What are the essential components of science? What do these key aspects of science look like in grade 5–8 science classrooms? In order to begin to explore these questions, let’s consider the following vignette from Ms. Nelson’s seventh-grade classroom.

In the spring, Ms. Nelson’s seventh-grade class begins an earth science unit in which they explore the question: What is the water quality of our stream? To answer this question, the students collect several water quality measurements from a stream behind their school. Ms. Nelson assigns groups of students to collect and analyze data from different sections of the stream. Group B, which consists of Cesar, Jennifer,
and Josh, collects the following data at site four of the stream during three different times of the month.

<table>
<thead>
<tr>
<th>Test</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.9</td>
<td>8.2</td>
<td>7.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Temp Change (°C)</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Conductivity (mg/l)</td>
<td>350</td>
<td>293</td>
<td>325</td>
<td>323</td>
</tr>
<tr>
<td>Dissolved Oxygen (%)</td>
<td>64</td>
<td>63</td>
<td>58</td>
<td>62</td>
</tr>
</tbody>
</table>

Once the students collect the data, Ms. Nelson gives them national standards for water quality and asks each group to use their data and the standards to construct a scientific explanation that answers their research question about the water quality of the stream. The first step students in Group B decide to do is to calculate the average result of each test and add another column to their table to include these averages. Their new data table looks like this:

<table>
<thead>
<tr>
<th>Test</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Water Standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp Change (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductivity (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved Oxygen (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Next, Group B discusses their results and tries to use their data to determine the water quality of the stream.

Jennifer: The water quality is good because the pH is in the good range.

Josh: I disagree. Look—the water quality is only fair because of the conductivity results.

Cesar: I think the different tests may suggest different things in terms of the water quality. Let’s add a column next to the average column that shows how our findings compare to the national standards.

Jennifer and Josh agree with Cesar’s suggestion and they add one more column to their table that compares their averages to the national water quality standards.

<table>
<thead>
<tr>
<th>Test</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
<th>National Water Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.9</td>
<td>8.2</td>
<td>7.9</td>
<td>8.0</td>
<td>good</td>
</tr>
<tr>
<td>Temp Change (°C)</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>1.7</td>
<td>excellent</td>
</tr>
<tr>
<td>Conductivity (mg/l)</td>
<td>350</td>
<td>293</td>
<td>325</td>
<td>323</td>
<td>fair</td>
</tr>
<tr>
<td>Dissolved Oxygen (%)</td>
<td>64</td>
<td>63</td>
<td>58</td>
<td>62</td>
<td>fair</td>
</tr>
</tbody>
</table>
Josh: See—the water quality is only fair because both the conductivity and dissolved oxygen are fair.

Cesar: I don’t know. What about pH? What about the temperature change?

The three students begin to debate whether the evidence suggests that the water quality is fair or good using their understanding of water quality and the national standards. Later, during a full-class discussion, Group B shares their disagreement with the entire class. They end up using the additional data from the other groups to resolve their debate in order to have sufficient evidence to determine the water quality of the stream.

This vignette shows students engaging in important aspects of what it means to do science in that they are analyzing data, making sense of data, and constructing explanations. The scenario shows students discussing what their stream data means in terms of the water quality and using that data as evidence to support claims that they make to explain real-world phenomena. As such, these students are using and developing important twenty-first-century skills that they will be able to use throughout their lives in a variety of different contexts (National Research Council, 2008).

How can you incorporate similar scientific practices into your classroom? How can you help students develop skills they will need throughout their lives? This book will support you in answering these questions and provide you with strategies to help your students construct scientific explanations. This chapter discusses the role of explanations in science, presents a classroom example of students constructing scientific explanations, provides a justification for why students should construct scientific explanations, and describes the challenges students face in both their writing and during classroom discussions.

