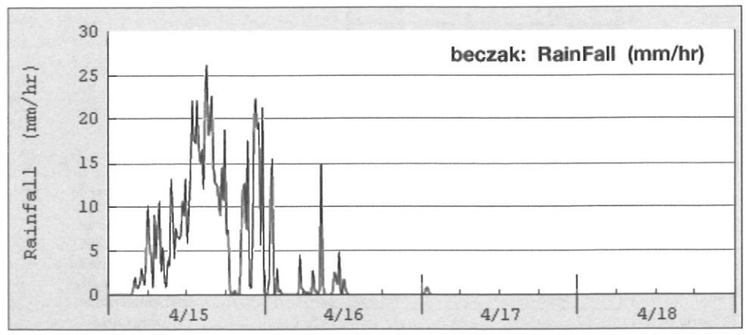


Source: Created by Margie Turrin with data from the Beczak Environmental Education Center (*www.beczak.org*).

5b. Figure 4.5 shows another data set that might help us understand what happened to the salinity. The graph in this figure shows *rainfall* for the same dates as shown in the salinity graph (Figure 4.4). Focusing on the rainfall graph, describe the weather at the Beczak Environmental Education Center on April 15.

Figure 4.5

Rainfall in the Hudson River at River Mile 18, Apr. 15-Apr. 18



Source: Created by Margie Turrin with data from Beczak Environmental Education Center (*www.beczak.org*).

5c. Now describe the weather at Beczak on April 16.

5d. Look back at Figure 4.4. Describe what happened to the salinity *after* the rainfall ended.

5e. You have described a rainfall event and seen what happened to salinity in the river. Write a hypothesis that explains the observations you made in steps 5a–5d.

6. Some communities along the upper Hudson estuary use the river as the source of their drinking water. Standard water treatment plants do not remove salt, so it is important to be sure the water in these areas is not too salty to drink. Experts have determined that 100 ppm salinity falls within acceptable drinking water standards. The location where the river salinity reaches 100 ppm has been labeled the "salt front." Each day the U. S. Geological Survey (USGS) records the location of the salt front in river miles (Table 4.2) as a guide for the communities that use the river for drinking water.

Table 4.2

Salt Front Location* for Hudson River in River Miles (RMs)

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	71
Mar. 21	62	Aug. 21	71
Mar. 25	68	Aug. 25	69
Mar. 29	58	Aug. 29	69
Apr. 1	28	Sept. 1	70
Apr. 5	12	Sept. 5	69
Apr. 9	0	Sept. 9	68
Apr. 13	30	Sept. 13	70
Apr. 17	38	Sept. 17	73
Apr. 21	60	Sept. 21	67
Apr. 25	58	Sept. 25	71
Apr. 29	38	Sept. 29	71

*The salt front location is where salinity measures 100 ppm.

Source: U.S. Geological Survey's website on the Hudson River salt front: *http://ny.water.usgs.gov/projects/dialer_plots/saltfront.html*

6a. On the graph on page 99 (Figure 4.6) the *x*-axis is the date and the *y*-axis is river mile (RM) location. You will be plotting the RM location for the salt front for the dates listed. Using a red pencil, plot the salt front data for August and September (the second set of dates on the chart) in one continuous line on the graph. Describe the location of the salt front for August and September. Use both river miles and names of communities in your answer.

6b. Plot the March and April salt front data on the same graph using a blue pencil. Label your graph. Describe

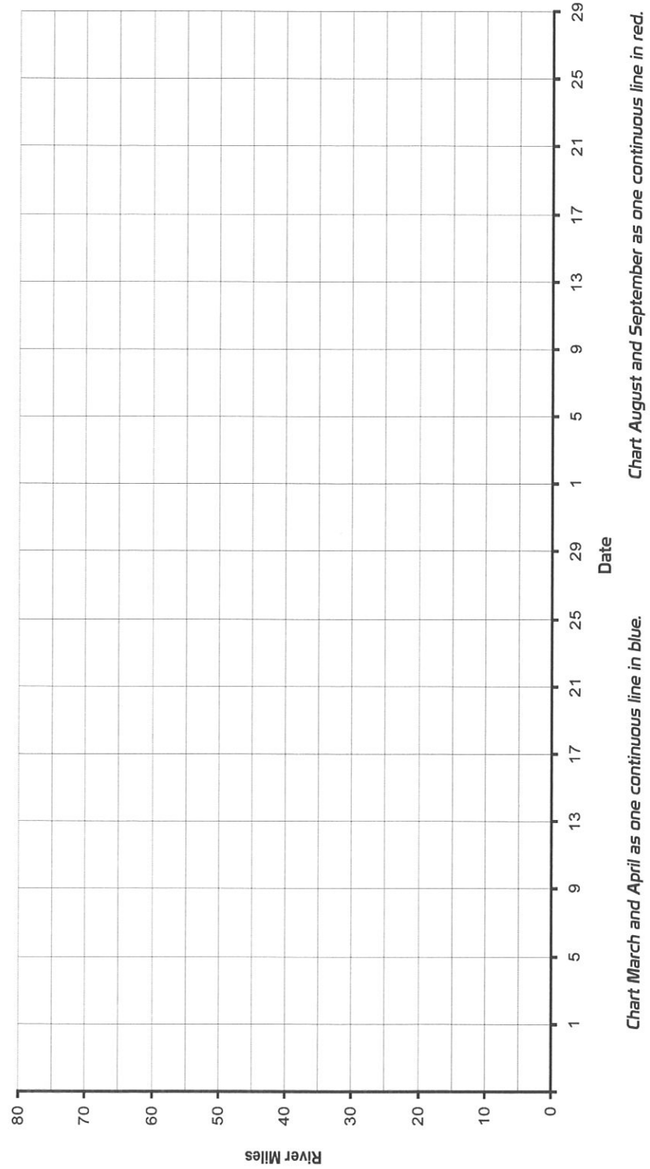
the location of the salt front in March and April. Use both river miles and names of communities in your answer.

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.

6d. Using the map in Figure 4.2 and the data from your graph, list two communities along the Hudson River where the salinity of the water was low enough to use for drinking water throughout all of August and September.

7. Thinking about the processes you explored in step 5 and the data in step 6, what might cause the differences between the March–April and August–September salt front locations? Explain your answer.

Figure 4.6
Hudson River Salt Front Location (to be completed by student)



Topic: Estuaries

Data Puzzle 4

Pedagogical Content Knowledge Guide

Is the Hudson River too salty to drink?

In this puzzle, students examine three different sets of salinity data collected from the Hudson River estuary in New York. The puzzle includes data collected along the length of the estuary on the same date; data collected over a span of days that includes before, during, and after a rain event; and finally data collected over a span of several months. Each piece of the puzzle allows students to extract a different insight into the dynamic nature of the saltwater and freshwater mixing of an estuary—how an estuary varies over space, how it responds to regional rain events, and how it varies with the season.

This puzzle works well in an Earth science, environmental science, or oceanography class.

Prior Skills Needed

- Basic map-reading skills
- The ability to read a time series graph
- The ability to plot data on a time series graph

Aha! Insights

- The salinity levels in the Hudson River estuary vary from location to location on the river *and* also change at a single location over time. All is in flux.
- One storm's worth of rainfall can drastically change the salinity of the river. It takes time, however, for the storm water to collect from the far reaches of the watershed and drain down into the river, so the change in river salinity happens later than the rainfall.
- The salinity of the river changes with the seasons, getting saltier when the weather is hotter and drier.
- The Hudson River doesn't just flow in one direction—it has inflows from all directions! Salty water from the Atlantic Ocean comes into the estuary from the south and freshwater from the watershed comes into the estuary from the north, east, and west.

Prior Understandings Needed

- **Oceans** are salt water systems; **rivers** and **streams** are freshwater systems.
- **Estuary:** partially enclosed body of water where freshwater from a river meets salty ocean water.
- **Salinity:** a measure of the concentration of dissolved salts in water. The main salt in seawater is sodium chloride; many other salts are present in lesser quantities.
- **Parts per million (ppm):** A ppm is one particle of a given substance for every 999,999 other particles. This can be a very abstract concept to students. The following comparison list from the National Environmental Services Center (see "Resources") is designed to assist students with visualizing this measurement:

  One ppm is like

  - one inch in 16 miles,
  - one second in 11.5 days,
  - one minute in two years,
  - one cent in $10,000, or
  - one car in bumper-to-bumper traffic from Cleveland to San Francisco.
- **Density:** Salt water or brackish water has a higher density than freshwater because it contains dissolved substances that add mass to the water within which they are dissolved. Layering of water of different densities occurs in an estuary, with saltier water beneath fresher water.
- **Dilution:** adding more of an item (in this case, freshwater) to diminish the strength of some other ingredient (in this case, salt).
- **Tides:** the alternating rise and fall (up and down) movement of the surface level of oceans, bays, inlets, and estuaries caused by gravitational attraction of the Moon and Sun.
- **Tidal currents:** the alternating horizontal movement (in and out) of water associated with the rise and fall of the tides.
- **Water cycle:** the movement and changing form of water on, above, and below the surface of the Earth.

- **Watershed (drainage basin):** the area of land that ultimately drains into a particular river (in this case, the area that drains into the Hudson River). Also see Data Puzzle #5, "Where did the water go?" The topic of that puzzle is watersheds.
- **Tributaries:** streams and creeks that empty into larger water bodies as part of the drainage network of a watershed.
- **Drainage network:** the interconnected drainage system of a watershed, including surface and groundwater inputs.
- **Runoff:** precipitation that doesn't evaporate, transpire, or penetrate the ground surface to become groundwater, but flows over the surface to the nearest river, lake, or stream.
- **Hypothesis:** a proposal or tentative explanation intended to explain certain observations or conditions.

Teacher Preparation

1. Work through the steps in the data puzzle yourself (pp. 93–99). Use "Step-by-Step: How to Solve Data Puzzle #4" (pp. 105–114) 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 begin the puzzle—for example, *dilution, drainage basin, estuary, river mile, runoff, salinity, salt front, tidal current, tides, tributary, water cycle,* and *watershed.*
4. Gather and prepare suggested materials:
   - For each student: ruler, pencil, 1 red pencil, 1 blue pencil, 1 copy of Data Puzzle #4 (pp. 93–99)

- For the class: map of the United States
- (optional) Use the U.S. Environmental Protection Agency's National Estuary Program website (see "Resources") to locate a map of an estuary near your school.

5. Plan any pre-puzzle activities (see below) and extension activities (p. 119). Check the Data Puzzles website *(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

- To reinforce the concepts of watershed drainage and how freshwater from land areas moves into rivers and streams, have students do one of the following activities. (The URLs for these three activities are listed first in "Resources.")
  - color a complex water cycle
  - explore an interactive water cycle
  - label an interactive water cycle drawing
- Do Data Puzzle #5, "Where did the water go?", **before** this puzzle to introduce your students to the concepts of watershed and runoff.
- Use Figure 4.7, Watershed Map of the Hudson River, or the one on the Data Puzzle website (*www.ldeo.columbia.edu/edu/data_puzzles*) to show students the outline and size of the Hudson River watershed. Over 90% of the 13,400 square miles of the watershed lies in New York, with additional watershed areas in Vermont, Massachusetts, Connecticut, and New Jersey. The largest tributary to the Hudson River is the Mohawk River, entering the Hudson from the west just above the Troy Dam and the estuary section of the river.
- Do the EPA "Surf Your Watershed" activity (see under "Resources": U.S. Environmental Protection Agency).
- Review the concept of dilution. Here is an activity that students can see and taste (see safety note on p. 105):

  Start with four clear containers that are at least 250 ml capacity. Pour 50 ml of red Kool-Aid or a red juice into each of the cups. Put the first cup aside as is. Add 50 ml of water to the second cup, add 100 ml water to the third cup, and add 150 ml of water to the fourth cup.

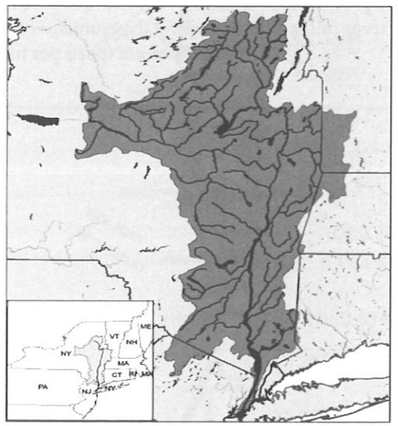
Place the cups on a sheet of white paper to demonstrate the color differences. Using teaspoons, allow students to taste each sample so they can taste the dilution. To connect this activity to step 6 in the Data Puzzle about locating the salt front, discuss how much water would need to be added to water at 35,000 ppm salinity to reduce it to 100 ppm.

Safety Note: Conduct this activity in a general classroom (not a science lab; never eat or drink in a science lab) where no hazardous chemicals (e.g., applied pesticides, chemical cleaners, or chemicals in a science demo) have been used. Before starting the activity, wash areas such as desk tops where the samples are to be mixed.

Step-by-Step: How to Solve Data Puzzle #4

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.

Figure 4.7
Watershed Map of the Hudson River

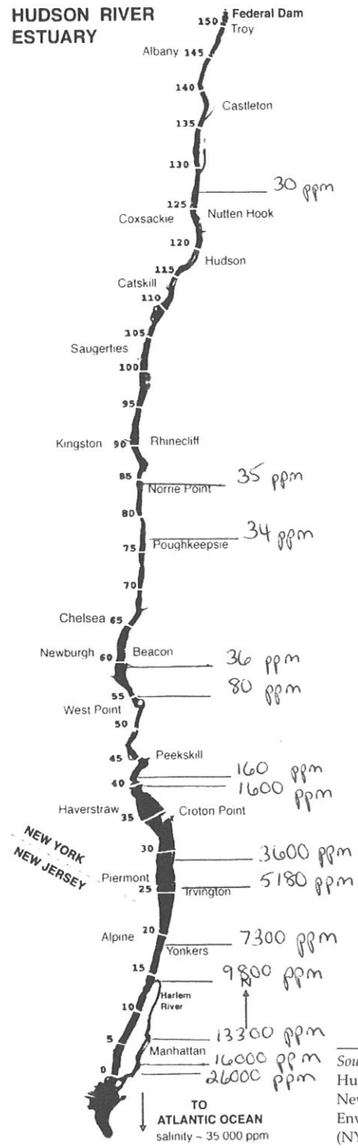


Source: Created by Frank Nitche using data publicly available from the U.S. Geological Survey and the New York State Geographic Information System (GIS) Clearinghouse.

Answer Key	Critical Thinking
To answer the question "Is the Hudson River too salty to drink?" you would need to know about estuaries. There are many important estuaries in North America including, for example, the Hudson River Mississippi River, Chesapeake Bay, Puget Sound, and San Francisco Bay to name a few. An estuary is a place where saltwater from an ocean mixes with freshwater from inland rivers and streams. This mixing creates a "brackish," or partially salty, mix. The ocean tides and currents are also important, as their twice-daily cycle assists with mixing the salty water and freshwater. The Hudson River (located in New York State and New Jersey; see Figure 4.1) flows a total of 315 miles, but only the southern 153 miles (Figure 4.2) are considered the estuary. Located along the length of the map in Figure 4.2 are numbers that represent "river miles" (indicated by the white lines on the map). A river mile measures distance as if you were traveling on the river, starting with zero at the southern tip of Manhattan and measuring northward along the river.	(C) This brief introduction is intended to call to mind already-learned content, not to teach new concepts. Concepts that students need to be familiar with prior to doing the puzzle are estuary, river, tide, and fresh/brackish/salty water. (S) Students must orient themselves to the map in Figure 4.2, understanding the following: • North is toward the top of the map and south is toward the bottom of the map. The location map in Figure 4.1 and the north arrow in Figure 4.2—in addition to knowledge of geography—provide the necessary reference frame. • The ocean is at the south end of the map. The river flows southward, toward the ocean. • River miles increase from the mouth of the river inland (northward). River miles wind around the curves of the river.
1. Table 4.1 contains surface salinity readings collected by school groups during the annual "A Day in the Life of the Hudson River." The salinity is recorded in parts per million (ppm). Ocean water is ~35,000 ppm, and distilled water is 0 ppm. Write the salinity readings from the different river miles onto the map in Figure 4.2. See answers in Figure 4.8.	(S) Students reorganize information from a tabular arrangement into a spatial arrangement. (Q) Students use units of parts per million, a ratio measure of concentration. In helping students to understand these units, a comparison to the more familiar percent (parts per hundred) may be helpful.

Figure 4.8

Answers for Figure 4.2



Source: Created by Steve Stanne, Hudson River Estuary Program, New York State Department of Environmental Conservation (NYSDEC).