The Role of Explanations in Science

Science is fundamentally about explaining the world around us. Scientists try to understand how and why different phenomena occur. For example, they investigate the following kinds of questions: Why is global climate change occurring? Can genetically modified foods be bad for our health? and How can we develop more efficient automobiles? In answering these questions, scientists collect data, make sense of the data and use the data as evidence to explain these complex and important phenomena. The use of evidence drives scientists’ understandings of the world around them. For example, to determine the cause for global climate change, scientists often debate whether the changes result from naturally occurring climatic cycles or from human actions. In order to test these different claims, scientists collect data and develop theories for why the evidence supports or refutes the varying claims. Specifically for climate change, scientists analyze data and look for trends in data for air and ocean temperatures, the amount
and severity of hurricanes, and the amount of greenhouse gases in the atmosphere. Scientists develop competing claims and debate the validity of those claims with other scientists.

This fundamental practice of developing and critiquing scientific explanations is essential not only for scientists, but also for your students (NRC, 2000 NRC, 2008). When students develop and critique explanations it not only helps them learn the science content, but it can also motivate them to want to study science as they realize learning science is more than just memorizing facts. Furthermore, it prepares them to be scientifically literate adults as they learn to read critically the claims of others and to communicate their own ideas with supporting evidence and reasoning. Students need to engage in this important inquiry practice as they conduct their own explorations of the world around them as well as in science class. For example, fifth-grade students may conduct an investigation about the biodiversity in their schoolyard in order to construct an explanation about why some species are able to survive in that environment. Eighth-grade students may build a Rube Goldberg machine in order to construct an explanation about how energy transfers from one form to another. Inquiry science is not only about engaging students in conducting investigations—it also involves students making sense of those investigations through the process of constructing explanations. The depth of students’ ability to learn science depends on this meaning making process.

Scientific Explanations in the Classroom

Our initial interest in scientific explanations stemmed from working with middle school science teachers in a large urban school district. At the time, we were piloting a middle school science curriculum, How can I make new stuff from old stuff? (McNeil, Harris, Heitzman, Lizzotte, Sutherland, & Krajcik, 2004), and we were interested in the effectiveness of the science lessons and investigations. The eight-week chemistry unit focused on three key science concepts: substances and properties, chemical reactions and conservation of mass. From observing different lessons, analyzing student writing and talking with teachers it became clear that one challenge across all the science investigations was students’ ability to make sense of data and construct scientific explanations in which they justified their claims. Students were engaged in the investigations, but it was this meaning-making piece after the investigations that was challenging.

For example, during the curriculum students collected data on two unknowns (fat and soap) to find out whether they were the same or different substances. Their data collection included color, melting point, solubility, density, and hardness for both substances. Table 1.1 illustrates the data the students collected for fat and soap.

After collecting the data, students then wrote a scientific explanation to answer the following writing prompt: Write a scientific explanation stating whether fat and
soap are the same substance or different substances. Figure 1.1 includes the writing sample for one seventh-grade student, Brandon. This is Brandon’s initial scientific explanation about soap and fat being different substances.

Brandon’s claim is correct that “fat and soap are both stuff, but they are different substances.” Yet he provides little scientific support to justify his claim; instead, he talks about cooking and washing, the purposes of the two substances. Initially, we were surprised that students, like Brandon, did not use the data they had collected in their investigations to support their claims. We soon found that this was a trend in the science writing of upper elementary and middle school students. In

<table>
<thead>
<tr>
<th>Data</th>
<th>Soap</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Milky white</td>
<td>Off-white or slightly yellow</td>
</tr>
<tr>
<td>Hardness</td>
<td>Hard</td>
<td>Soft-squishy</td>
</tr>
<tr>
<td>Solubility</td>
<td>Water—yes</td>
<td>Water—no Oil—yes</td>
</tr>
<tr>
<td>Melting Point</td>
<td>Higher than 100°C</td>
<td>~ 37°C</td>
</tr>
<tr>
<td>Density</td>
<td>0.84 g/cm³</td>
<td>0.92 g/cm³</td>
</tr>
</tbody>
</table>

^1All students’ and teachers’ names are pseudonyms.
Brandon’s case, although his everyday knowledge is important and should be incorporated into the classroom discussion, he also needs to understand that the *purpose* of two objects actually does not tell you if they are *made* of the same substance. For example, both a soda can and an automobile might be made out of aluminum. Although they are made out of the same substance, they have very different purposes. Furthermore, Brandon just states that the data table is his evidence instead of talking about specific information in the data table, such as solubility and density. We found this to be another trend with students. In order to justify his claim, Brandon needs to explicitly provide the evidence and describe why those properties are evidence that fat and soap are different substances.

After the students wrote their initial explanations, their teacher, Mr. Kaplan, conducted a lesson specifically focused on scientific explanation introducing a framework for writing scientific explanation (discussed in Chapter 2) and incorporating various teaching strategies such as modeling examples and providing feedback (discussed in Chapter 4). The framework and teaching strategies came from research we conducted with teachers during the previous two years to help students with scientific explanations (McNeill & Krajcik, 2008a). Mr. Kaplan then asked his students to revise their scientific explanations. Figure 1.2 includes Brandon’s revised explanation after the lesson focused on scientific explanations.

**FIGURE 1.2**
Brandon’s Revised Explanation about Soap and Fat

Fat and soap are different substances. Fat is of white and soap is milky white. Fat is soft squishy and soap is hard. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 70°C and soap has a melting point above 100°C. Fat has a density of 0.92 g/cm³ and soap has a density of 0.84 g/cm³. These are different properties. Because fat and soap have different properties, I know they are different.
Brandon’s revised explanation provides a much stronger justification for his claim that fat and soap are different substances. This example illustrates our goal for students in terms of both their writing and discussions in class. Brandon uses the scientific evidence that he collected in class—color, hardness, solubility, melting point and density. He specifically talks about the evidence and how the characteristics were different for fat and soap. Finally, he describes his reasoning for why this evidence supports his claim: “These are all properties. Because fat and soap have different properties, I know they are different.” In just one lesson, Brandon shows impressive improvement in his science writing.

Many of the other students in Mr. Kaplan’s class still struggled with justifying their claims after one lesson. Throughout the school year, Mr. Kaplan continued to have students write scientific explanations and used various teaching strategies to support them in this writing. Having students create written responses like this does not happen overnight. Engaging students in constructing strong scientific explanations, like learning anything new, takes careful support and nurturing from teachers. Helping students to articulate and explain their ideas using evidence as exemplified by Brandon’s revised explanation presents challenging work for teachers, particularly when students have not been encouraged to use evidence to support their claims in previous science classes. But all students can construct strong scientific explanations when they are provided with sufficient time, practice, and instructional support.

**Benefits of Scientific Explanations**

Scientific explanations can play a key role in science classrooms offering numerous benefits to teachers and students. The National Research Council released an important report, *Taking Science to School* (Duschl, Schweingruber, & Shouse, 2007), which synthesizes the latest educational research for K-8 science teaching. *Ready, Set Science* (Michaels, Shouse, & Schweingruber, 2008) is a follow-up to the report for science educational practitioners that applies the findings to classroom practice. Both reports advocate four major goals for K-8 students in science: (1) know and use scientific ideas, (2) generate and evaluate scientific evidence and explanations, (3) understand the nature and development of scientific knowledge, and (4) participate productively in scientific practices and discourse. While scientific explanation aligns explicitly with the second goal, the practice of engaging students in scientific explanations can help you achieve all four goals with your students as they participate in these essential aspects of science.

Engaging your students in scientific explanations can provide numerous benefits (McNeill, 2009; McNeill & Krajcik, 2008a; McNeill et al., 2006) such as help them: (1) understand science concepts, (2) develop twenty-first-century skills, (3) use evidence to support claims, (4) reason logically, (5) consider and critique alternative explanations, and (6) understand the nature of science. Improvement in these
different areas not only helps them succeed in school science, but also better prepares them to be scientifically literate adults. Furthermore, engaging your students in scientific explanations provides you insight into student thinking, offers excellent assessment opportunities, and provides literacy connections for writing across the content areas. In this section, each of these benefits are discussed in more detail.