(continued)

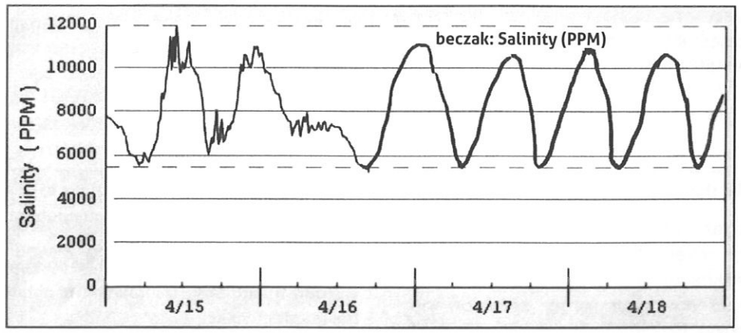
Answer Key	Critical Thinking
2a. How does the salinity in the data vary with distance from the Atlantic Ocean? The salinity in the Hudson River is higher where it is closer to the ocean (south), and decreases as you go farther north, away from the ocean. 2b. What might be the cause of this variation in salinity? The salt water from the ocean pushes into the river from the south. The Hudson River watershed drains freshwater from the land and tributaries. The freshwater mixes with the salt water when they come into contact. The farther you move away from the ocean, the more diluted the salt water becomes as a result of this freshwater input.	(S) Students scan across the numbers arrayed on the map and discern a spatial trend from higher salinity in the south near the ocean toward lower salinity farther north. (Q) Students translate from numbers in ppm to a verbal description. Note that there is an exception to the trend at river miles 76 and 84.5, but it is quantitatively tiny relative to the overall trend (1 ppm out of 35) and should be disregarded in describing the regional picture. (C) Students draw on their knowledge of rivers and estuaries to interpret Figure 4.8. Answers may include as many as four previously learned processes, although most students will not think of all four. • River and tributaries carry freshwater. • Tidal currents carry ocean water inland. • Tidal currents mix freshwater and salt water. • In an estuary, high-density salt water intrudes into the estuary, forming a wedge underneath the lower-density freshwater.
3. Native Americans call this river *Muhheakantuck* (the river that flows both ways). Referring back to the opening paragraph, can you explain why they gave the river this name? Ocean tides cause water to flow in and out of the Hudson River estuary on a regular cycle. *Teaching Note:* The Native American name is pronounced Muh-HEE-kan-tuck.	(C)(S) Tides are usually taught in terms of sea level rising and falling in response to the gravitational pull of the Moon and Sun. To answer this question, students need to think in terms of tides as water currents moving horizontally, north and south, upriver and downriver, flood and ebb. *Teaching Note:* Water in the Hudson River estuary does flow in a southerly direction overall. If you were to drop an orange into the river at the top of the estuary (at Troy) it would ultimately move out of the Hudson River and into the harbor and then the Atlantic Ocean, but it could take as long as four months, depending on the amount of freshwater input.

Answer Key	Critical Thinking
4. We have talked about the tides. Figure 4.3 displays data collected in April of a recent year by instruments at the Beczak Environmental Center in Yonkers, located at river mile 18. Notice the rise and fall of salinity levels twice a day on 4/15 and 4/16. Salinity in the river fluctuates rhythmically with the tidal cycle. Trace your pencil along the observed rise and fall of salinity. Predict what the salinity will be like on 4/17 and 4/18 and show your prediction by completing the salinity line on the graph with your pencil. *Possible student answer:* I predict that the salinity will continue to increase and decrease twice a day with the flood and ebb tides (see Figure 4.9).	(T) Students recognize that the graph in Figure 4.3 is recording a periodic phenomenon—something that repeats at regular intervals of time—and that the time interval between repetitions is about half a day. (C) They connect the twice-a-day repeat time with their knowledge of tidal cycles. (T) Students make a prediction about the future behavior of a system. To do so, they use • their observation that the system is behaving in a regular, repeatable way and • their understanding that there is a mechanism (tides) behind the observed regularity that would be expected to continue into the future.

Figure 4.9

Salinity Levels in the Hudson River at River Mile 18, Apr. 15–Apr. 18

(Same figure as Figure 4.3 but with student prediction entered. As students are introduced to additional information, they figure out that this prediction does not come true. See Figure 4.4, p. 96, for actual data.)



Source: Created by Margie Turrin with data from the Beczak Environmental Education Center *(www.beczak.org)*.

Teaching Note: **Stop here for discussion with your class.** This discussion time is an opportunity to ensure that your students understand that the tidal cycle moves water and salinity both north and south in the river on a regular basis twice a day.

(continued)

Answer Key	Critical Thinking
5a. Now let's look at the actual data (Figure 4.4). This graph shows what really happened to the salinity on 4/17 and 4/18. Compare what you predicted with what actually occurred. *Main answer:* Instead of the salinity levels going up and down twice a day as we predicted, the data show that the salinity levels dropped off steadily from midday 4/16 through to the end of the day 4/18. *Supplementary:* If you look really carefully, you can see that the rise and fall of the tidal cycle is still evident—although with a much smaller amplitude in salinity—all the way through to midday on 4/18.	(S) Students recognize that the graph of observed data differs significantly from their prediction. (T) Students use temporal language to describe the behavior of the graphed phenomenon (salinity) over time. Temporal language can include *expressions of time* such as "today," "last week," or "midday" or *relations of time* such as "twice a day."
5b. Figure 4.5 shows another data set that might help us understand what happened to the salinity. The graph in this figure shows *rainfall* for the same dates as shown in the salinity graph (Figure 4.4). Focusing on the rainfall graph, describe the weather at the Beczak Environmental Education Center on April 15. *Possible student answer:* It was a rainy day that started out with the rain falling moderately and then increasing steadily, with two really strong bursts of rain. The highest peak on the rainfall graph indicates that rain fell at a rate of 26.0 mm/hr. at one point during the afternoon.	(S) Students scan across a data set that has lots of short-term variability to pick out the major features and trends. (T) Students use temporal language to describe changes over time in the graphed phenomenon (rainfall). (Q) Students describe the graphed phenomenon with accurate quantitative rainfall values obtained from the graph. *Teaching Note:* You might provide rainfall definitions that are used by meteorologists: Drizzle = 0.25 mm/hr. Light rain = 1.0 mm/hr. Moderate rain = 4.0 mm/hr. Heavy rain = 16.0 mm/hr. or higher
5c. Now describe the weather at Beczak on April 16. There was less rain than on the previous day. There were several brief showers during the morning (spikes on the graph reaching 5mm/hr.) and one brief downpour (larger spike on the graph reaching 15mm/hr.). There was no rainfall in the afternoon.	(T) Students use temporal language to describe changes over time in the graphed phenomenon (rainfall). (Q) Students describe the graphed phenomenon with accurate quantitative rainfall values obtained from the graph.

Answer Key	Critical Thinking
5d. Look back at Figure 4.4. Describe what happened to the salinity *after* the rainfall ended. The salinity dropped fairly steadily after the rainfall ended. Beginning midday April 16 the salinity began a steady decline, falling from a high of 12,000 ppm down to concentrations of ~200 ppm by April 18.	(T) Students combine information from the rainfall graph and the salinity graph, using date and time as the index to connect the two data sets. (T) Students use temporal language to describe changes over time in the graphed phenomenon (salinity). (Q) Students describe salinity with accurate quantitative values obtained from the graph.
5e. You have described a rainfall event and seen what happened to salinity in the river. Write a hypothesis that explains the observations you made in steps 5a–5d. If you have been teaching the "If…then… because…" framework for hypothesis construction, a good answer might be look like this: "**If** there is a lot of rain, **then** the salinity in the Hudson River will drop over the next few days **because** runoff from the watershed dilutes the river water." If you aren't using this structure, a good answer might look like this: "My hypothesis is that the salinity of the river was diluted by freshwater runoff from the rain." These hypotheses suggest why the salinity decreased and also why there was a time lag between the rainfall and the drop in salinity. The freshwater includes the surface runoff from the surrounding land of the whole watershed, not just the rain falling directly into the river. It takes awhile after the rain begins for the freshwater to reach the river through the drainage network of the watershed.	(Q) Students recall the concept of dilution and use this concept to formulate a tentative explanation for the observed decrease in concentration of salt in the river. (T) Students recognize that there is a time lag between the falling of the rain and the dilution of saltiness by freshwater. (S) Students have a mental image of rain falling over a wide area, running off the land and traveling through tributaries to the Hudson. They recognize that this travel over distance requires time, and they connect this travel time to the observed time lag. *Teaching Note:* Some students may have been taught that a "hypothesis" is the starting point for an investigation. They might not be familiar with the idea of a hypothesis as an explanation or interpretation at the end of an investigation. This is an opportunity to point out that Earth science hypotheses are often based on observations of a real-world occurrence. Such a hypothesis can become the basis for a future investigation.

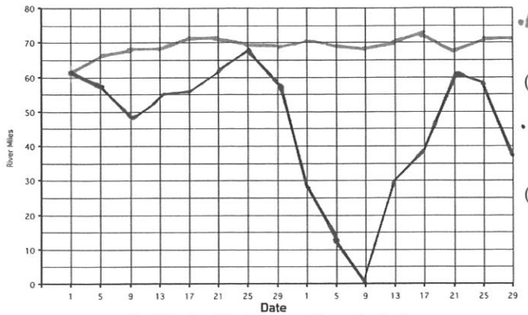
(continued)

Answer Key	Critical Thinking
6. Some communities along the upper Hudson estuary use the river as the source of their drinking water. Standard water treatment plants do not remove salt, so it is important to be sure the water in these areas is not too salty to drink. Experts have determined that 100 ppm salinity falls within acceptable drinking water standards. The location where the river salinity reaches 100 ppm has been labeled the "salt front." Each day the United States Geological Survey records the location of the salt front in river miles (see Table 4.2, p. 97) as a guide for the communities that use the river for drinking water. *Teaching Note:* Before students begin step 6, check during a class discussion to make sure that they understand the concept of salt front. Emphasize that answers to all parts of step 6 should describe the river, not the graph.	
6a. On the graph on page 99 (Figure 4.6), the *x*-axis is the date and the *y*-axis is river mile (RM) location. You will be plotting the RM location for the salt front for the dates listed. Using a red pencil, plot the salt front data for August and September in one continuous line on the graph. See the completed graph in Figure 4.10, page 114. Note that the color for August and September in this book is gray. Describe the location of the salt front for August and September. Use both river miles and names of communities in your answer. The salt front didn't move very much. It was stable at around river mile (RM) 65–70, which is between Chelsea and Poughkeepsie.	(Q) Students accurately transfer quantitative data from table to graph. (T)(S) Students interpret the nearly flat line on the graph as indicating that the position of the salt front hardly changed at all over the observed time interval. To make this interpretation, they must understand that the *y*-axis on this graph shows spatial position, unlike the more familiar graphs with quantity or amount on the *y*-axis. (S) Students connect the river miles on the *y*-axis of the graph to river miles on the map and on the earth.

Answer Key	Critical Thinking
6b. Plot the March and April salt front data on the same graph using a blue pencil. Label your graph. See the graph in Figure 4.10, page 114. March and April data show as black in this book. Describe the location of the salt front in March and April. Use both river miles and names of communities in your answer. For most of March and April, the salt front fluctuated between RM 45 and 65, which is between Chelsea and Peekskill. After March 25, the salt front moved drastically all the way downriver to the southern tip of Manhattan (RM 0) on April 9. Then it returned to its earlier position, around RM 60 near Beacon and Newburgh.	(Q) Students accurately transfer quantitative data from table to graph. (T) Students interpret a position versus time graph. When the data line is nearly flat (in step 6a), students infer that the salt front is stable. When the data line deviates substantially from its earlier stable position, they infer that there has been a major shift in the location of the salt front. Students use temporal language to describe the behavior of the salt front over time. (S) Students connect the river miles on the *y*-axis of the graph to river miles on the map and on the Earth.
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. The salt front in August and September remained fairly consistent, moving only between RM 62 and RM 73 (approximately from Newburgh to Poughkeepsie). 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.	(S)(T) Students interpret the position versus time graph in terms of • *position* (in March and April the salt front is always closer to the ocean—i.e., farther south—than in August and September) • *variability of position* (in August and September, the salt front location is more stable than in March and April)
6d. Using the map in Figure 4.2 and the data from your graph, list two communities along the Hudson River where the salinity of the water was low enough to use for drinking water throughout all of August and September. Any community north of Poughkeepsie is a good answer. The salt front never moved north of RM 73, which is just south of Poughkeepsie. *Teaching Note:* Discuss with students that salinity is not the only determination of whether water is safe to drink. Most of our drinking water, including that from the Hudson River, is treated prior to use to remove any bacteria, pathogens or other contaminants.	(C) To complete steps 6a to 6d, students must use the information given in the introduction to these steps, plus the concept of a threshold value, to conclude that they are looking for communities that remain north of the salt front at all times. (S) Students must connect salt front position plotted on the graph with the geographical positions on the map.

Figure 4.10

Answers for Figure 4.6



(will be red on student answer sheets)

(will be blue on student answer sheets)

Chart March and April as one continuous line in blue.
Chart August and September as one continuous line in red.

(continued)

Answer Key	Critical Thinking
7. Thinking of the processes you explored in step 5 and the data in step 6, what might cause the differences between the March–April salt front location and the August–September salt front location? Explain your answer. In the spring in temperate climates, there tends to be a lot of rain. With repeated rain events, the ground becomes saturated and so the runoff and drainage from the watershed are often in larger amounts than during other times of the year. In addition, early in the spring the warming weather mixed with rain causes snowmelt in the upper watershed. The addition of large amounts of additional freshwater to the river pushes the salt front south, toward the ocean. In late summer and early autumn, the consistently drier days and warm summer weather cause a reduction in freshwater in the small streams and tributaries that are a source of freshwater to the Hudson River. This reduced flow into the Hudson allows the saltier water to push farther upriver.	(C) Students can make use of the following knowledge and concepts in this step. Most students will not include all these elements in their answers. • Understand that evaporation varies with temperature, that temperature varies with season, and that in the northeastern United States the temperature is higher in August and September than in March and April. • Understand the concept of seasonality, recalling that rainfall in the northeastern United States tends to be abundant in the spring. • Understand the concept of ground saturation, and anticipate that during times when rainfall is relatively high and/or evaporation is relatively low there will be a lot of freshwater runoff into the Hudson, pushing the salt front south. • Understand that the Hudson watershed extends far enough north for winter snowfall, that accumulated snowpack melts in the spring, and that melting of the snow cover will deliver a sudden burst of freshwater to the river, pushing the salt front south. *Teaching Note:* An analogy might be to think of the freshwater input from the watershed in the north and the salt water influence from the Atlantic Ocean in the south as being two contenders who are arm wrestling. At any given time, one side might be pushing harder than the other, causing the salt front to move further in the direction of the harder push. In this analogy, if the Atlantic is pushing harder, the salt front moves north up the river, but if the freshwater is pushing harder because of rainfall or snowmelt, the salt front will move south down the river.

Common Student Misconceptions

- *Because rainfall and salinity are high at the same time (Figures 4.4 and 4.5), students may interpret the graphs of rainfall and salinity to mean that rainfall causes an increase in salinity. This is NOT true!*

To understand the point of confusion, it is important to observe that during the time of heavy rain, the salinity graph is reflecting the **standard** tidal rhythms of the salinity in the Hudson River. The twice-a-day regular rhythm has not yet been affected by the rain. Rainfall actually dilutes the salinity levels in the water, but because of the large volume of the river compared to the amount of rain falling, this effect is not apparent in the salinity data until 24 to 48 hours after heavy rainfall—by which time the drainage of the entire watershed is felt.

- *Students may not understand that the ocean is a concentrated source of salinity. They may feel that the constant process of rocks being dissolved by water is what makes the Hudson salty.*

The strongest contributor to the salt content in the Hudson River is the Atlantic Ocean. There is a low background amount of salt in the Hudson River caused from the ongoing geologic erosion of rock formations in the watershed, but this amount is much lower than the salinities observed in the southern Hudson.

- *All rivers flow in only one direction.*

Rivers with a tidal influence respond to the tides as well as to elevation as they flow. About half of the Hudson River's 315 mi. length flows only north to south. The other half, its lower range, is tidal through its connection to the Atlantic Ocean. The Hudson River has an unusually long tidal section, a result of the lack of elevation change in the river. There is only an approximate 2 ft. change in elevation along the lower 153 mi. section from New York harbor to the Troy Dam.

- *Downstream is always south in a river.*

Rivers do not always flow from north to south. Rivers will flow downhill, which can be any compass direction. Perhaps the most famous north-flowing river is the Nile River in Egypt.

- *The salinity in the Hudson River is controlled only by the tides.*

The Hudson River tides are only one piece in the salinity story of the Hudson River. See the answers to steps 2b, 5e, and 7.

- *Salinity in the Hudson is a result of pollution.*

The Hudson River is an estuary and therefore has a steady addition of salt water from the Atlantic Ocean. Many smaller streams in the wider watershed are experiencing a rise in salinity from use of salt on the roads in the winter, but for the Hudson the primary source of salt is the Atlantic Ocean.

- *The Hudson River is the same 365 days a year.*

The Hudson River is in a constant state of change. The salt front is only one example of this constant change; it shifts south and north in response to freshwater inputs and salt water moving in from the ocean. For a chart of the daily location of the salt front, go to the U.S. Geological Survey website link found under "Sources for Data Puzzle #4."