**Understand Science Concepts**

When writing scientific explanations, students apply scientific ideas to answer a question or problem using appropriate evidence. As recommended in *Ready, Set, Science!* (Michaels, Shouse & Schweingruber, 2008), students need to be able to know, use and interpret scientific ideas. Science instruction often involves students conducting investigations or making observations of the world around them. Yet making sense of those experiences and understanding the science concepts involved in those instructional tasks can be challenging for students. Asking students to construct a scientific explanation at the end of an investigation supports students in making sense of their data through the application of science concepts. This assignment can enrich their understanding of the science concepts by helping them make connections and apply the concepts within a new context. Creating a scientific explanation requires students to really think and reason about a phenomenon. For example, in Brandon’s writing he had to apply his understanding of substances and properties to determine that fat and soap were different substances. Revising his scientific explanation encouraged him to reflect on and articulate the scientific principles that he was using to answer the question. In the vignette at the beginning of the chapter, during Jennifer, Josh, and Cesar’s discussion, they had to apply their understanding of water quality to make sense of the data they had collected from the stream. The act of constructing a scientific explanation requires that students apply concepts in new and flexible ways to make sense of complex scientific phenomena.

**Develop Twenty-First-Century Skills**

Engaging in scientific explanations also supports students in developing important twenty-first-century skills that are essential for a world being transformed by technology, communication and the growth of knowledge (Rhoton & Shane, 2006). Recently, the National Academies (NRC, 2008) sponsored a report to explore the intersection between science education and the development of twenty-first-century skills. The National Academies identified five broad skills that are essential for a range of twenty-first-century jobs, from low-wage service jobs to professional occupations: (1) adaptability—ability to cope with uncertain and new situations, (2) complex communication—skills in processing, interpreting, and communicating information, (3) nonroutine problem solving—analyzing information, recognizing patterns, and generating solutions, (4) self-management—ability to be
self-motivating and self-monitoring and (5) systems thinking—systems analysis, systems evaluation, and adopting a big picture perspective. Incorporating scientific explanation in your classroom can support your students in acquiring the first four of these skills (Krajcik & Sutherland, 2009). Since scientific explanation can be adapted across a variety of content, it can help students adapt to new situations, communicate with others, engage in problem solving, and support them in their own self-monitoring.

Use of Evidence to Support Claims

Another recommendation of Ready, Set, Science! (2008) is to generate and use evidence, which the authors discuss as being at the heart of science. We agree that using evidence is essential to science. Unfortunately, in science classrooms students often do not make use of evidence they collect. Conducting investigations can become more procedural and less focused on the use of evidence to answer a question or explain phenomena. Using evidence is critically important to communicate convincingly to other people. Being able to write in this particular way can help students in future learning and in real world contexts as it provides them with an excellent opportunity to practice two twenty-first-century skills—complex communication and nonroutine problem solving. For example, evidence is often used in nonscientific fields, as in the media and popular culture to support claims such as why you should buy a particular product, vote for a particular politician or support the building of a new school in town. Individuals need to be critical of that evidence in examining whether the evidence is appropriate for the claim and whether there is enough evidence to support the claim as they make decisions in their everyday lives.

Reason Logically

Engaging in scientific explanations often improves students’ ability to reason in science as they become more adept at this type of analytical thinking. In many science classrooms, we have noticed not only a change in students’ writing, but also a change in classroom discussions. For example, in one seventh-grade classroom a student proposed that making Kool-Aid was a chemical reaction. The teacher probed the student by asking for her evidence to support that claim, which initiated a classroom debate about how you could determine whether or not making Kool-Aid is a chemical reaction. One student said that his evidence was that the Kool-Aid tasted different after you mixed it. Other students in the class disagreed, stating that taste was not evidence of a chemical reaction; rather, they needed to examine properties such as color and density to determine if they had really made a new substance. This type of questioning and reasoning is essential in science not only for scientists, but also for all scientifically literate citizens. Questioning is critical to fostering an inquiry orientation in your classroom. Scientific explanations highlight the role of using reasoning to show why the data are evidence for the claim and
applying scientific principles to understand phenomena. Students need encouragement and support to engage in this type of logical reasoning whenever they are making sense of their science experiences.

**Consider and Critique Alternative Explanations**

Having students construct their own scientific explanations also encourages them to grow more constructively critical of other individuals’ spoken and written explanations. Engaging in scientific explanations requires students to consider how other people are justifying their claims and whether or not their justifications are appropriate. Knowing how to listen to the evidence and justifications provided by others is an important component of being able to communicate. Furthermore, students need to be able to construct rebuttals where they defend why an alternative explanation is not appropriate for a particular question. For example, in the water quality vignette from Ms. Nelson’s class the students debated alternative explanations of their stream data trying to determine whether the water quality was fair or good. This type of critical stance helps people better assess science topics not only in science class, but also when presented in popular culture. Controversial science issues, such as cloning, nuclear energy, or global climate change, crop up frequently in magazines, on television, and on the Internet. For people to be critical consumers of popular science who make informed decisions in their everyday lives, they need to understand how these scientific explanations are constructed, justified, and debated. Because of this relevance to everyday life, becoming scientifically literate is important for all learners, not just those who continue on to have careers in the sciences. Furthermore, the ability to consider and critique alternative explanations ties directly to twenty-first century skills, including adaptability, communication, and problem solving. It is important for schools to foster these skills in the next generation, due to applicability across different job contexts and real-world situations.

**Understand the Nature of Science**

Engaging in scientific explanations can also help shift students’ views of science from a static set of facts to a body of knowledge that has been socially created by scientists and constantly changes and grows with new innovations and discoveries. Viewing science as just a set of facts to memorize can discourage some students from being interested in science and pursuing it further in school as a career. Instead, science is actually filled with dispute as scientists debate and try to better understand the world around us. For example, scientists investigate how eating and other health choices influence human aging and disease. One decade-long study of rhesus monkeys investigates how a reduced calorie diet impacts age-related disorders such as cancer, diabetes, and heart disease and brain atrophy in monkeys. Although there are positive effects for monkeys, scientists debate the potential implications in terms of humans. Furthermore, questions remain whether it is just
calorie restriction or if it is the removal of certain types of foods that would be most important in reducing the probability of certain diseases in humans. The field of public health is full of debate as scientists try to better understand the human body and how our choices impact our health. Introducing students to some of these debates in science as well as engaging students in debates where they have to justify their claims with evidence can help students see how knowledge is constructed in science and that science is a dynamic and creative field.

**Other Classroom Benefits**

Besides improving students’ understandings and abilities, integrating this type of writing and conversation into your science class also provides other benefits. When students justify their claims with evidence and reasoning, you gain insight into students’ thinking and understanding. You can see and hear how students understand the science concepts and how students apply those science concepts to make sense of the world around them. These insights serve as an essential formative assessment tool that you can use to adapt your own instruction and more closely meet the needs of your students. Scientific explanation tasks also serve as important summative tools, in both classrooms and on state standardized tests, to evaluate whether students have developed flexible and usable science knowledge. This type of science writing, which requires students to justify their claims, is frequently included in the open-ended items on state standardized tests. For example, Brandon’s revised scientific explanation for fat and soap would be much more likely to receive a higher score on a state standardized test than his first explanation, because of his use of scientific evidence and reasoning.

Integrating scientific explanations into the science curriculum also provides an excellent literacy connection and opportunity for writing across the content areas (Moje, Peek-Brown, Sutherland, Marx, Blumenfeld, & Krajcik, 2004; Sutherland, McNeill, Krajcik, & Colson, 2006). This type of persuasive writing is an important genre of academic writing that often receives less attention in K-12 schools in the United States; instead, schools often focus on personal narrative or storytelling (Purcell-Gates, Duke, & Martineau, 2007). Incorporating scientific explanations into your classroom instruction provides an excellent opportunity for analytic writing that includes the use of evidence. Connecting writing scientific explanations to students’ other classes, such as English and Social Studies, can help students integrate and apply what they are learning in all their classes. Other classes also frequently use evidence to support claims; it is just that “what counts” as evidence in English class (e.g., a quote form a novel) is different from “what counts” as evidence in science. In fact, the common core standards for English Language Arts for grades 6-12 developed by the Council of Chief State School Officers and the National Governors Association (2010) lists argumentation in which students use evidence and reasons to support claims as a common core standard for writing. Students need support and practice in evidence-based persuasive writing across the different content areas.
Alignment with the National Science Standards