- *Only the rain that falls directly into the river has an impact on its salinity.*

The runoff or drainage from the watershed has a much stronger impact than the rainfall falling directly into the river.

- *The major freshwater impact of rain will register immediately on the salinity levels of the river.*

The impact of a rain storm will depend on the total volume of rain that falls. However the immediate impact of the water falling in the river is generally not as significant as the aftermath of the storm when the runoff and drainage of water from the rain event "flushes" out from the entire watershed.

- *The freshwater input from a storm event will be long lasting on the river.*

The addition of freshwater to the river from a storm is not long lasting. The river rebounds quickly from a freshwater addition, often in only a few days. *Note:* It is important to notice that the horizontal (time) scale for the rainfall and salinity charts in step 5 (Figures 4.4 and 4.5) is very different from the horizontal (time) scale on the salt front chart (Figures 4.6 and 4.9) in step 6. The rainfall and salinity charts cover only a four-day period, while the salt front chart spans two months.

Tough Questions (With Answers)

These are questions that your students may ask you or that you could ask them.

Q. Why is river mile zero at the end of the river (south) rather than the beginning of the river (north)?

A. River miles are a measure used in many rivers, not just the Hudson, and river mile zero is always at the mouth or downstream end of the river. In general, it is possible to pick a clear and unambiguous spot at the downstream end of a river and designate this as river mile zero. As you go upstream, you encounter smaller and smaller streams, and then rivulets, and there is no clear-cut beginning point from which to start measuring. River miles were used as a navigation description. Historically, when the European explorers and settlers arrived in the "New World," they approached the rivers from the ocean with their seagoing ships (vessels quite different from the sleek canoes of the native population, which were designed for use on inland waters). They began their explorations working inland, with river miles advancing up the navigable section of the river in the direction of exploration, rather than in the direction of water flow.

Q. Why doesn't the salinity level in the "Day in the Life of the Hudson River" measurements (Table 4.1) go down to zero?

A. There is a background level of salinity in the Hudson, a result of erosion of rocks and soil. This erosion over time is a natural, gradual process, which leads to the salt ions being washed down the river where they ultimately end up in the ocean, contributing to its overall salinity. The salinity in the Hudson also has contributions from human influences such as the use of road salts in snow removal.

Q. Why does the salinity increase upstream (rather than decrease) from 34 ppm at RM 76 back up to 35 ppm at RM 84.5 in the "Day in the Life of the Hudson River" data?

A. It is not unusual to see small fluctuations or variations in data from natural systems, and we can't know the reason for this particular wiggle in the data. This small difference could be from different instruments being used. Or it could be a small but real difference caused by a natural phenomenon such as a tributary or eddy or a human influence such as a sewage treatment outfall. Scientists and students learn to "look past" small wiggles in Earth science data to perceive and interpret the larger scale trends in a new data set. Once the large scale trend is fully documented and interpreted, scientists might then look into smaller scale features, but this would require repeated measurements, closely spaced, using consistent instrumentation for all the measurements.

Q. Why does the salinity data in Figure 4.9 have so many little spikes superimposed on the regular tidal rise and fall?

A. The small spikes are due to local processes, such as eddies or wind, that can stir up the water column.

Q. Why does it look as if the salinity on April 15 goes up rather than down during the most rapid rainfall?

A. The tides cause a regular fluctuation in the salinity in the lower estuary. On flood (incoming) tides, saltier ocean water is pushed into the estuary causing a rise in the salinity. On April 15, the flood tide just happened to match the strongest periods of rain.

Q. How does the USGS actually measure the salt in the estuary?

A. There are several different techniques used to measure salinity (or ionic concentrations) of natural waters. The USGS actually measures chloride concentration, which is a slightly different metric for reporting ion concentrations. The technique involves a combination of instrument measurements and modeling to fill in the information between the USGS instruments. More information on this topic can be found at the USGS website listed under "Sources for Data Puzzle #4": U.S. Geological Survey.

Q. Why is this estuary so long and skinny?

A. This estuary bed was shaped by glaciation much like the fjords in Norway. The hard materials of the Hudson Highlands (granitic gneiss and other metamorphic rocks) made it difficult for the glaciers to carve into the material and kept the carved channel fairly narrow. (For more information on the geology of the Hudson River, see the U.S. Geological Survey website on this topic, listed in "Resources.")

Q. What is the difference between tides and currents?

A. Tides move water up and down in response to the gravitational pull of the Moon and Sun. On a high tide, the water is higher against the shoreline, and on a low tide the water is lower. Currents move water sideways (horizontally) and can be caused by a variety of processes. The difference between high and low tide can cause currents (tidal currents) if there is a bay or estuary with a gentle gradient, such that the water must travel a long way horizontally to achieve a few feet of rise of elevation. The tidal current in the Hudson River follows the tide, pushing water into the estuary and pulling it back out again. If you were to stand in the river, you would feel the water pushing hard northward against your legs when the current is described as "incoming" or "flood." When the current shifts and is "outgoing" or "ebb," you would feel the water flowing strongly south.

Q. Does the term **salt front** *in the estuary have anything to do with the terms* **warm front** *and* **cold front** *that we hear in weather reports?*

A. The similarity is that both uses of the term *front* describe a boundary. Warm and cold fronts are the boundaries or meeting locations of different air masses. A salt front is where the leading edge of the salt water meets the freshwater of the river. (See Data Puzzle #2.)

Q. Why is the Hudson sometimes called a river and sometimes called an estuary? Which term is correct?

A. Both terms are correct. The Hudson is a river because freshwater travels from the upper reaches of the watershed through the Hudson to reach the Atlantic Ocean. The Hudson is an estuary because the water ebbs and floods with the tide and is intermediate in salinity between freshwater and ocean water.

Q. Why is the Hudson called an estuary only up to Troy, New York, even though the river begins well north of Troy?

A. It is true that the Hudson River extends north of Troy for 162 miles. However, the estuary section of the Hudson River, which is 153 miles, ends at Troy as a result of a significant increase in elevation. The increased elevation is caused by the dam at Troy, which creates a boundary that blocks the tides from traveling any farther up the river. There has been a dam of some sort in this location since 1823. The current dam, built in 1913–1915 by the federal government, is the earliest in a series of dams in the upper Hudson River built to make the water deep enough for navigation. (Recall that estuaries are where freshwater meets and mixes with ocean water, resulting in "brackish" or moderately salty water and various tidal influences. In the Hudson River, salt from the Atlantic Ocean doesn't go all the way to Troy but the ocean tides do.)

Extension Activities

- Research how rainfall data and salinity data are collected.
- Compare and contrast this river estuary to other estuaries. The website "Surf Your Watershed" from the U.S. Environmental Protection Agency (see "Resources") is a good starting point.
- For students and teachers living in the geographic area examined in this puzzle, a teachable moment following a big storm would be to ask, "What do you think is happening to the salinity in the Hudson River today?" For information, go to the U.S. Geological Survey's salt front page (see "Sources for Data Puzzle #4"), the U.S. Environmental Protection Agency's "Surf Your Watershed" site (see "Resources"), or the Hudson River Environmental Conditions Observing System site (see "Resources").

- Research how land use changes in the watershed might impact the salinity of the Hudson. This research can turn up several conflicting answers:
  a. Water is taken out for new growth or usages upriver, tending to increase river salinity.
  b. Increased development can increase impermeable surfaces, which in turn increases runoff into the river, tending to decrease river salinity.
  c. Increased growth and development can increase the use of road salt, which ends up washing into the river, tending to increase river salinity.
- Research what other factors (other than salinity) must be considered in order for water to be declared safe to drink.
- Explore further the topic of estuaries and their unique characteristics by using some of the resources provided in the section titled "Resources."
- The Hudson River is referred to as a historic river because of the role it played in the history and development of the United States. Every river has a story. Is there a river in or near your community? Research its role in the historic and economic development of your community.
- Teachers can introduce and review the concept of a density interface between two different liquids, using a hands-on activity with table salt, water, and food coloring. The "Resources" section has some useful sites for this purpose. Link this activity to the concept of salt wedges in rivers.
- The EPA has set a secondary drinking water standard of 250 mg/L for **chloride**. The amount of chloride can be directly tied to the amount of sodium in drinking water. Research what the negative effects could be if you were to drink water that exceeded the 250 mg/L level of chloride.

Sources for Data Puzzle #4

Beczak Environmental Education Center
Beczak is a Yonkers-based environmental education center with real-time weather and water-quality monitoring equipment located onsite. The data for steps 4 and 5 were collected in the spring of 2007 from the center's monitoring station. To connect to the monitoring data, click on the link "Hudson River real-time environmental data" on the website.
www.beczak.org/emsystem.htm

A Day in the Life of the Hudson River.
"A Day in the Life of the Hudson River," an education project focused on the Hudson River, is sponsored by the Hudson River Estuary Program of the New York State Department of Environmental Conservation in partnership with the Lamont-Doherty Earth Observatory. Data are collected and available for curriculum projects and activities. The data for steps 1 and 2 were collected as part of this project in the fall of 2006.
www.ldeo.columbia.edu/edu/k12/snapshotday

U.S. Geological Survey, Troy, New York (Hudson River salt front data)
Location of the salt front in the Hudson River is provided in several different formats. Data for step 6 were from this source:
http://ny.water.usgs.gov/projects/dialer_plots/saltfront.html

Resources

Color a complex water cycle
http://bluebison.net/books/coloring_books/0806/water_cycle_coloring_page.jpg

Explore an interactive water cycle
www.yvw.com.au/waterschool/seniors/water_cycle.html

Label an interactive water cycle drawing
http://education.jlab.org/reading/water_cycle.html

Hudson River Environmental Conditions Observing System (HRECOS)
A real-time monitoring system, with several instrument locations collecting water-quality and meteorological data in the Hudson River.
www.hrecos.org

National Environmental Services Center (NESC). "How to explain ppm and ppb to your students" (an article by Zane Satterfield, NESC engineering scientist).
www.nesc.wvu.edu/ndwc/articles/ot/fa04/q&a.pdf

New York State Climate Office
Visit this site to learn more about the climate of New York, including rainfall and snowfall for the state. The "Snowfall" section notes that "the Adirondack region has an average seasonal snowfall in excess of 90 inches." When this large amount of snow melts, it adds a large amount of freshwater to the downriver drainage basin (the Hudson River).
http://nysc.eas.cornell.edu/climate_of_ny.html

U.S. Environmental Protection Agency, National Estuary Program
Website that features information on many estuaries throughout the country; includes maps and program overviews and highlights
www.epa.gov/nep/studyareas.html

U.S. Environmental Protection Agency: Surf Your Watershed
http://cfpub.epa.gov/surf/locate/index.cfm

U.S. Geological Survey
Website on the geology of the Hudson Valley
http://3dparks.wr.usgs.gov/nyc/valleyandridge/hudsonvalley.htm

Additional Relevant Web Resources

Activities that explore differences in densities
www.teachersdomain.org/resource/phy03.sci.phys.matter.lp_density
American Meteorological Society: Water in the Earth System
www.ametsoc.org/amsedu/WES/home.html
Explore the uniqueness of estuaries
www.estuaries.gov/Estuaries101/Teachers/Default.aspx?ID=102
Good basic explanation of density
www.visionlearning.com/library/module_viewer.php?mid=37
NASA Goddard Space Flight Center: water/hydrologic cycle diagram
www.csr.utexas.edu/grace/gallery/other/misc/water_cycle_sys.html
National Oceanic and Atmospheric Administration (NOAA). Tidal information website
http://tidesandcurrents.noaa.gov/tides07
U.S. Weather: Average Temperatures and Rainfall in U.S. Cities
Towns along the Hudson for which this site provides weather data include New York (RM 0), Yonkers (RM 18), Poughkeepsie (RM 75), and Albany (RM 145).
http://countrystudies.us/united-states/weather
Weather Underground
www.wunderground.com
What does ppm or ppb mean?
www.nesc.wvu.edu/ndwc/articles/OT/FA04/Q&A.pdf
What is an estuary?
www.epa.gov/nep/about1.htm
www.epa.gov/nep
www.hrecos.org

Nonprofit Organizations With Both Educational And Advocacy Missions Regarding the Hudson River

Hudson River Sloop Clearwater
www.clearwater.org
Riverkeeper
www.riverkeeper.org

Where did the water go?

Local research scientists installed a stream monitoring station on Cascade Brook in order to better understand how water moves through this small watershed. The downstream community depends on the water from this watershed and has been monitoring rainfall in the watershed for several years. Now that there is a stream monitoring station installed, the community wants to see if the rainfall numbers match the stream flow numbers at the monitoring station. If too little of the rainfall water is flowing through the station, there is a concern that water supplies might run short. Let's find out.

Stream Monitoring Station on Cascade Brook



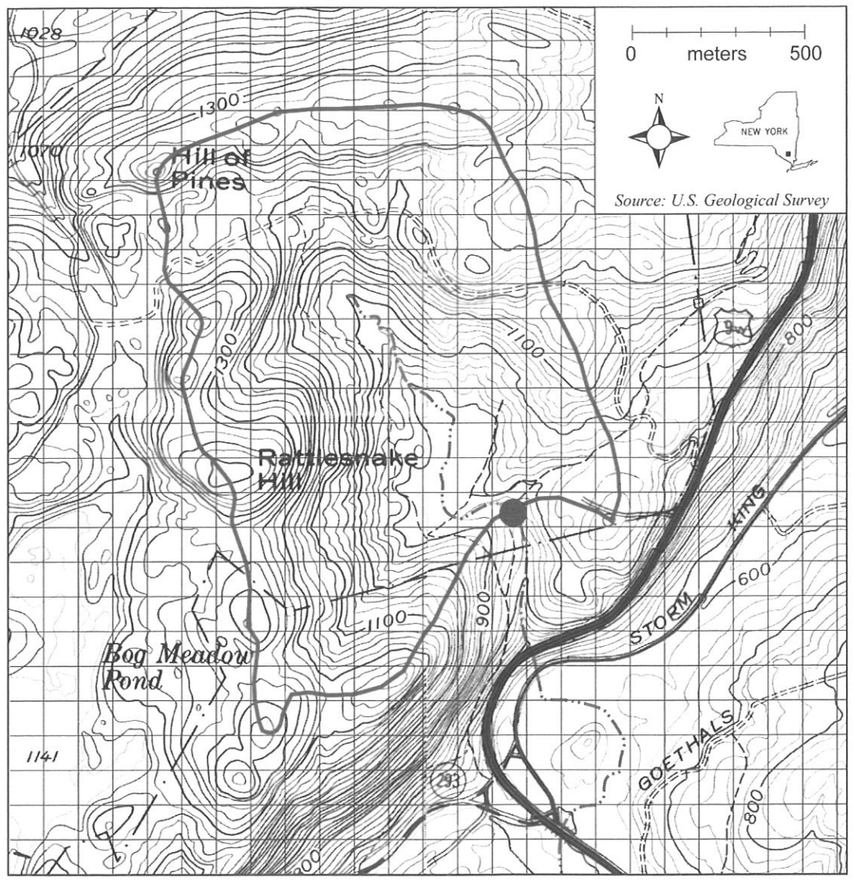
Source: Courtesy of Martin Stute.

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

1. Orient yourself to the topographic map (Figure 5.1, p. 124).
   1a. Label the stream "Cascade Brook."
   1b. In what state is Cascade Brook located?
   1c. Draw an arrow on the map to mark the direction in which the stream is flowing. In what compass direction is the stream flowing?
   1d. Find the stream monitoring station. Label the boundary of the watershed that feeds into the stream monitoring station.

Figure 5.1

Topographic Map of Cascade Brook and Surrounding Landscape (to be completed by student)



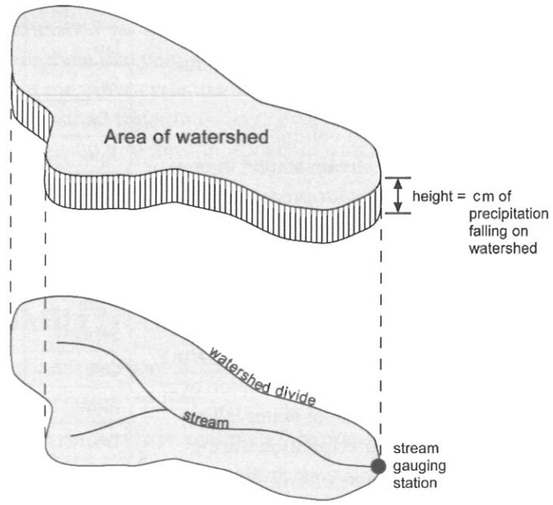
Source: Adapted from U.S. Geological Survey topographic maps for Cornwall-on-Hudson and West Point, NY. Courtesy of USGS.

2. Notice that there is a grid superimposed on the map. Each square in this grid represents 100 m by 100 m in the real world. Using the grid, estimate the area of the watershed that feeds into the stream monitoring station. Include each square that is more than 50% inside the watershed. Show your work, and include units in your answer.