Because of the key role of scientific explanations in science, they are prevalent in the national standards as well as many state standards. The national standards documents, *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993; 2009) and *National Science Education Standards* (National Research Council, 1996), advocate the importance of scientific explanation, evidence, and argument in science classrooms. For example, the *Benchmarks for Science Literacy* state, “Present a brief scientific explanation orally or in writing that includes a claim and the evidence and reasoning that supports the claim.” (12D/M6**) and the *National Science Education Standards* state, “Communicate scientific procedures and explanations” (A: 1/7, 5–8). These standards stress the importance of having students create explanations in writing and talk in science classrooms. The *Benchmarks* further elaborate some of the components that should be included in an explanation such as the evidence and reasoning to support the claim. Both documents also discuss the importance of students’ critical analysis of multiple explanations. For example, the *Benchmarks* state, “Notice and criticize the reasoning in arguments in which the claims are not consistent with the evidence given” (12E/M5b**) and the *National Science Education Standards* state, “Recognize and analyze alternative explanations and predictions” (A: 1/6, 5–8). Both of these national standards stress the importance of considering and critiquing multiple explanations for the same phenomena. Appendix 1A includes a complete list of the standards from *Benchmarks for Science Literacy* and Appendix 1B from the *National Science Education Standards* that align with the goals we have been discussing around scientific explanation.

In a follow-up document to the *National Science Education Standards*, the National Research Council published *Inquiry and the National Science Education Standards* (2000) that further elaborates and clarifies the model of inquiry that they view as essential for K-12 science instruction. This document also stresses the importance of scientific explanation in science fields. The document describes five essential features of classroom inquiry:

1. engaging in scientifically-oriented questions
2. giving priority to evidence
3. formulating explanations from evidence
4. connecting explanations to scientific knowledge, and
5. communicating and justifying explanations.

Four of the five essential features include a focus on scientific explanations. As these examples illustrate, the importance of developing, using, and critiquing scientific explanations, evidence, and argument are prevalent throughout the standards yet the language is not always consistent. If you look at Appendix A, the AAAS *Benchmarks* discuss the importance of using claims, evidence, and reasoning in both
Scientific explanations and arguments. In working with teachers, we have debated whether the word explanation or argument is more accessible for elementary and middle school students as a label for this important practice. In the examples you will see throughout the book, the majority of the time the teachers chose to refer to it as scientific explanation, though there are a couple of exceptions in which the teacher or set of teachers decided to call this scientific inquiry practice scientific argument or refer to the acronym for the framework we will discuss (i.e., CER). Although we think it is important to engage students in this practice where they justify their claims with evidence and reasoning, we think it is less important whether that practice is called explanation, argument, or CER. We will refer to it as scientific explanation throughout the book to be consistent, but believe it is up to each individual teacher in terms of what they want to call this scientific inquiry practice with their students.

Student Challenges with Scientific Explanations

Although an important goal for classroom science, constructing scientific explanations presents challenges for students. Students often provide claims, but little or no justifications for those claims. These challenges can be important to keep in mind as you support your students in this complex scientific inquiry practice. Our work with teachers and classroom research (McNeill & Krajcik, 2007; McNeill et al., 2006) shows that students typically have difficulty in three different areas: (1) using appropriate and sufficient evidence, (2) providing reasoning for why their evidence supports their claim, and (3) considering alternative explanations and providing rebuttals. We have developed numerous strategies with teachers over the years to help students overcome these challenges. In future chapters, we will discuss these strategies, but first we want to summarize some of the typical student difficulties in science around justifying their claims.