3. You have just calculated the *area* of the watershed feeding into the stream monitoring station. Now we want to calculate the *volume* of water falling within this area (see Figure 5.2). This region received 114 cm of precipitation in a given year. In other words, if the year's worth of precipitation were to be spread evenly across the landscape, it would form a layer 114 cm deep. What was the volume of water that fell into the watershed during this year? Show your work, and include units in your answer.

Figure 5.2

Volume of Precipitation Falling on a Watershed



Source: Illustration by Linda Pistolesi.

4. Make a prediction. You have calculated the volume of water that fell in the watershed. What do you think was the volume of water that flowed through the stream monitoring station during this same year? Write your prediction down on a separate piece of paper, fold it over, and do not open it again until you have completed the puzzle.



Check with your teacher before going on. Your teacher might collect the predictions for a class discussion.

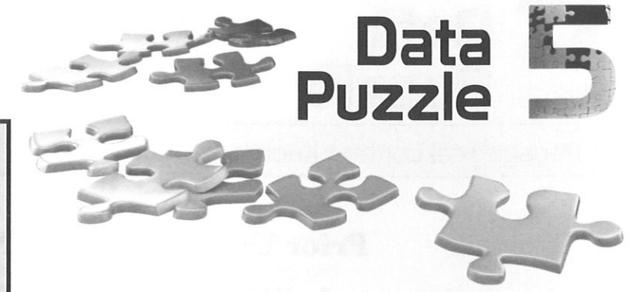
5. Table 5.1 shows the volume of water that passed through the Cascade Brook stream monitoring station each month for one year. Suggest some reasons (hypotheses) why the volume of stream flow varies so much from month to month. *Clue:* Think about the climate of this region of the country.
6. What is the total volume of water that flowed through Cascade Brook at the stream monitoring station over the entire year? Show your work, and include units in your answer.
7. Compare the measured volume of water flowing through the stream station in one year (see step 6) with your prediction of the volume of water flowing through the stream station (see step 4). Are they similar or different?
8. Now let's look at this quantitatively. Compare the total volume of water flowing through the stream monitoring station over the year with the volume of water falling in the watershed as precipitation during that same time. Express your findings as a percentage in a complete sentence.
9. Suggest some reasons (hypotheses) why these amounts are not the same. Be prepared to defend your favorite hypothesis in class discussion.

Table 5.1

Volume of Water Passing Through Stream Monitoring Station, Jan.–Dec.

Month	Water Passing Through Stream Monitoring Station (cubic meters)
Jan.	99,094
Feb.	70,992
Mar.	81,842
Apr.	115,930
May	146,614
June	84,127
July	262
Aug.	0
Sept.	0
Oct.	76,429
Nov.	163,473
Dec.	130,619

Source: Courtesy of Black Rock Forest.



Pedagogical Content Knowledge Guide

Where did the water go?

In this Data Puzzle, students calculate the amount of precipitation that fell in a watershed over the course of one year and the amount of water that exited from that watershed via the outflow stream. They then compare these two values and draw on their knowledge of the water cycle to infer that the large amount of "missing" water must have exited the watershed either up into the atmosphere or down into groundwater.

This puzzle works well in an Earth science or environmental science course or unit.

Aha! Insights

- You can actually measure the water as it moves through the water cycle.
- The "invisible" pathways in the water cycle (infiltration and evapotranspiration) carry nearly as much water as the visible pathway of the rushing stream. In fact, ***almost half*** of the water that fell onto the watershed did not flow out through the stream!

Prior Skills Needed

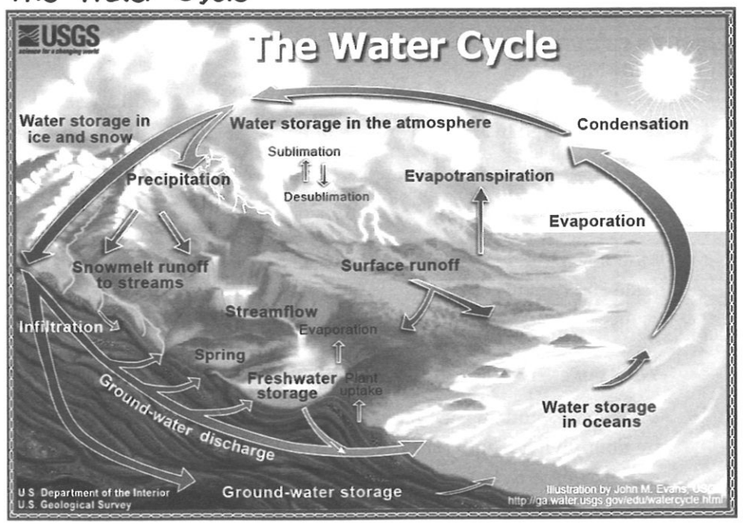
- Map interpretation, including use of map scale and compass rose.
- How to convert from centimeters to meters.
- What square meters and cubic meters are.
- From math, students need to remember that an area can be calculated by multiplying length times width. A volume can be calculated by multiplying area times height.
- This puzzle includes a series of mathematical calculations (area, volume, percent, addition) introduced in a real-world situation where formulas are not provided. Some teachers have found it useful to do a lesson on dimensional analysis prior to using this puzzle.

Prior Understandings Needed

- Students should have a basic knowledge of topography and topographic contours and know how symbols are used on topographic maps. The necessary symbols are shown in the puzzle, beneath the map in Figure 5.1.
- Interpreting the topo map will be easier if students know the "rule of Vs": Topographic contour lines crossing a stream valley form a sharp-pointed V shape, with the drainage channel passing through the point of the V. The V points in the upstream direction.
- Students need a simple mental model of the *water cycle* as a system of flows or pathways by which water moves through the Earth system. In particular, students need to be familiar with the following water cycle components: *precipitation, stream flow, evaporation, groundwater.* Use Figure 5.3 for a diagram of the water cycle or a similar diagram from your class textbook.

Figure 5.3

The Water Cycle



Source: Diagram by John M. Evans. Courtesy of the U.S. Geological Survey.

- If your curriculum includes the concepts of *evapotranspiration* and *infiltration,* students will be able to use those concepts, but they can reach the Aha! insights without them.
- Students need to understand the concept of a *watershed* (the area of land that contributes water to a given point, such as the mouth of a river). There is a good animation that illustrates this definition at *http://techalive.mtu.edu/meec/module01/whatiswatershed.htm.* See Figure 5.4 for a diagram of a watershed. In the diagram, the spotted heavy black line outlines the border of the watershed that feeds into the larger stream at the bottom of the diagram.

Figure 5.4

Diagram of a Watershed



Source: Oregon Watershed Assessment Manual, prepared by Watershed Professionals Network, LLL (*www.watershednet.com*), July 1999. Courtesy of Oregon Watershed Enhancement Board (*www.oweb.state.or.us*).

- For step 5, students need to know a bit about the climate of New York State: July and August are usually the hottest months of the year and tend to be dry; January and February are usually the coldest months of the year and are often below freezing. If students lack this knowledge, you can have them skip step 5 and still reach the Aha! insights.

Teacher Preparation

1. Work through the steps in the data puzzle yourself (pp. 123–126). Use "Step-by-Step: How to Solve Data Puzzle #5" (pp. 132–138) 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 describes the critical thinking that students will need to solve each step.
2. Consider your students' math skills. If you think they will get lost in the calculations and have trouble determining which mathematical operations to use at each step, take a look at the supplemental worksheet entitled "Optional Additional Scaffolding" provided on the Data Puzzles website (*www.ldeo.columbia.edu/edu/data_puzzles*). This teacher-prepared worksheet guides students through the mathematical calculations of the puzzle, while still allowing them to reach the Aha! Insights. If your students are capable of working without this "cookbook"-style worksheet, however, the authors strongly encourage you **not** to use the worksheet, so as to better develop your students' analytical and problem-solving skills.
3. Write down your learning goals for this puzzle. The goals you select will vary, based on the academic needs and skills of your students and the specific focus of your school or 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.
4. Select key vocabulary to review with students **before** they start the puzzle—for example, *area, drainage basin, evaporation, evapotranspiration* (a combination of evaporation and plant transpiration of water from the Earth to the atmosphere), *infiltration* (water sinking into the ground), *runoff, stream monitoring station* (measures rate and volume of water passing through a point along a river), *transpiration, tributary, volume, water cycle,* and *watershed.*

5. Gather and prepare suggested materials:
   - For each student: pencil, calculator, a copy of Data Puzzle #5 (pp. 123–126)
   - For the class: map of the United States
   - (recommended) Some way to show the topographic map in color. A colored version of the map is provided on the Data Puzzles website (*www.ldeo.columbia.edu/edu/data_puzzles*). You can project it with a computer projector or print out a few copies on a color printer.
6. Plan any pre-puzzle activities (see below) and extension activities (p. 141). Check the Data Puzzles website (*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

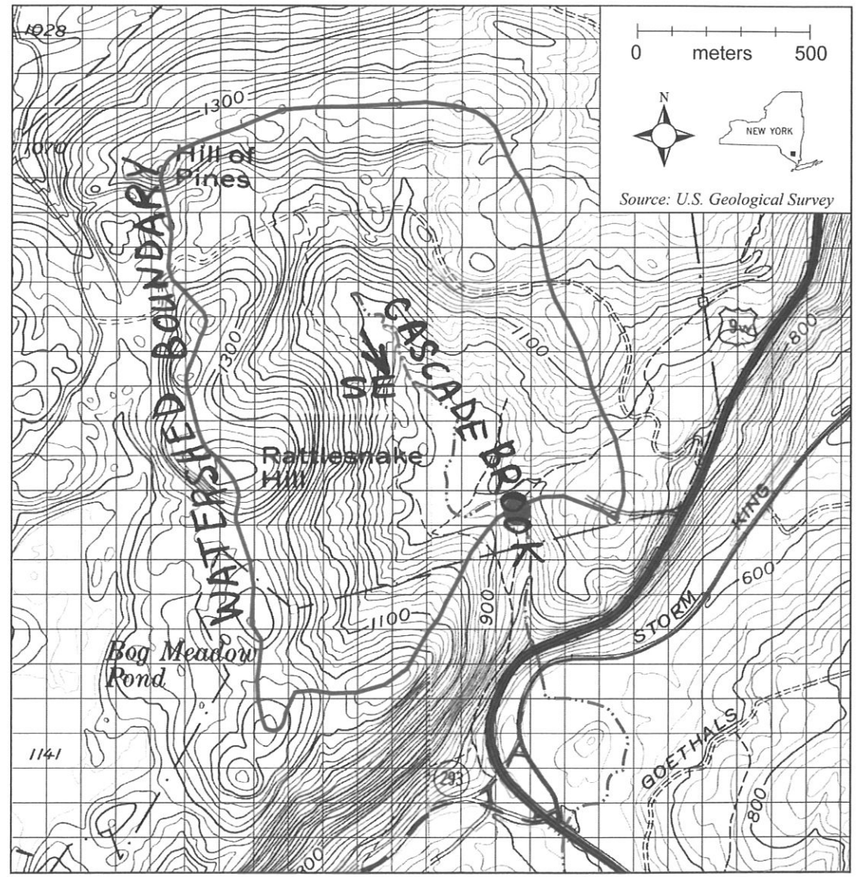
- ABC Mini Water Cycle: Students create a solar "still" in your classroom to observe the cycle of water from solid, liquid, and gas (see ABC Science Online under "Resources").
- Explore a virtual watershed with your students. Southwest Florida Water Management District (see "Resources") has designed an activity booklet covering basic watershed activities and concepts.
- To reinforce the concepts of watershed drainage and how freshwater from land areas moves into rivers and streams, have students do one of the following activities. (The URLs for these three activities are located in "Resources.")
  - Explore an interactive water cycle
  - Color a complex water cycle
  - Label an interactive water cycle drawing
- The standard topographic map provided with this Data Puzzle (Figure 5.1) has the outline of the watershed already marked on it. If your students are skilled users of topographic maps (or you wish them to become so), you can have them determine the position of the Cascade Brook drainage area themselves by analyzing the topographic contours in the unmarked map provided on the Data Puzzles website.

Step-by-Step: How to Solve Data Puzzle #5

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
1. Orient yourself to the topographic map (Figure 5.1): 1a. Label the stream "Cascade Brook." See Figure 5.5.	(S) Interpret map symbols to identify stream. (S) Use inset map to find where the field area is located.
1b. In what state is Cascade Brook located? New York State	(S) Interpret topographic contours to know which way is downhill.
1c. Draw an arrow on the map to mark the direction in which the stream is flowing. In what compass direction is the stream flowing? southeast or SSE	(S) Use compass rose to assign compass direction to arrow on map. (C) Recall the concept of *watershed*.
1d. Find the stream monitoring station. Label the boundary of the watershed that feeds into the stream monitoring station. See Figure 5.5. (The heavy gray line outlines the boundaries.)	(S) Understand that the boundary between watersheds runs along local topographic highs—thus detect that the heavy gray line is the boundary of the catchment area that feeds into the stream monitoring station.

Figure 5.5
Answers for Figure 5.1



Source: Adapted from U.S. Geological Survey topographic maps for Cornwall-on-Hudson and West Point, NY. Courtesy of USGS.

(continued)

Answer Key	Critical Thinking
2. Notice that there is a grid superimposed on the map. Each square in this grid represents 100 m by 100 m in the real world. Using the grid, estimate the area of the watershed that feeds into the stream monitoring station. Include each square that is more than 50% inside the watershed. Show your work and include units in your answer. a. Each square on the map grid is 100 m by 100 m in size. b. Calculate the area of one grid square, using the formula for area: The area of one grid square length × width = 100 m × 100 m = 10,000 m^2. c. Count the number of grid squares that are inside the heavy gray line on the map. Students' answers will differ slightly, depending on how they count the partial squares around the edge of the watershed. The answer should come out between 144 and 164 grid squares. Let's use 154 grid squares for our calculation. d. Compute the total area of the watershed, using multiplication to combine the areas of all of the small grid squares: Area of watershed = 154 grid squares × 10,000 m^2/square = 1,540,000 m^2.	(S) Understand the meaning of *area* deeply enough to realize that grid squares can be used to estimate area of an irregularly shaped region. (Q) Recall and use the formula for area to calculate the area of one grid square. (Q) Recognize that multiplication is the correct operation to use to calculate total area from the information you have: number of squares and area per square. (Q) Complete the multiplication correctly, with correct units throughout. *Teaching Note:* If your students know how to use scientific notation, this is a good place to use it. The area of one grid square would then be 1.0×10^4 m^2, and the watershed would be 1.54×10^6 m^2.

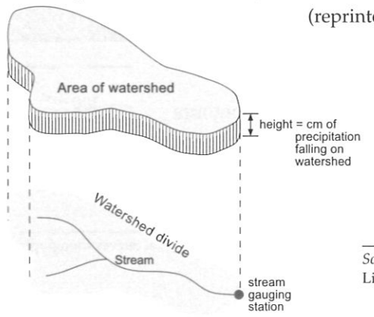
Teaching Note: Visualizing Volume

One of the keys to this puzzle is to form a mental picture of the volume of precipitation that fell on the watershed, as shown in Figure 5.2., reprinted here from page 125. The volume can be calculated by multiplying the area of the watershed times the thickness of the layer of precipitation that fell on the watershed.

Figure 5.2

Volume of Precipitation Falling on a Watershed

(reprinted from p. 125)



Source: Illustration by Linda Pistolesi.

Answer Key	Critical Thinking
3. You have just calculated the *area* of the watershed feeding into the stream monitoring station. Now we want to calculate the *volume* of water falling within this area. The region received 114 cm of precipitation in a given year. In other words, if the year's worth of precipitation were to be spread evenly across the landscape, it would form a layer 114 cm deep. What was the volume of water that fell into the watershed during this year? Show your work, and include units in your answer. You can calculate a volume by multiplying the area of the base of the volume times its height. First, convert the centimeters into meters, so that the answer will be in cubic meters: 114 cm of precipitation × 1 m/100 cm = 1.14 m of precipitation fell on the watershed in one year Area of watershed × thickness of layer of precipitation = Volume of precipitation 1,540,000 m^2 × 1.14 m = 1,755,600 m^3 of precipitation (or approx. 1.76×10^6 m^3) 1,755,600 m^3 (or 1.76×10^6 m^3) of precipitation fell on watershed in one year	(S) Visualize a 114 cm vertical thick layer of water. The teacher can support this process by have students measure 114 cm from the floor to help students get a more experiential feel for how much water fell. Envision a year-long series of precipitation events; each one deposits a thin layer of water and all the layers together accumulate to 114 cm of water. (S) With the help of the diagram in Figure 5.2 visualize the volume of water that fell on the watershed as a 114 cm thick layer spread across the surface of the watershed. (Q) Recall from math that you can calculate a volume by multiplying the area of the base of the volume times its height. Recognize that this is the appropriate calculation to calculate the requested volume. OR (S) Understand the meaning of *volume* deeply enough to realize from Figure 5.2, or a mental equivalent, that area × height will give volume. (Q) Notice that the units for height (cm) are not the same as the units for area (m^2) and that the answer is desired in meters. Recall that 100 cm equals 1 m. Convert the height (thickness) of the water layer from cm to m. (Q) Complete the multiplication correctly, with correct units throughout.
4. Make a prediction. You have calculated the volume of water that fell in the watershed, but what do you think was the volume of water that flowed through the stream monitoring station during this same year? Write your prediction down on a separate piece of paper, fold it over, and do not open it again until you have completed the puzzle. Student answers will vary. Many students predict that the volume of water flowing out through the stream station will be the same as the volume of water that fell as precipitation into the watershed. Some students may predict (correctly) that the stream flow volume will be smaller than the precipitation volume. *Teaching Note:* You may want to collect the predictions for discussion at this point.	(C) Recall the various pathways that water travels in the water cycle. (S) Distinguish between pathways that deliver water to the monitoring station (streams) and pathways that exit the watershed without passing through the monitoring station (e.g., evaporation, transpiration). (Q) Estimate the relative magnitude of the pathways that deliver water to the stream monitoring station and those that remove water from the watershed without passing through the stream station.

(continued)

Answer Key	Critical Thinking
5. Table 5.1 shows how much water passed through the Cascade Brook stream monitoring station each month for one year. Suggest some reasons (hypotheses) why the volume of stream flow varies so much from month to month. *Clue:* Think about the climate of this region of the country. a. The main thing to notice here is that the stream flow is much lower in July, August, and September than in any of the other months. These are the summer months in New York State. The zeroes in the rows for August and September indicate that the stream dried up entirely during those months during the year these data were collected. One reason could be that there was less rainfall in the summer months. Another reason could be that it was so sunny and hot in the summer that a lot of the rainfall evaporated before it could reach the stream. b. A secondary point that some students might notice is that the stream flow was somewhat lower in the winter months of January, February, and March than in the surrounding months. A reason for this could be that the stream was frozen for part of those months. Another reason could be that the precipitation fell as snow and formed a snowpack on the slopes of the watershed rather than running down into the stream.	(Q) By visual examination of the numbers in Table 5.1, notice that the stream flow is much lower in July, August, and September than in the other months. Use number sense to recognize that this difference is significant and calls for an explanation. (C) Recall from experience or study that the climate of New York is often dry in July, August and September. (T) Hypothesize that stream flow was low when precipitation was low. (C) 1. Recall from experience or study that the climate of New York is hot in July, August, and September. 2. Recall that evaporation is part of the water cycle. 3. Recall that evaporation is enhanced by heating. (T) Combine these three ideas and hypothesize that stream flow was low to nonexistent during these months because rainfall evaporated from the ground before it could reach the stream. (Q) By visual inspection, notice that stream flow was also low in winter, especially February. Use number sense to recognize that this may be significant. (C) 1. Recall from experience or study that the climate of New York is often below freezing in winter. 2. Recall that precipitation falls as snow when air temperatures are below freezing. 3. Recall that streams freeze over when water temperature is below zero. (T) Combine these ideas and hypothesize that the recorded stream flow was low during months when precipitation stayed on the landscape as snowpack and the stream was partially frozen.

Answer Key	Critical Thinking
6. What is the total volume of water that flowed through Cascade Brook at the stream monitoring station over the entire year? Show your work, and include units in your answer. Sum up the volume of water that flowed through the stream station in each of the 12 months to get the total volume of water flowing through the station over the course of the entire year: January stream flow + February stream flow + March stream flow + etc. = 969, 382 m^3 of water flowed through stream station in one year (or approximately 9.7 × 10^5 m^3). Insist on units in student answers.	(Q) Recognize that addition is the correct operation to perform to find a total when constituent parts are the starting information. (Q) Complete the sum accurately, with correct units throughout.
7. Compare the measured volume of water flowing through the stream station in one year (see step 6) with the predicted volume of water (see step 4). Are they similar or different? Most students find that less water is passing through the stream monitoring station than they expected.	(Q) Make an accurate comparison between a measured volume and a predicted volume. Decide whether the difference is insignificant (they are "similar") or significant (they are "different").
8. Now let's look at this quantitatively. Compare the total volume of water flowing through the stream monitoring station over the year with the volume of water falling in the watershed as precipitation during that same time. Express your findings as a percentage in a complete sentence. The volume of water flowing through the stream monitoring station over the year (969,382 m^3) was less than the volume falling in the watershed as precipitation during that same interval (1,755,600 m^3). To express this as a percentage: 969,382m^3 exiting through the stream gauge / 1,755,600 m^3 fell in watershed = 0.55 = 55% Only 55% of the total volume of water that fell in the watershed during the year exited through the stream monitoring station.	(S) Envision that in a simple basin (like a sink or bathtub) all or almost all of the water falling in the basin would exit through the drain at the low end of the basin. (Q) Use number sense to notice that the watershed is not even close to this imagined basin situation. Instead, the amount of water exiting the basin via the stream is MUCH lower than the amount falling into the basin. (Q) Understand that a percentage expresses a ratio between a part and a whole. Recognize that the "whole" is the whole amount of water that fell on the watershed and that the "part" is that portion of the incoming water that exited via the stream flow station. (Q) Set up the percentage correctly, and perform division accurately, maintaining units throughout.

(continued)

Answer Key	Critical Thinking
9. Suggest some reasons (hypotheses) why these water amounts are not the same. Be prepared to defend your favorite hypothesis in class discussion. Based on knowledge of the water cycle, students can hypothesize that water that did not exit the watershed via the stream could have • gone back into the atmosphere by evaporation from the soil, the stream itself, the pond, or a wetland that lies upstream from the pond; • gone back into the atmosphere through transpiration, which is evaporation from the leaves or other aerial parts of plants; or • gone down into the ground through infiltration. All three of these processes are probably going on at the same time.	(C) Recall the concepts of *conservation of mass* and *phases of matter.* From these concepts, infer that the missing water cannot have simply ceased to exist, but it may have changed its appearance. (C) Recall the concept of the water cycle, shown in most textbooks as a diagram. (S) Understand that the arrows on the typical textbook water cycle diagram indicate fluxes or pathways of water from reservoir to reservoir. Understand that multiple pathways can be active at the same time. On a mental or textbook representation of the water cycle, identify pathways that could intercept water before it reaches the stream: evaporation, transpiration, infiltration.
Teaching Note: Students "know" about evaporation and groundwater from having seen the arrows on water cycle diagrams. The Aha! of this activity is to make the connection between the data, the calculation, and the concept.	

Common Student Misconceptions

- *Which way is downhill?*

Some students will say that downstream is toward the "bottom" of the map. It just so happens that this stream does flow toward the south, and this map just happens to be oriented so that south is toward the bottom of the map when the map is held upright with the text right-side-up. But this line of reasoning won't work for all streams or all maps. To nip this misunderstanding in the bud, encourage your students to use north, south, east, and west when referring to directions on a map. Reserve the terms down and up for the directions toward and away from the center of the Earth, respectively.

- *Zero output from a stream is impossible.*

Some students might feel that zero output from a stream means that the data are flawed because they see water in streams all year long. Cascade Brook is an intermittent stream—a stream that flows for only part of the year, during times when there is sufficient input from rain or snowmelt. During dry months, the stream can cease to flow.

- *Map symbols*

Students may confuse the symbols for road, stream, and watershed boundary, all of which are shown on the map by curvy lines. Projecting the color version of the map may help (available on the Data Puzzle website). Also, the watershed boundary follows local topographic highs, whereas streams follow topographic lows, and roads traverse both lows and highs.

- *Setting up the calculations*

If students are struggling with how to set up the calculations, insist that they use units on all values in every calculation. Show them how to check their setups by making sure that the answer is coming out in the appropriate units.

- *Calculating total stream flow*

In step 6, some students think they should calculate an average (mean). Encourage them to discuss in words the meaning of *average* and *total* as those words apply to the stream flow data.

Tough Questions (With Answers)

These are questions that your students may ask you or that you could ask them.

Q. ***What if the precipitation falls as snow? Snow takes up a lot of volume when it first falls, but it melts down into a much smaller volume before it goes into the stream.***

A. You are right to point out that snow decreases in volume, first as it compacts in the days after the snowfall, and then again when it melts. To get around this problem, water scientists usually refer to annual precipitation as though it had all been in the form of rain. That's how we use the term *annual precipitation* in this puzzle.

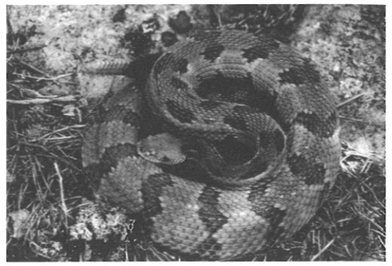
Q. ***Are there really rattlesnakes on "Rattlesnake Hill" on the map?***

A. Timber rattlesnakes (Figure 5.6a, p. 140) do live in the Hudson Highlands, so a rattlesnake encounter at the time that the area was being mapped probably does underlie the choice of name. The timber rattlesnake played a symbolic role in the American Revolution. The rattle has thirteen segments, which became a symbol for the original Thirteen Colonies. Timber rattlesnakes do not usually strike unless provoked, which inspired the phrase "Don't Tread on Me" on the flag (the "jack") flown on U.S. Navy ships (Figure 5.6b).

Q. How does the stream monitoring station work?

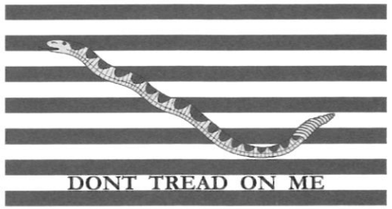
A. This kind of stream monitoring station is called a V-notch weir (Figure 5.7). A small dam was built across the stream, creating a pond. As the stream water exits the pond and continues on its way downstream, it passes through a notch in the upper edge of the dam. The notch is shaped like a wide V; it restrains how much water can exit the pond in a given amount of time. In the small building adjacent to the pond, there is a water level recorder that records the level of the water in the pond. As the water level rises or falls in the stream, it also rises or falls in the pond behind the dam. This change raises or lowers the float in the stilling well, shown at the right-hand side of the diagram. The level of the float is recorded by the water level recorder. When the stream flow is low, only a trickle of water passes through the notch, and the level of the water at the notch is down toward the lower, pointy end of the V. When the stream flow is high, water rushes through the V, and the level of water at the notch rises up toward the middle or even the top of the V. This same shape of V-notch weir is used in many streams and channels, and so there is a well-established empirical relationship between the height of the water above the base of the V and the stream discharge in cubic meters per second. For more information on stream monitoring stations and why they are used, see under "Resources," New Jersey State website on stream monitoring.

Figure 5.6a
Timber Rattlesnake



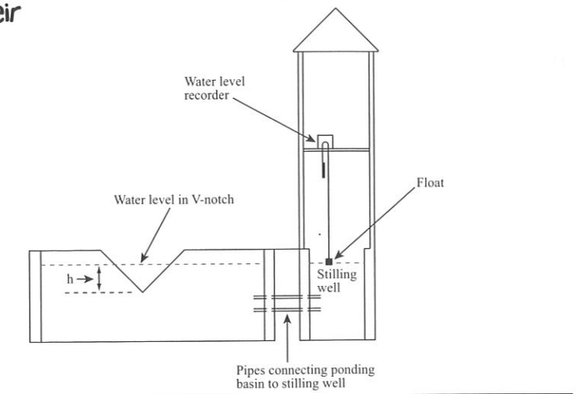
Source: Courtesy of Edwin McGowan.

Figure 5.6b
First Navy Jack (Flag)



Source: Courtesy of The World Flag Database *(www.flags.net)*.

Figure 5.7
Diagram of a Stream Monitoring Station With V-Notch Weir



Source: Courtesy of Thomas G. Siccama.

Extension Activities

- When calculating the size of the watershed, discuss why everyone did not get the same watershed size. Calculate mean and standard deviation of the student answers, and discuss what these numbers signify.
- Graphing data: The puzzle presents the stream flow data in tabular form. Discuss what type of graph would be best for presenting this data, then have the students make a graph. Discuss the pros and cons of table versus graph representations.
- Do a comparison to another watershed—for example, what watershed do you live in? Would the watershed in the puzzle have a higher or lower percent of runoff or stream flow than yours? Explain your answer. OR: If your watershed would not provide significantly different results, select a highly urban watershed for comparison.
- If your learning goals include mastery of topographic maps, have the students draw a profile along the stream gradient.
- The U.S. Environmental Protection Agency watershed site (see "Resources") includes a variety of activities on learning about your own watershed. This website talks about ways that young people can make a difference through their involvement in various watershed activities–for example, by becoming a watershed volunteer, participating in stream cleanups or storm-drain markings, or building a rain garden.

Sources for Data Puzzle #5

The annual rainfall estimate used in the puzzle (see step 3 in the Data Puzzle, p. 125) comes from the National Oceanic and Atmospheric Administration: *www.erh.noaa.gov/er/btv/images/ny_pcpn.gif.*

The stream flow data used in this puzzle (Table 5.1) are from the Environmental Monitoring Network at Black Rock Forest in Cornwall, NY. Directions to access these and related data are at *www.blackrockforest.org/docs/scientist-resources/DataResources/index.html.* The puzzle used data from an annual seasonal cycle collected from March 2002 through February 2003.

Topographic maps are available from the U.S. Geological Survey (USGS) at *http://topomaps.usgs.gov/ordering_maps.html.* The topographic map used in this puzzle (Figure 5.1) spans two USGS map sheets: West Point, NY, and Cornwall, NY.

Resources

ABC Science Online. A watershed activity that focuses on the water cycle
www.abc.net.au/science/surfingscientist/pdf/lesson_plan09.pdf

Black Rock Forest (where Cascade Brook is located)
www.blackrockforest.org

Color a complex water cycle
http://bluebison.net/books/coloring_books/0806/water_cycle_coloring_page.jpg

Explore an interactive water cycle.
www.yvw.com.au/waterschool/seniors/water_cycle.html

First Navy Jack (Flag) (the "Don't Tread on Me" flag)
http://en.wikipedia.org/wiki/First_Navy_Jack

Label an interactive water cycle drawing
http://education.jlab.org/reading/water_cycle.html

NASA: The Water Cycle: A Multi-Phased Journey
http://earthobservatory.nasa.gov//Library/Water/water_2.html

New Jersey State website on stream monitoring
www.state.nj.us/drbc/gage/gageshp.htm

(New York) Significant Habitats and Habitat Complexes of the New York Bight Watershed: New York-New Jersey Highlands, Complex #25
http://training.fws.gov/library/pubs5/web_link/text/ny_njh.htm

Rainfall data: Average monthly rainfall data for locations in New York and New Jersey (and thousands of places worldwide) can be obtained from World Climate:
www.worldclimate.com

Southwest Florida Water Management District activities
www.swfwmd.state.fl.us/education/interactive/watershed/pdf/teachguide.pdf

The U.S. Environmental Protection Agency website is a good one for watershed information. It contains a definition of a watershed, describes the importance of watersheds, and allows you to locate your own watershed with clickable maps on the "Surf Your Watershed" site. Several of the page links follow:
http://cfpub.epa.gov/surf/locate/index.cfm

www.epa.gov/adopt
www.epa.gov/owow/watershed

U.S. Geological Survey: Water Science for Schools
http://ga.water.usgs.gov/edu/mearth.html

U.S. Geological Survey: The Water Cycle
http://ga.water.usgs.gov/edu/watercycle.html

U.S. Geological Survey: Science in Your Watershed
http://water.usgs.gov/wsc/index.html

U.S. Geological Survey: What Is a Watershed?
http://ga.water.usgs.gov/edu/watershed.html

U.S. Geological Survey: Teacher's Guide to "What Do Maps Show?" (see especially Lesson 4, "Reading a Topographic Map")
http://egsc.usgs.gov/isb/pubs/booklets/symbols/reading.html

V-Notch (triangular) Weir Calculator
www.lmnoeng.com/Weirs/vweir.htm

What Is a Weir and How Does It Work?
www.hubbardbrook.org/w6_tour/weir-stop/weirwork.htm

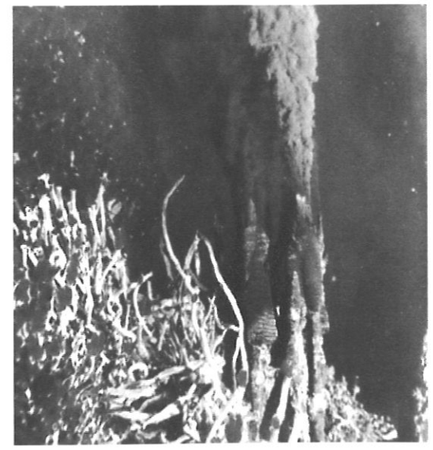
Student Pages

How much heat is released by a seafloor hydrothermal vent?

Hydrothermal vents are places where hot, mineral-laden water jets out of the sea floor, as shown in the photograph in Figure 6.1. These vents are found at places where two of the Earth's tectonic plates are pulling apart from each other. At such places, called *mid-ocean ridges*, hot rocks and magma are close to the sea floor.

Water from hydrothermal vents changes the chemistry of the ocean, supports chemosynthetic life forms, and transports heat from the Earth's crust into the ocean. But just how much heat do these vents produce?

Figure 6.1
Hydrothermal Vent on Ocean Floor



Source: Courtesy of the National Aeronautics and Space Administration (NASA).