Using Appropriate and Sufficient Evidence

In terms of using evidence, students often rely on their own opinions or personal experiences instead of using the data they have collected or the data that has been provided to them. For example, a group of sixth-grade students collects and analyzes data to determine whether or not the mass of an object influences how fast it falls to the earth. The students drop three different blocks that have the same volume, but different masses (e.g., 20 g., 44 g., and 142 g.) and time how long it takes the blocks to fall. The students’ average data for the three blocks is 1.5 seconds, 1.7 seconds, and 1.6 seconds suggesting that mass does not affect how fast objects fall. However, the students write in their scientific explanation that heavier objects fall faster because the lightest block was a little slower and a piece of paper will take longer to hit the ground than a rock. It is important to connect students’ everyday experiences, knowledge and ways of knowing to the work they conduct in science class. Yet it is also important for students to understand what counts as appropriate
Importance of Supporting Students in Scientific Explanation

evidence to support a claim and that personal experiences or opinions are not always the most appropriate way to justify a claim in science. Students need to consider questions such as: What claim can I make considering the evidence I have collected? What other types of evidence do I need to support my claim?

Students also struggle at times using or considering enough data to support their claim. Sometimes students focus on one specific data point and do not consider the entire set of data and the conclusions that may be drawn from that data. For example, a group of eighth grade students investigate what area of their school has the most bacteria. They use agar plates to test multiple locations in their science classroom, the hallway, the bathroom and the cafeteria. Although on average, the agar plates from the cafeteria resulted in the most bacteria growth, the students conclude that the bathroom has the most bacteria. Most of the agar plates from the bathroom had little growth, but one plate from the handle of the sink resulted in high bacteria growth. The students focus on the results from this one plate to form their conclusion. Students need help thinking about and making sense of all of the data they have collected. Furthermore, knowing when they have enough data to support their claims is an important ability for students to develop. Your students should consider the question: Do I have enough data to support this claim?

Providing Reasoning

When students do provide evidence to support their claims, they often struggle to articulate their reasoning for why the evidence supports the claim. Yet, providing reasoning is one of the most important capabilities we should help our students develop. Students should be using their understanding of the science concepts to select certain data to answer the question or problem. For example, when a group of seventh graders conduct an investigation focused on how many different habitats are in their schoolyard, they need to use their scientific understanding that a habitat is an area where an organism lives and grows that is able to meet the needs of the organism (e.g., food, water, and shelter). Students’ understanding of habitat influences what data they collect and use to support their claim. Yet in writing their scientific explanation students often omit why they chose certain data or explain what a habitat is. For example, one seventh grade student wrote that there were three habitats in his school year and listed the organisms and the food available to the organisms in the three locations, but he did not provide his reasoning for why the presence of organisms and food are evidence of different habitats. Over years of working with and observing students, we have found that the reasoning is the most difficult component of the scientific explanation process for students (McNeill et al., 2006). They have difficulty articulating what scientific theory they used to answer the question or to select evidence to determine the answer. Students should consider questions such as: Why does the evidence support the claim? What science concept links my evidence to my claim?
Considering Alternative Explanations

Another aspect of scientific explanations that proves difficult for students is considering alternative explanations and rebuttals for why another explanation might not be appropriate. Students focus on one answer and have difficulty seeing that there are potentially multiple different ways to explain a phenomenon. No matter the complexity or simplicity of the science topic, students struggle to consider multiple explanations when investigating a particular phenomenon. This difficulty can occur when students are investigating topics as complex as genetically modified food to simpler concepts such as what causes objects to float. For example, a group of fifth grade students investigate what causes objects to float. They conduct an investigation where they drop different objects in a bucket of water and observe whether they float. The students find that all the objects that had holes in them (e.g., washer and a button) sank, so they conclude that having a hole in an object makes it sink. In actuality, the density of the object determines whether it sinks, but the students did not come up with this alternative explanation. If the students had considered this alternative explanation, this might have led them to test some additional objects. Students should have considered questions such as: What might be an alternative explanation? What other evidence would I need to test the alternative explanation? For example, since the metal washer sank, an alternative explanation could be that objects made of certain substances (e.g., metal and plastic) sink. They could test a solid piece of metal and a solid piece of plastic to determine if they sink as well.

For more complex science topics or for students with more experience, you may want them to construct a rebuttal as well, which can be challenging for students. For example, students could be investigating whether genetically modified foods are beneficial or harmful for human health. In addition to providing a justification for their position, students can be asked to construct a rebuttal that provides counter evidence and reasoning for why the alternative claim is not appropriate. For example, when a group of eighth grade students was preparing for a debate about genetically modified foods, their initial rebuttal was just that the other group was “wrong” and did not know what they were talking about. Their teacher pushed the group to consider what evidence weakened the plausibility of the alternative claim. Students should consider questions such as: Is there evidence or reasoning that suggests the alternative explanation is not appropriate or as strong of an explanation?