Directions: Follow steps 1 to 18 below. Use additional sheets of paper as needed and answer questions in complete sentences.

Heating Up Water in Tea Kettles

1. First, a reminder of some concepts and units we will need to solve this puzzle. We are using metric units: liters (L), milliliters (ml), grams (g), meters (m), centimeters (cm), degrees Celsius (°C), and calories (cal). **Be sure to include units in all your answers.**

   1a. How many milliliters are in a liter?

   1b. What is the density of water? (Although the density of Earth's

water varies, we are making an approximate calculation so it is OK to use the density of pure water at standard pressure and temperature.)

1c. What is the temperature of water as it begins to boil?
Note: *Your answer is only good at sea level. At a higher pressure, the boiling temperature would be higher, too.*

1d. What is specific heat?

1e. What is the specific heat of liquid water?



Discuss step 1 with your teacher before moving on to step 2.



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2. Imagine a kettle full of water at room temperature, 20°C. Now imagine heating the kettle until just before it begins to boil. (Assume no phase change occurs.) What would be the change in temperature of the water in the kettle?

3. Recalling your knowledge of the specific heat of water, how much energy was required to heat 1 g of the water in the kettle from room temperature up to the temperature just before it began to boil (again with no phase change)? Show how you found your answer.

4a. A typical kettle holds 2.5 L of water. What is its volume in milliliters?

4b. What is the mass of the water in a full kettle? (*Hint:* Use your knowledge of density of water.)

5. How much energy was required to heat the entire kettle up to the point just before it began to boil? (*Hint:* You have determined how much energy was required to heat each gram of water in the kettle, and how many grams of water there are in the kettle. Combine these two pieces of information to answer this question.)

Now you know just how much heat is needed to bring one tea kettle to the point of boiling. Let's see how that compares to the heat being released by one hydrothermal vent.

Heating Up Hydrothermal Vent Water

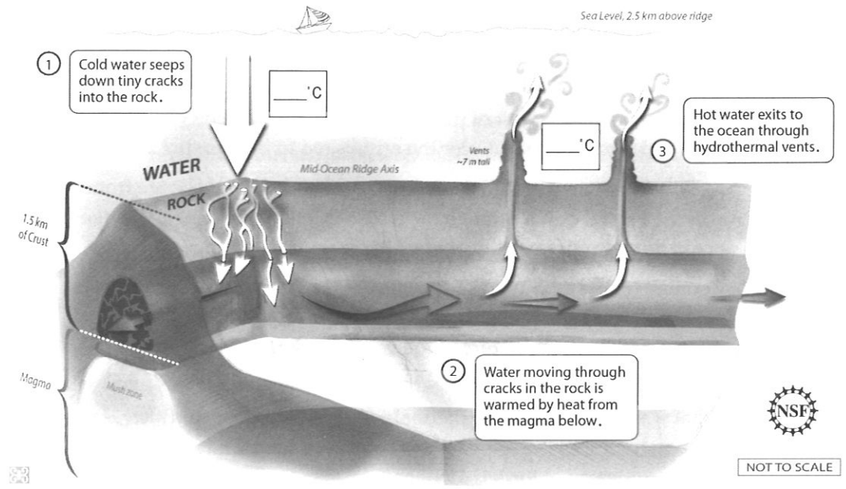
6. Scientists studying hydrothermal vents use research submersibles to observe and photograph the vents and take samples of vent water. Describe observable features of the vent shown in the photograph in Figure 6.1, page 145.

7. Scientists measured the opening of one typical hydrothermal vent to be 3 cm in diameter. Sketch a 3 cm diameter circle along with your other vent observations. What would be the most accurate analogy to describe water coming out of a vent this size? Circle your choice below.

- Like water out of a water pistol
- Like water out of a garden hose
- Like water out of a fire hydrant

Introduction to Steps 8–11: The water that comes out of hydrothermal vents begins as cold seawater. It seeps down through cracks in the rocks of the ocean floor, somewhat like rain seeps into the ground after a storm on land. At mid-ocean ridges where hydrothermal vents occur, hot magma is close under the sea floor. If the sinking water comes into contact with hot rocks warmed by underlying magma, it can be heated up to the temperature of a hydrothermal vent.

Figure 6.2
Changes in Seawater Temperatures (to be completed by student)



Source: Diagram by Zina Deretsky, National Science Foundation, modified from *www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=110976&org=NSF* by Deresky with permission.

8. The temperature of seawater at the bottom of the ocean is approximately 2°C. Write in "2°C" in the appropriate space in the diagram in Figure 6.2 on page 148 to show the temperature of the water sinking down through cracks in the sea floor. Color the down-going flow blue to indicate cold.

9. Scientists also use submersibles to place instruments in and around vents to look for changes in the chemistry and temperature of vent water over time. Table 6.1 shows some temperature data from a vent in the East Pacific Rise, which is 2,550 m below the ocean surface. The vent is located in a field area for biologists studying vent organisms. Scan down through the data table. Select one of the following three choices to describe the temperature of the vent water during this time interval. Defend your answer.

   - highly variable
   - slightly variable
   - nearly constant

   The temperature of this hydrothermal vent water is hot enough to melt plastic! When hydrothermal vents were first discovered, the pilots of the submersible were worried that the windows of the submersible might melt. Thankfully, the windows did not melt.

10a. Calculate the average temperature of the vent water during the five-month period in Table 6.1. Put your answer in the table, rounding to the nearest tenth of a degree.

10b. Record your answer on Figure 6.2 (p. 147) to show the temperature of the water coming up out of the Earth's crust, through the vent openings, and into the ocean. Color the arrows red to indicate hot water.

11. By how many degrees did the temperature of the water change from when it seeped down through the sea floor to when it returned to the ocean as hydrothermal vent water? Show your reasoning.

12. Recalling your knowledge of specific heat of water, how much thermal energy would be required to raise the temperature of 1 g of ocean water up to the temperature of the vent water? (*Hint:* It may help to look back at your tea kettle calculation.)

13. What was the source of the thermal energy that caused this increase in temperature?

14. Hydrothermal vents release much more than 1 g of water. In fact, one hydrothermal vent has been estimated to expel hot water at a rate of

Table 6.1
Temperature Data From a Vent in the East Pacific Rise (to be completed by student)

Month	Average Temperature
Nov.	347.0°C
Dec.	347.7°C
Jan.	347.8°C
Feb.	347.9°C
Mar.	347.9°C
Average	

3 L per second. For a vent expelling water at 3 L per second,

14a. how many liters of hot water would be released in a minute?

14b. how many liters of hot water would be released in an hour?

14c. how many milliliters of hot water would be released in an hour?

14d. what is the mass, in grams, of hot water released in an hour?

15. How much thermal energy was required to heat the water released from one vent in one hour up to hydrothermal vent temperature? Show your reasoning. (*Hints:* You will need to combine two numbers you have already calculated. Refer to your teakettle calculation. Be careful about units; you are looking for an answer in calories.)

Is This a Lot of Heat?

Congratulations on completing this calculation. Scientists make such approximate calculations to get a "sense" or a "feel" for how large or small an object is or how important or unimportant a process is. This intuitive Earth-sense is valuable, even if some of the numbers going into the calculation may not be precise.

Are we dealing in this puzzle with a lot of thermal energy or not very much? How does the hydrothermal vent thermal energy compare to tea kettle energy?

To Recap: In step 5, you calculated how much thermal energy is required to raise one kettleful of water from room temperature to the boiling temperature. In step 15, you calculated how much thermal energy is required to raise one hour's worth of vent water output from normal sea floor temperature up to hydrothermal vent temperature. Now let's move on.

16. Think about the amount of thermal energy from the Earth that was used to heat up the water that came from the vent during the time (about one hour) that you have been working on this puzzle. If that energy had been used to heat tea kettles instead, how many kettles could have been heated to the boiling point?

17. One kettle can fill approximately 10 mugs. How many mugs could be filled from the number of kettles in your answer in step 16?

18. Imagine that one cold day we wanted to serve a mug of cocoa to every man, woman, and child in an entire town. Which of the towns in Table 6.2 has a population that could be served by the number of mugs heated by an hour's worth of vent heat energy? Try not to waste any more cocoa than necessary. Explain your answer.

Table 6.2
Four U.S. Towns and Their Populations

Town	Population
Boise City, ID	185,787
Boston, MA	589,141
Fort Lauderdale, FL	152,397
Buffalo, NY	292,649

Topic: Hydrothermal Vents

Data Puzzle 6

Pedagogical Content Knowledge Guide

How much heat is released by a seafloor hydrothermal vent?

In this Data Puzzle, students compare the amount of heat given off by a hydrothermal vent with the amount of heat needed to bring a kettle of water up to boiling temperature. Recognizing that the heat released from one vent in an hour would heat a cup of coffee/tea/cocoa for every man, woman, and child in a good-size town helps students to realize the large amount of heat that comes from the interior of the Earth.

This puzzle works well in an Earth science or elective geology class or in an undergraduate marine geology class.

Aha! Insights

- The amount of heat released by one hydrothermal vent is huge!
- The interior of the Earth is really hot!

Prior Skills Needed

- Ability to use a calculator
- Basic ability to think quantitatively, including knowing when to use which arithmetic operation
- Habit of mind of always using units and of carrying units through calculations

Prior Understandings Needed

- Students will need an understanding of very large numbers (can be with the use of scientific notation).
- Students should know the basics of plate tectonics. They should be familiar with the three kinds of plate margins (divergent, convergent,

and transform) and know that divergent plate margins are where new oceanic crust is formed.

- Students should know that when groundwater comes into contact with hot rocks near a magma body, the water is heated up. If the resulting hot water comes to the Earth's surface, it can form hot springs and geysers. Hot springs on a mid-ocean ridge divergent plate boundary are called *hydrothermal vents*.
- Students should know that at the bottom of the ocean, there is increased pressure caused by the mass of the overlying water. At high pressure, the boiling temperature of water is higher than at sea level.

Teacher Preparation

1. Work through the steps in the Data Puzzle yourself (pp. 145–150). Use "Step-by-Step: How to Solve Data Puzzle #6" (pp. 154–161) to anticipate which steps may be difficult for students and plan what kind of clues will help them past 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 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 start to work on the puzzle—for example, *hydrothermal vent, divergent plate boundary, specific heat capacity, heat energy,* and *thermal energy.*
4. Gather and prepare suggested materials:
   - For each student: ruler and compass to create a 3 cm circle, calculator, red and blue pencils, a copy of Data Puzzle #6 (pp. 145–150)
   - For the class: a map of the world depicting mid-ocean ridges (see "Resources" section under General Information, Heezen Tharp Mid-Ocean Ridge Map)

   - (optional) Videos depicting hydrothermal vents, black smokers, and vent research (see "Resources" section under General Information on Hydrothermal Vents: Dive and Discover website and Science Channel Videos website)
   - (optional) A tea kettle (If you do bring one in, be sure it is at least 2.5 L.)
6. Plan any pre-puzzle activities (see below) and extension activities (p. 164). Check the Data Puzzles website *(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

- This Data Puzzle lends itself well to scientific notation. If students practice using scientific notation before working with the puzzle, they will have an easier time working with the large numbers in the puzzle.
- The calculations in this puzzle involve many different units and require conversions among units. Students may benefit from practice in the scientists' problem-solving trick of using units to figure out how to set up a calculation. This method is known variously as the "factor-label method," the "unit factor method," or "dimensional analysis." See "Resources" section under General Information, Practice Working With Different Units.
- Several vendors sell heat transfer lab kits. Under "Resources," see Activities to Explore Specific Concepts in This Puzzle.
- Have the students observe and describe a hydrothermal vent using photographs or any of the resources listed in "Resources" section under General Information on Hydrothermal Vents.

Step-By-Step: How to Solve Data Puzzle #6

Teaching Notes:

- Stress to the students that they must use units throughout all their work and that the units must be consistent. Teachers may want to warn the students that the numbers will become very large.
- 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
1a. How many milliliters are in a liter? There are 1,000 ml in 1 L. 1b. What is the density of water? (Although the density of Earth's water varies, we are making an approximate calculation, so it is OK to use the density of pure water at standard pressure and temperature.) The density of water is 1 g/ml. 1c. What is the temperature of water as it begins to boil? **Note:** Your answer is good only at sea level. At a higher pressure the boiling temperature would be higher, too. The temperature at which water begins to boil is 100°C at standard pressure (sea level). 1d. What is specific heat? Specific heat is the amount of thermal energy needed to raise the temperature of a material by a specified amount. 1e. What is the specific heat of liquid water? The specific heat of water is 1 cal per degree Celsius per gram of water.	(Q) It is essential that students include units on all numbers throughout the puzzle. Units help them connect the numerical values to the real-world materials and processes under discussion; units also help students figure out which mathematical operation is needed at each step. (C) Note that there are two separate pieces of knowledge to be recalled or looked up: • conceptual understanding of the meaning of specific heat • declarative knowledge that the specific heat of liquid water is 1 cal/°C-g.
Teaching Note: **STOP HERE** to make sure that students have the answers to step 1 under control before they move on. They should have an understanding of some of the basic building blocks of the puzzle: temperature of boiling water at sea level and specific heat. If the students are having trouble with this first part of the puzzle, they will not be successful with the rest of the puzzle.	
2. Imagine a kettle full of water at room temperature, 20°C. Now imagine heating the kettle until just before it begins to boil. (Assume no phase change occurs.) What would be the change in temperature of the water in the kettle? Room temperature is defined as 20°C. The temperature at which water begins to boil is 100°C. From 20°C to 100°C is an 80°C change in temperature.	(Q) Students need to mathematicize the verbally expressed notion of change between a starting condition and an ending condition. This can be done it two ways. Arithmetic approach: The student recognizes that *change* equates with *difference,* which can be obtained by subtraction. The student subtracts the starting condition from the ending condition to calculate the change in temperature. (S) Spatial approach: To obtain the difference, the student envisions the distance along a line of numbers such as those that appear on a traditional thermometer.

Answer Key	Critical Thinking
3. Recalling your knowledge of specific heat of water, how much energy was required to heat 1 g of the water in the kettle from room temperature up to the temperature just before it began to boil (again with no phase change)? Show how you got your answer. 1 cal is needed to raise the temperature of 1 g of water by 1°C. The water temperature was raised by 80°C to go from room temperature to the beginning of boiling. This took 80°C × 1 cal/°C-g = 80 cal/g. To heat 1 g of water therefore requires 80 cal.	(C) Students need to apply their understanding of the concept of specific heat, plus their knowledge of the value of the specific heat of water. (Q) Students need to recognize that the question is asking for an answer in energy and that the units of energy are calories. The available information is • the change of temperature in °C and • the specific heat of water in cal/°C-g. If students use units conscientiously, they can apply dimensional analysis to set up the calculation.
4a. A typical kettle holds 2.5 L of water. What is its volume in milliliters? 2.5 L × 1,000 ml/L = 2,500 ml 4b. What is the mass of the water in a full kettle? *(Hint:* Use your knowledge of the density of water.) 2,500 ml × 1 g/ml = 2,500 g	(C) Recall that 1 L equals 1,000 ml. (Q) Unit conversion: liters to milliliters. (C) Recall and understand the relationship among volume, mass, and density. (C) Recall the density of water. (Q) Set up the calculation to determine the mass of water in the kettle from its volume and density. Students can use dimensional analysis or enter values into a previously learned equation for density. (Q) Complete the calculation accurately.
5. How much energy was required to heat the entire kettle up to the point just before it began to boil? (*Hint:* You have determined how much energy was required to heat each gram of water in the kettle and how many grams of water there are in the kettle. Combine these two pieces of information to answer this question.) 80 cal/g × 2,500 g = 200,000 cal/kettle (or in scientific notation: 2.0×10^5 cal/kettle) Now you know just how much heat is needed to bring one tea kettle to the point of boiling. Let's see how that compares to the heat being released by one hydrothermal vent.	(Q) Set up the calculation, recognizing that multiplication is the appropriate operation. (Q) Complete the calculation accurately.