Students need to be able to identify and evaluate multiple potential explanations and rule out other options—a practice that is central to making decisions in various life scenarios. Supporting students in rebutting alternative explanations ultimately fosters in them an increased ability to think through various options in other life situations. This aspect of scientific explanation promotes another important aspect of twenty-first century skills—workers of the future will need to consider which is the best possible option among many choices when problem solving and when adapting to new and uncertain situations.
Check Point

Constructing scientific explanations is an essential component of science as scientists try to understand how and why different phenomena occur. Recent science education reform documents and national standards advocate for the importance of supporting students in constructing scientific explanations where they justify the claims they make with appropriate evidence and reasoning as well as consider and refute alternative explanations. Engaging students in scientific explanations can have many benefits such as helping students: (1) understand science concepts, (2) develop twenty-first century skills, (3) use evidence to support claims, (4) reason logically, (5) consider and critique alternative explanations, and (6) understand the nature of science. Yet students can have many challenges with constructing scientific explanations such as using evidence, providing reasoning, and considering alternative explanations and rebuttals. Constructing a strong scientific explanation is a challenging task and students may not have a lot of experience. Consequently, for students to succeed in this task they need multiple opportunities for practice as well as instructional support from their teachers to help them improve over time. In future chapters, we will describe how to design learning and assessment tasks as well as how to incorporate different teaching strategies into your instruction in order to help your students achieve greater success with this important scientific inquiry practice.

Study Group Questions

1. Do you think your students would benefit from constructing scientific explanations? Why or why not?
2. Examine the national standards in Appendix A and B. How do your state or district standards align with students constructing scientific explanations?
3. Think about times in the past when you have engaged your students in scientific explanations in either writing or science talk. What are some challenges that your students had with this type of writing or talk? What did you find challenging about incorporating scientific explanations into your classroom?
### Appendix 1A: AAAS Benchmarks (2009) for Scientific Explanation

Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence. (AAAS, 1B/M1b*)

Often different explanations can be given for the same observations, and it is not always possible to tell which one is correct. (AAAS, 12A/M3*)

Present a brief scientific explanation orally or in writing that includes a claim and the evidence and reasoning that supports the claim. 12D/M6**

Seek to gain a better understanding of a scientific idea by asking for an explanation, restating an explanation in a different way, and asking questions when some aspect of an explanation is not clear. 12D/M7**

Explain a scientific idea to someone else, checking understanding and responding to questions. 12D/M8**

Question claims based on vague attributions (such as “Leading doctors say . . .”) or on statements made by celebrities or others outside the area of their particular expertise. 12E/M1

Be skeptical of claims based on very small samples or biased samples. 12E/M3*

Notice and criticize the reasoning in arguments in which fact and opinion are intermingled. 12E/M5a

Notice and criticize the reasoning in arguments in which the claims are not consistent with the evidence given. 12E/M5b*

Be skeptical of claims based only on analogies. 12E/M5c*

Notice and criticize the reasoning in arguments in which no mention is made of whether control groups are used or whether the control groups are very much like the experimental group. 12E/M5d*

Be skeptical of arguments in which all members of a group (such as teenagers or chemists) are implied to have nearly identical characteristics that differ from those of other groups. 12E/M5e


### Appendix 1B: NRC Standards (1996) for Scientific Explanation


Think critically and logically to make the relationships between evidence and explanation. (NRC, 1996, A: 1/5, 5–8)

Recognize and analyze alternative explanations and predictions. (NRC, 1996, A: 1/6, 5–8)

Communicate scientific procedures and explanations. (NRC, 1996, A: 1/7, 5–8)

Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances. (NRC, A2/5:5–8)

Science advances through legitimate skepticism. Asking questions and querying other scientists’ explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identify faulty reasoning pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations. (NRC, A2/6:5–8)

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