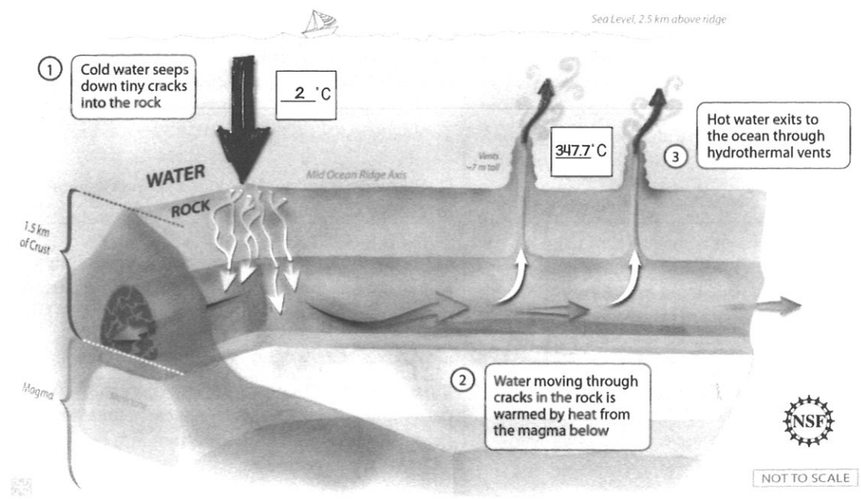
(continued)

Answer Key	Critical Thinking
6. Scientists studying hydrothermal vents use research submersibles to observe and photograph the vents and take samples of vent water. Describe observable features of the vent shown in the photograph in Figure 6.1. Answers will vary but may include black "smoke," marine life, chimneys, rocks.	(S) Recognize a visual depiction of various natural phenomena that students may have previously learned about through other representations. *Teaching Note:* Observing and describing photographs and video of a vent system help students build mental models of the venting process, thereby adding to their content knowledge (C).
7. Scientists measured the opening of one typical hydrothermal vent to be 3 cm in diameter. Sketch a 3 cm diameter circle along with your other vent observations. What would be the most accurate analogy to describe water coming out of a vent this size? • Like water out of a water pistol too small ~0.2 cm • Like water out of a garden hose correct answer • Like water out of a fire hydrant too large ~3 to 4 in. *Introduction to Steps 8–11:* The water that comes out of hydrothermal vents begins as cold seawater. It sinks down through cracks in the rocks of the ocean floor, somewhat like rain seeps into the ground after a storm on land. At mid-ocean ridges where hydrothermal vents occur, hot magma is close under the sea floor. If the sinking water comes into contact with hot rocks warmed by underlying magma, it can be heated up to the temperature of a hydrothermal vent.	(S) Envision the true size of a structure (vent opening) that students have only previously seen in arbitrarily-scaled representations (photos and videos). Do this in two ways: • by sketching at true scale and • by analogy with more familiar water sources. This question is intended to add *scale* to students' mental model of the venting process.

Answer Key	Critical Thinking
8. The temperature of seawater at the bottom of the ocean is approximately 2°C. Write in "2°C" in the appropriate space in the diagram in Figure 6.2 to show the temperature of the water sinking down through cracks in the sea floor. Color the down-going flow blue to indicate cold. See Figure 6.3 with answers filled in. In the student answers, the larger, downward-pointing arrow will be blue and the smaller, upward-pointing arrows will be red.	(S) This step helps build students' understanding that Earth processes are situated spatially; in other words, different processes happen in different places.

Figure 6.3

Answers to Figure 6.2



Source: Diagram by Zina Deretsky, National Science Foundation, modified from *www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=110976&org=NSF* by Deresky with permission.

(continued)

Answer Key	Critical Thinking
Table 6.3 **Answer to Table 6.1** Month / Average Temperature Nov. 347.0°C Dec. 347.7°C Jan. 347.8°C Feb. 347.9°C Mar. 347.9°C **Average 347.7°C**	
9. Scientists also use submersibles to place instruments in and around vents to look for changes in the chemistry and temperature of vent water over time. Table 6.1 shows some temperature data from a vent in the East Pacific Rise. The vent is located 2,550 m below the ocean surface in a field area for biologists studying vent organisms. Scan down through the data table. Select one of the following three choices to describe the temperature of the vent water during this time interval. Defend your answer. • highly variable • slightly variable • nearly constant There is less than a degree of variation out of ~350° total over five months of measurement. For a natural process, most scientists would characterize this as "nearly constant." A thoughtfully defended choice of "slightly variable" is also acceptable.	(Q) This is a chance to discuss the relative magnitude and variation in the attribute being measured. The observed variation is a few tenths of a degree, out of hundreds of degrees total, over five months of measurement. In an engineered system this might be characterized as "variable." But almost all natural systems vary over time, so most Earth scientists would characterize this data set as "nearly constant." (T) Students examine data over a span of several months to look for variability. (Q) Estimation and number sense: Students should be able to answer this question by eye, without performing a numerical calculation. In the original data set, measurements were taken every three minutes throughout the five-month observation period; the measurements were nearly constant on the hour-to-hour as well as month-to-month timescales. Not all vents are this constant.

Answer Key	Critical Thinking
10a. Calculate the average temperature of the vent water during the five-month period in Table 6.1. Write your answer in the table, rounding to the nearest tenth of a degree. See Table 6.3: 347.7°C. 10b. Record your answer on Figure 6.2 to show the temperature of the water coming up out of the Earth's crust, through the vent openings, and into the ocean. Color the arrows red to indicate hot water. See Figure 6.3.	(Q) Calculate a mean. (S) In combination with step 8, this step helps build students' understanding that Earth processes are situated spatially; in other words, different processes happen in different places.
11. By how many degrees did the temperature of the water change from when it seeped down through the sea floor to when it returned to the sea floor as hydrothermal vent water? Show your reasoning. 347.7°C - 2°C = 345.7°C	(Q) As with step 2, students need to mathematicize the verbally expressed notion of change between a starting condition and an ending condition. Referring back to step 2 may help students recognize that subtraction is the appropriate operation to calculate change.
12. Recalling your knowledge of specific heat of water, how much thermal energy would be required to raise the temperature of 1 g of water up to the temperature of the vent water? (*Hint:* It may help to look back at your tea kettle calculation.) 345.7°C × 1 cal/°C-g = 345.7 cal/g	(C) As in step 3, students need to apply their understanding of the concept of specific heat as well as their knowledge of the value of the specific heat of water. (Q) As in step 3, if students use units conscientiously, they can apply dimensional analysis to set up the calculation.
13. What was the source of the thermal energy that caused this increase in temperature? The immediate source of the energy was the hot rocks and magma that underlie the mid-ocean ridge. The thermal energy carried by the magma was from the mantle.	(C) Students must recall or look up sources of heat in the crust and mantle. It is important that students not get so ensnared in the details of the calculation that they forget to think about the Earth.

(continued)

Answer Key	Critical Thinking
14. Hydrothermal vents release much more than 1g of water. In fact, one hydrothermal vent has been estimated to expel hot water at a rate of 3 L per second. For a vent expelling water at 3 L per second, 14a. how many liters of hot water would be released in a minute? 3 L/sec. × 60 sec./min. = 180 L/min. 14b. how many liters of hot water would be released in an hour? 180 L/min. × 60 min./hr. = 10,800 L/hr. 14c. how many milliliters of hot water would be released in an hour? 10,800 L/hr. × 1,000 ml/L = 10,800,000 ml/hr. or in scientific notation: 1.08×10^4 L/hr. × 1.0×10^3 ml/L = 1.08×10^7 ml/hr. 14d. what is the mass, in grams, of hot water released in an hour? 10,800,000 ml/hr. × 1 g/ml = 10,800,000 g/hr. or using scientific notation: 1.08×10^7 ml/hr. × 1 g/ml = 1.08×10^7 g/hr.	(Q)(T) Unit conversions with units of time: convert flux from volume per second, to volume per minute, to volume per hour. (Q) Unit conversions with units of volume: convert flux from liters per hour to milliliters per hour. (C) Understand density and recall that the density of water is 1 g/ml. (Q) Use density of water and volume of water per unit of time to calculate the mass per unit of time of water.
15. How much thermal energy was required to heat the water released from one vent in one hour to hydrothermal vent temperature? Show your reasoning. (*Hints:* You will need to combine two numbers you have already calculated. Refer to your tea kettle calculation. Be careful about units.) 10,800,000 g/hr. × 345.7 cal/g = 3,733,560,000 cal/hr. or using scientific notation: 1.08×10^7 g/hr. × 3.46×10^2 cal/g = 3.73×10^9 cal/hr.	(Q) Recognize that the pertinent available information is the following: • amount of energy needed for each amount of mass (cal/g) [from step 12] • amount of mass released from the vent for each amount of time (g/hr.) [from step 14] (Q) Set up the calculation correctly, recognizing that multiplication is the appropriate operation. (Q) Complete the calculation accurately.
Are we dealing in this puzzle with a lot of heat energy or not very much? How does the hydrothermal vent thermal energy compare to tea kettle energy? ***To Recap:*** In step 5, you calculated how much thermal energy is required to raise one kettleful of water from room temperature to the boiling temperature. In step 15, you calculated how much thermal energy is required to raise one hour's worth of vent output water from normal sea floor temperature up to hydrothermal vent temperature. Now let's move on.	

Answer Key	Critical Thinking
16. Think about the amount of thermal energy from the Earth that was used to heat up the water that came from the vent during the time (about one hour) that you have been in class working on this puzzle. If that energy had been used to heat tea kettles instead, how many kettles could have been heated to the boiling point? 3,733,560,000 cal/hr. ÷ 200,000 cal/kettle = 18,668 kettles/hr. or 3.7×10^9 cal/hr. ÷ 2.0×10^5 cal/kettle = 1.87×10^4 kettles/hr.	(Q) Recognize that the pertinent available information is the following: • amount of thermal energy used to heat the water that came from the vent in one hour (cal/hr.) [from step 15] • amount of thermal energy needed to heat up one kettle to the boiling point (cal/kettle) [from step 5] (Q) Set up the calculation correctly, recognizing that division is the appropriate operation. (Q) Complete the calculation accurately.
17. One kettle can fill approximately 10 mugs. How many mugs could be filled from the number of kettles in your answer to step 16? 18,668 kettles × 10 mugs/kettle = 186,680 mugs or 1.87×10^4 kettles/hr. × 10 mugs/kettle = 1.87×10^5 mugs	(Q) Set up the calculation correctly, recognizing that multiplication is the appropriate operation. (Q) Complete the calculation accurately.
18. Imagine that one cold day we wanted to serve a mug of cocoa to every man, woman, and child in an entire town. Which of the towns in Table 6.2 has a population that could be served by the number of mugs heated by an hour's worth of vent energy? Try not to waste any more cocoa than necessary. Boise City Explain your answer. *Sample student answer:* First, I looked for a city with a population that is smaller than the number of mugs that I calculated in step 17. I found both Fort Lauderdale and Boise City. Between these two choices, Boise City is better because Fort Lauderdale has a smaller population and even after each person got one mug there would be a lot of wasted mugs left over.	(Q) Recognize that the question is asking for the name of a town whose population is smaller than 186,680. Compare large numbers to find such a city in the table. (Q) Realize that there are two cities that meet the criterion that the populations should be smaller than the number of mugs. Develop a second criterion to distinguish between these options: that the city's population should be as close as possible to the number of mugs (without exceeding it) so as to minimize wasted cocoa.

Common Student Misconceptions

- *Students may describe the vent organisms as "plants."*

They are not plants because they do not photosynthesize. There is no sunlight at the water depth of the vents so instead of using sunlight they chemosynthesize.

- *Students may think vents are the same as volcanoes.*

Water comes out of vents, and magma comes out of volcanoes.

- *Students might describe material coming out of vents as steam, lava, or smoke.*

The name *black smokers* might even contribute to that misconception. The blackness of the vent water comes from tiny particles that precipitated out of the mineral-laden vent water. Lava might come out of a nearby fissure.

- *Students think the vents grow.*

The chimneys are not alive. They are made of minerals that have been deposited over time. The chimneys are not made of coral or seashells.

- *Students may think that the hot vent water came from deep in the Earth's interior.*

In fact, the water was ordinary seawater that trickled down through cracks in the seafloor. It was heated up by contact with the hot rocks that surround a magma chamber in the Earth's crust.

- *Students may think there are hydrothermal vents everywhere on the mid-ocean ridge.*

Vents are more common on fast-spreading ridges than on slow-spreading ridges.

Tough Questions (With Answers)

These are questions that your students may ask you or that you could ask them.

*Q. **This data puzzle discusses water coming out of the hydrothermal vents at 347°C. If the water is above 100°C, why isn't it steam?***

A. The water at the bottom of the ocean is under tremendous pressure, so it remains in its liquid form. The boiling point of water at a depth of 3,000 meters is ~ 410°C.

*Q. **Isn't the density of the water at the hydrothermal vent affected by the materials in the vent? Isn't salt water more dense than freshwater?***

A. That's correct. Salt water is more dense than freshwater. The density of ocean water at 2,550 m, where hydrothermal vents are found, is about 1.04 g/ml. Since we are just making an approximate calculation to get a feel for the magnitude of the process, it is OK to use 1 g/ml for both the kettle water and the vent water.

*Q. **If the hydrothermal vent water gets its thermal energy from magma and hot rocks, and the magma gets its thermal energy from the mantle, where does the mantle get its thermal energy from?***

A. There are two sources of thermal energy in the mantle. The first is radioactive decay from certain minerals in the mantle; this process continues to generate new heat. The second is "residual heat" left over from the formation of the Earth.

*Q. **Are all vents the same temperature?***

A. All vents are not the same temperature, and the temperature of a single vent can change over a period of time.

*Q. **What is the pressure at the depth of the hydrothermal vents?***

A. Pressures increase about one atmosphere for every 10 m of water depth. The hydrothermal vent is about 2,500 m below the ocean surface so the pressure would be more than 250 times that at sea level.

*Q. **How far away from the vent would water still feel warm?***

A. Heat is quickly dissipated as the vent water mixes with other ocean water. At 40 m away from a vent opening, the temperature spike from the vent can barely be detected even by the most sensitive temperature sensors.

*Q. **Why is the water black?***

A. Fine mineral particles (metal sulfides) are suspended in the turbulent water being released from the vent.

*Q. **What are white smokers?***

A. White smokers are hydrothermal vents that are cooler (<50°C) and slower-flowing than black smokers. They carry a different suite of suspended minerals than black smokers, which gives the emerging material a white color.

*Q. **What are the structures that the vent water comes out of?***

A. They are called chimneys and are made from minerals (notably, metal sulfides) precipitated out of the vent water as it cools.

Q. Why don't the smokers make the ocean hotter?

A. The smokers do contribute slightly to the global ocean heat budget, but it is a small amount because the oceans are so vast.

Q. The diagram in Figure 6.2 shows seawater going down into the crust along the ridge axis and then coming up as a hydrothermal vent at a different spot along the same ridge axis. This diagram differs from other visualizations that students may have seen of seawater sinking down into the older crust off to the side of the ridge axis and then traveling through the crust perpendicular to the ridge axis to reach the hydrothermal vent. Which is correct?

A. Until very recently, scientists did think that the vent water entered the crust off to the side of the ridge axis. But by placing seismometers on the seafloor, scientists have been able to detect that the water flows through the crust parallel to the ridge axis following existing cracks and fissures.

Extension Activities

- Tie this Data Puzzle into a showing of *Aliens of the Deep* and/or *Volcanoes of the Deep Sea* (IMAX movies) and a discussion of extremeophiles (creatures that use the vent energy as their ultimate source of energy).
- Visit a website about vents and related topics. URLs for the following topics are listed in "Resources":
  a. Volcanoes of the Deep (listed under Hydrothermal Vent Curriculum Activities)
  b. American Museum of Natural History. Expedition: "Black Smokers" (listed under General Information on Hydrothermal Vents)
  c. University of Delaware resource page (listed under General Information on Hydrothermal Vents)
- Compare conditions at deep sea vents to conditions on other planets.
- Compare and contrast deep sea vents with hot springs or geysers on land.

Sources for Data Puzzle #6

Source of population numbers used in this puzzle is the 2000 Census: US Municipalities Over 50,000: Ranked by 2000 Population
www.demographia.com/db-2000city50k.htm

Source of vent data used in this puzzle is the RIDGE 2000 program. RIDGE is an interdisciplinary project designed to study the Earth's oceanic spreading ridge system as an integrated whole.
www.ridge2000.org

Resources

General Information

Heezen Tharp Mid-Ocean Ridge Map (hydrothermal vents form along the mid-ocean ridge system)
www.earthinstitute.columbia.edu/news/2006/images/HeezenTharp_900.jpg

Practice Working With Different Units: Factor-Label Method or Dimensional Analysis
www.fordhamprep.org/gcurran/sho/sho/lessons/lesson24.htm
www.chem.tamu.edu/class/fyp/mathrev/mr-da.html
www4.ncsu.edu/unity/lockers/users/f/felder/public/kenny/papers/units.html

General Information on Hydrothermal Vents

American Museum of Natural History Expeditions
"Black Smokers." Online "expedition."
www.amnh.org/nationalcenter/expeditions/blacksmokers/black_smokers.html

National Oceanic and Atmospheric Administration (NOAA). NOAA VENTS Program: Exploring Deep Ocean Ecosystems. Links to information, research, and videos on hydrothermal vents.
www.pmel.noaa.gov/vents

The Science Channel Videos. Greatest Discoveries: Hydrothermal Vents.
http://science.discovery.com/videos/100-greatest-discoveries-shorts-hydrothermal-vents.html

University of Delaware. Hydrothermal Vents.
www.ocean.udel.edu/deepsea/level-2/geology/vents.html

Woods Hole Oceanographic Institution
Alvin Page (Alvin is a deep submergence vehicle)
www.whoi.edu/page.do?pid=8422
Dive and Discover: Deeper Discovery. Hydrothermal Vents: Basics. Links to additional information, research, and videos on hydrothermal vents.
www.divediscover.whoi.edu/vents/vent-infomod.html

References and Journal Articles on Hydrothermal Vents

American Museum of Natural History. Deep Sea Vents Reading List.
www.amnh.org/education/resources/rfl/web/dsv/dsv_reading_list.html

Popular Science article on vents ("Creatures of the Thermal Vents" by D. Stover)
http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ps_vents.html

Information from 9° North—East Pacific Rise
(This is the area where the information for this data puzzle was collected.)

2004 Expedition 9° North—East Pacific Rise
East Pacific Rise Research
http://epr2004.sr.unh.edu
Expedition log
http://epr2004.sr.unh.edu/log.html
Chief Scientist Karen Von Damm's Log
http://divediscover.sr.unh.edu/011902.html

Marine Advanced Technology Education Center—9 Degrees North
0www.marinetech.org/nine_degrees/

Hydrothermal Vent Curriculum Activities

The Bridge (a website from Virginia Institute of Marine Sciences). Go to Geology Data Tip Archives for July 1999
http://web.vims.edu/bridge/archive0799.html?svr=www

National Oceanic and Atmospheric Administration (NOAA). NeMO (New Millenium Observatory) Education. Activities link
www.pmel.noaa.gov/vents/nemo/education.html

NOVA Teachers. Volcanoes of the Deep. Activities for students.
www.pbs.org/wgbh/nova/teachers/programs/2609_abyss.html

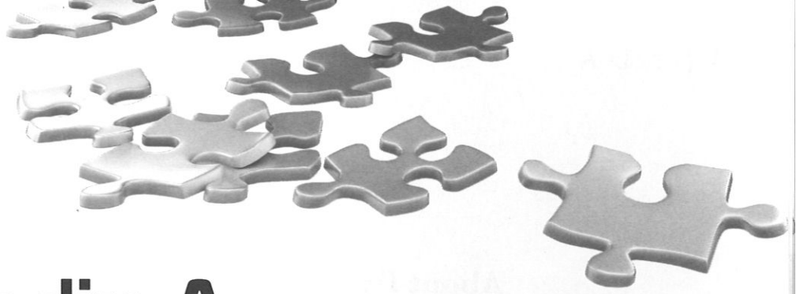
Ocean AdVENTure! Welcome Aboard!
http://library.thinkquest.org/18828/index.html

Volcanoes of the Deep Sea (IMAX movie) (first link) and teacher resource page of activities (second link)
www.volcanoesofthedeepsea.com
www.stephenlow.com/educators/Votds-Teachers-Guide-web.pdf

Activities to Explore Specific Concepts in This Puzzle

A heat transfer lab kit for a pre-activity (one of these or any other vendor you prefer)
http://wardsci.com/product.asp_Q_pn_E_IG0003932_A_Heat+Transfer+Activity
http://sciencekit.com/heat-transfer-kit/p/IG0027391

National Earth Science Teachers Association. Windows to the Universe: Density of Ocean Water
www.windows.ucar.edu/tour/link=/earth/Water/density.html%26edu=elem



Appendix A
Bibliographic Notes

The pedagogical approach described in this book—teaching Earth science with authentic Earth data—is grounded in the experience of the authors and of collaborating teachers and in the literature on teaching and learning. This appendix provides an entry point into the relevant literature for readers who wish to explore this approach further.

About Teaching With Archival Data

Most education research on students' interpretation of data concerns small data sets that the students collected themselves. When students work with data that they did not collect themselves, especially professionally collected large data sets, the data sets tend to be more complicated, and the students don't have firsthand experience with the data-collecting instruments and procedures. Some relevant articles on student-collected data versus professionally collected data used by students are as follows:

Edelson, D. C., D. N. Gordin, and R. D. Pea. 1999. Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences* 8: 391–450.
This classic article describes a pioneering effort to design and test inquiry activities in which middle school students work with professionally collected Earth science data.

Hug, B., and K. L. McNeill. 2008. Use of first-hand and second-hand data in science: Does data type influence classroom conversations? *International Journal of Science Education* 30 (13): 1725–1751.
This article documents both similarities and differences in the nature of the discourse among middle school student groups as they work with data that they collected themselves and data that they did not collect themselves.

Swenson, S., and K. A. Kastens. Forthcoming. Student interpretation of a global elevation map: What it is, how it was made, and what it is useful for. In *Qualitative inquiry in geoscience education research*, ed. A. Stokes and A Feig. Boulder, CO: Geological Society of America.
This article documents alternative conceptions among middle school and high school students as they interpret a representation of a global geoscience data set—in this case, a map of global bathymetry and topography.

About Discourse, Metacognition, and the Self-Explanation Effect

A substantial body of research has shown that for a wide range of tasks and among many different types of learners, students who are required to explain what they are thinking or doing show better mastery of the explained material than students who don't take that explanatory step. This is called the *self-explanation effect*, and it is a special case of metacognition, or thinking about one's thinking. The term *self-explanation* refers to generating explanations oneself, rather than hearing an explanation from a teacher or reading an explanation from the text.

Chi, M. T. H., N. DeLeeuw, M.-H. Chiu, and C. LaVancher. 1994. Eliciting self-explanations improves understanding. *Cognitive Science* 18: 439–477.

Chi and her group have published many excellent studies about the self-explanation effect. In this study, they targeted the same audience as Data Puzzles. Eighth graders who were required to explain aloud what they read in a high school science textbook after each sentence showed better mastery of the textbook material than students who merely read the sentences aloud. The self-explanation effect was most marked on the hardest posttest questions, those that required inference.

Donovan, M. S., and J. D. Bransford, eds. 2005. *How students learn: Science in the classroom.* Washington, DC: National Academies Press.

This book distills the research on learning into a form that is accessible to teachers and curriculum developers. The editors begin their book with three central take-home lessons, one of which is that "a 'metacognitive' approach to instruction can help students learn to take control of their own learning…." (p. 2).

Roth, W.-M., and D. Lawless. 2002. Science, culture, and the emergence of language. *Science Education* 86: 368–385.

This study takes an ethnographic approach to the 10th-grade physics classroom and documents how students build understanding through discourse about materials, including apparatus and data.

About Pedagogical Content Knowledge*

Shulman, L. S. 1986. Those who understand: Conception of teacher knowledge. *American Educator* (Spring): 9–15+.

Shulman, L. S. 1987. Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review* 57: 1–22.

In the two classic articles listed above, Shulman laid out the idea of *pedagogical content knowledge*, by which he meant knowledge about *how to teach a specific body of content* as contrasted with knowledge of the content itself or knowledge of general pedagogical techniques. Some elements of pedagogical content knowledge identified by Shulman include useful forms of representation and analogy, conceptions and misconceptions that learners bring to the classroom, and strategies most likely to be successful for reorganizing misconceptions.

About the Reasoning Processes Characteristic of Earth Scientists*

Kastens, K. A., and A. Rivet. 2008. Multiple modes of inquiry in Earth science. *The Science Teacher* (Jan.): 26–31.

This article describes six modes of inquiry that the authors consider to be characteristic of geoscience research: classical experimentation, methodical examination of variations across space, methodical examination of changes through time, interpreting processes in the geological record by analogy with modern processes, use of physical (analog) models, and use of computer models. For each mode, they provide examples of how this style of inquiry can be implemented in the classroom, and they advocate that a well-rounded Earth science education should include all six modes.

Kastens, K. A., C. A. Manduca, C. Cervato, R. Frodeman, C. Goodwin, L. S. Liben et al. 2009. How geoscientists think and learn. *EOS, Transactions, American Geophysical Union* 90 (31): 265–266.

This paper provides an overview of the findings of an interdisciplinary project to create a synthesis of research on thinking and learning in the geosciences. The main themes explored are geological time and temporal thinking, spatial thinking in geosciences, systems thinking in geosciences, and field-based thinking and learning.

About Spatial Thinking (or Spatial Reasoning)§

Clausen-May, T., and. P. Smith. 1998. *Spatial ability: A handbook for teachers.* Berkshire, UK: National Foundation for Educational Research.

This teacher-friendly guide to spatial ability is aimed primarily at elementary school teachers. The authors' central premise is that high-spatial-ability students are being shortchanged by existing instruction and that such students will blossom if their spatial abilities are fostered.

Kastens, K. A., and T. Ishikawa. 2006. Spatial thinking in the geosciences and cognitive sciences. In *Earth and mind: How geoscientists think and learn about the Earth*, ed. C. Manduca and D. Mogk, 53–76. Boulder, CO: Geological Society of America.

* For further discussion of this topic, see pages xii–xiii.

* For further discussion of this topic, see pages xv–xvii.

§ For further discussion of this topic, see pages xv–xvi.

This article describes geoscientists' tasks that appear to draw on visuo-spatial thinking. It then summarizes findings from the cognitive science literature that may shed light on how these tasks are accomplished.

National Research Council. 2006. *Learning to think spatially*. Washington, DC: National Academies Press.

This book makes the case that spatial reasoning is a powerful mode of thinking both for everyday life and for careers in science. The book summarizes developmental and cognitive psychology findings about how humans think about space, and it suggests ways in which spatial thinking can be fostered in K–12 education.

Newcombe, N. 2010. Picture this: Increasing math and science learning by improving spatial thinking. *American Educator* (Summer): 29–43. *www.aft.org/pdfs/americaneducator/summer2010/Newcombe.pdf*

This article by a developmental psychologist summarizes findings from cognitive science research on spatial thinking in terms that are relevant to science teachers. The author makes a good case that spatial performance can be improved through instruction and practice. The focus is on component skills such as mental rotation, rather than on reasoning about the underlying processes that cause spatial patterns.

About Temporal Thinking (or Temporal Reasoning)*

Dodick, J., and N. Orion. 2006. Building an understanding of geological time: A cognitive synthesis of the "macro" and "micro" scales of time. In *Earth and mind: How geoscientists think and learn about the Earth*, ed. C. Manduca and D. Mogk, 77–93. Boulder, CO: Geological Society of America.

This article describes a pedagogical approach that has proven successful in helping students grasp the vastness of geological time and the logic by which geologists make inferences about sequences of events from the relationships among rock strata.

Frodeman, R. 1995. Geological reasoning: Geology as an interpretive and historical science. *Geological Society of America Bulletin* 107: 960–968.

This article, by a philosopher of science, makes the case that the ways of knowing in geology are fundamentally different from those in experimental sciences such as physics. Geology's ways of knowing involve unraveling events of the past, using lines of reasoning akin to those used by scholars of human history.

* For further discussion of this topic, see page xvi.

Kastens, K. A. 2010. Temporal reasoning in the geosciences. At Earth & Mind: The Blog. *http://serc.carleton.edu/earthandmind/posts/temporal_thinki.html*

This essay provides an overview of temporal reasoning in the geosciences. It describes four kinds of time-related evidence that can lead to a scientific claim: evidence concerning sequence, co-occurrence, rate, and cyclicity.

About Quantitative Reasoning*

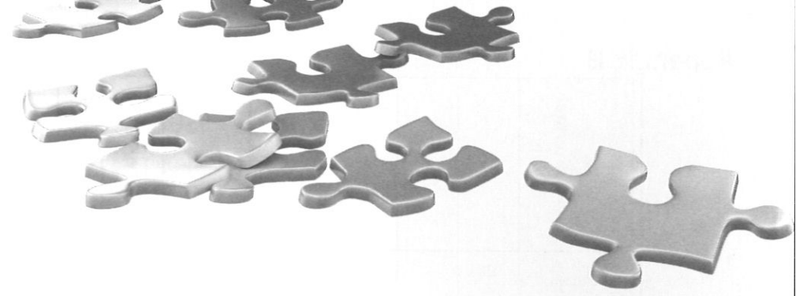
Egger, A. E., and A. Carpi. 2008. Data: Analysis and interpretation. *Visionlearning* Vol. POS-1 (1). *www.visionlearning.com/library/module_viewer.php?mid=154*

This website uses Earth science examples to describe the process of interpreting quantitative data. The site targets undergraduate educators, but the overview module is valuable for high school educators as well.

Teaching Quantitative Skills in the Geosciences *http://serc.carleton.edu/quantskills/index.html*

This website is a compilation of teacher-prepared materials about teaching methods, teaching resources, and tools and data sets for fostering students' ability to use math in thinking about the Earth. Although the site targets undergraduate educators, there is much here that will be of interest to high school teachers as well.

* For further discussion of this topic, see pages xvi.



Appendix B

Alignment With the National Science Education Standards (Grades 5–8 and 9–12) and the Principles and Standards for School Mathematics (Grades 6–12)

These tables summarize the elements from the national science and mathematics education standards that are aligned with each Data Puzzle. A more detailed standards alignment for each puzzle can be found on the Data Puzzle website, *www.ldeo.columbia.edu/edu/data_puzzles.*

National Science Education Standards—Grades 5–8

Category	Standard	Data Puzzle #1 Paleoclimate	Data Puzzle #2 Weather Forecasting	Data Puzzle #3 Earthquakes	Data Puzzle #4 Estuaries	Data Puzzle #5 Watersheds	Data Puzzle #6 Hydrothermal Vents
A. Science as Inquiry	Abilities necessary to do scientific inquiry	•	•	•	•	•	•
	Understandings about scientific inquiry	•	•	•	•	•	•
B. Physical Science	Properties and changes in properties of matter				•	•	•
	Motions and forces			•	•		
	Transfer of energy		•	•			•
C. Life Sciences	Diversity and adaptations of organisms	•					
D. Earth and Space Science	Structure of the Earth system		•	•	•	•	•
	Earth's history	•		•			
	Earth in the solar system				•		
F. Science in Personal and Social Perspectives	Personal health				•		
	Natural hazards		•	•			
	Science and technology in society		•	•	•	•	
G. History and Nature of Science	Science as a human endeavor	•		•	•	•	•
	Nature of science	•	•	•	•	•	•
	History of science			•	•		

National Science Education Standards—Grades 9–12

Category	Standard	Data Puzzle #1 Paleoclimate	Data Puzzle #2 Weather Forecasting	Data Puzzle #3 Earthquakes	Data Puzzle #4 Estuaries	Data Puzzle #5 Watersheds	Data Puzzle #6 Hydrothermal Vents
A. Science as Inquiry	Abilities necessary to do scientific inquiry	•	•	•	•	•	•
	Understandings about scientific inquiry	•	•	•	•	•	•
B. Physical Science	Motions and forces			•	•		
	Conservation of energy and increase in disorder						•
	Interactions of energy and matter			•	•	•	•
C. Life Sciences	The behavior of organisms	•					
D. Earth and Space Science	Energy in the Earth system		•	•			•
	Geochemical cycles				•	•	•
	Origin and evolution of the earth system	•					
F. Science in Personal and Social Perspectives	Personal and community health				•		
	Natural resources				•	•	
	Environmental quality				•		
	Natural and human induced hazards		•	•			
G. History and Nature of Science	Science as a human endeavor	•		•	•	•	•
	Nature of scientific knowledge	•	•	•	•	•	•
	Historical perspectives			•	•		
	Historical perspectives			•	•		

Source: National Research Council. 1996. *National science education standards.* Washington, DC: National Academies Press.

National Principles and Standards for School Mathematics—Grades 6–12

Category	Standard	Data Puzzle #1 Paleoclimate	Data Puzzle #2 Weather Forecasting	Data Puzzle #3 Earthquakes	Data Puzzle #4 Estuaries	Data Puzzle #5 Watersheds	Data Puzzle #6 Hydrothermal Vents
Numbers and Operations	Understand numbers, ways of representing numbers, relationships among numbers, and number systems	•	•	•	•	•	•
	Understand meanings of operations and how they relate to one another					•	•
	Compute fluently and make reasonable estimates					•	•
Algebra	Understand patterns, relations, and functions	•	•	•	•	•	•
	Represent and analyze mathematical situations and structures using algebraic symbols						•
	Analyze change in various contexts	•	•		•	•	
Geometry	Specify locations and describe spatial relationships using coordinate geometry and other representational systems	•	•	•	•	•	
	Use visualization [and] spatial reasoning … to solve problems	•	•	•	•	•	

National Principles and Standards for School Mathematics—Grades 6–12 *(continued)*

Category	Standard	Data Puzzle #1 Paleoclimate	Data Puzzle #2 Weather Forecasting	Data Puzzle #3 Earthquakes	Data Puzzle #4 Estuaries	Data Puzzle #5 Watersheds	Data Puzzle #6 Hydrothermal Vents
Measurement	Understand measurable attributes of objects and the units, systems, and processes of measurements	•	•	•	•	•	•
	Apply appropriate techniques, tools, and formulas …	•	•		•	•	•
Data Analysis and Probability	Develop and evaluate inferences and predictions based on data	•	•	•	•	•	•
Problem Solving	Solve problems that arise in mathematics and in other contexts … applying and adapting a variety of appropriate strategies	•	•	•	•	•	•
Connections	Recognize and apply mathematics in contexts outside of mathematics	•	•	•	•	•	•
Representation	Select, apply, and translate among mathematical representations to solve problems				•	•	•
	Use representations to … interpret physical, social, and mathematical phenomena	•	•	•	•	•	•

Source: National Council of Teachers of Mathematics (NCTM). 2000. *Principles and standards for school mathematics.* Reston, VA: NCTM.



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