2

Framework for Constructing Scientific Explanations

What does it mean to construct a scientific explanation? What are the important features of scientific writing? How can you introduce those features to your students? Let's consider the following vignette from Mr. Lyon's eighth-grade classroom.

> *Mr. Lyon's eighth-grade physical science class is examining what it means when a chemical reaction occurs, or more specifically, is discovering that a chemical reaction produces a new substance with different properties. Groups in his class dissolve a white powder in water to form a clear and transparent solution, then dissolve another white powder in water to form another clear and transparent solution. Student groups then pour the two clear liquids together and see a thick yellow solid that collects at the bottom of the test tube. Mr. Lyon hears several students say, "Cool," and "Where did that stuff come from?" Mr. Lyon then asks the groups to work together*

to write a scientific explanation that answers the question: Did a new substance form when the two solutions were poured together? He writes on the board:

A scientific explanation has three parts:

- *Claim: a conclusion to a question or problem*
- *Evidence: scientific data that supports the claim*
- *Reasoning: a justification that links the evidence to the claim (use scientific principles to make that claim)*

He then tells the class to write their explanation and to place their explanation on an overhead transparency. After the students finish discussing and writing their explanation, Mr. Lyon asks one of the groups to share their scientific explanation for class critique. Tonya, Shawn, and Miki volunteer to share their explanation. They place their explanation on the overhead and read it out loud:

> *We think a new substance formed because a solid yellow material formed when we poured the two solutions together.*

Mr. Lyon asks Tonya, Shawn, and Miki, "What is the claim in your explanation?" Miki answers, "Our claim is that a new substance formed." Mr. Lyon circles this part of their explanation and asks the class if they agree with this claim. All the student groups answer in unison: "Yeah."

> *We think a new substance formed because a solid yellow formed when we poured the two solutions together.*

Mr. Lyon then asks Tonya, Shawn, and Miki, "What is your evidence?" Shawn responds by saying, "A yellow solid formed."

Mr. Lyon underlines this part of their explanation and asks the class, "Do you agree with their evidence? Is there anything else they should add to their evidence?" Several students raise their hands.

> *We think a new substance formed because a solid yellow formed when we poured the two solutions together.*

Mr. Lyon calls on Owen. Owen says, "They also need to add that before there wasn't a solid present in the solutions. This shows a change from a solution to solid. Also, the solutions started as clear. The yellow shows a change in color." Other students agree that both pieces of information are important evidence for their claim.

Next, Mr. Lyon asks Tonya, Shawn, and Miki, "What is your reasoning in your explanation?" Tonya responds, "We forgot to include the reasoning." Miki adds, "You can tell since you circled the claim and underlined the evidence. There is nothing left to be the reasoning." Mr. Lyon then asks them *again, "What can you add as the reasoning? Why does your evidence support your claim? Remember to make sure you include scientific principles." Miki volunteers, "The solid yellow substance has difference properties." Mr. Lyon asks, "Anything else?" The group answers sheepishly, "We don't think so." Mr. Lyon then asks the class if they would add anything else. Several groups raise their hands.*

This scenario illustrates how a middle school teacher can support students in writing scientific explanations. Mr. Lyon broke the complex task of writing a scientific explanation into three components (i.e., a claim, evidence, and reasoning), provided practice for students in writing explanations, and encouraged peer review.

This chapter will help you understand how you can introduce scientific explanations to your students using a framework we developed with grade 5–8 teachers to support students in constructing scientific explanations. Although many of the examples focus on students' written scientific explanations, you can also use the framework in classroom discussions or small group work when students are trying to make sense of scientific data. We describe the framework first and then provide examples of student writing and videos to illustrate how to introduce the framework to your students.

Students' Understandings of Scientific Explanations

When we ask students to construct a scientific explanation, the word *explanation* might have very different meanings to students than we might intend them to have. The students' understanding of a scientific explanation does not necessarily match our expectations in terms of what we are hoping they will include in their writing and talk. When scientists create explanations, they are trying to understand how or why different phenomena occur, such as global climate change. Furthermore, scientists use evidence to support and justify their claims. Students' intuitive understandings of scientific explanations often do not include either of these ideas. Rather, students may view explanations as just describing and summarizing. For example, in interviews with fifth-grade students, we asked them: "What do you think it means for a scientist to create an explanation?" The students' responses often focused on an exchange between people, such as "if they tell somebody, like all the people, like in public that they learned something like new." In other instances, students spoke about describing or observations, such as "they try to explain um what they're doing, sort of like observing, describing what they see and what they're doing."

When asked about creating an explanation in science class, many students also talked about an exchange between people or observations. Unfortunately, almost half the students interviewed simply said that they did not know what it means to create a scientific explanation in school. Students' responses suggest that when we ask them for a scientific explanation in class, they tend to be unclear of what exactly to include in their writing, so we need to guide them in the process. It is important to help them understand what it means to write a scientific explanation.

Framework for Constructing Scientific Explanations

The instructional framework for scientific explanation provides students with guidelines for what to include in their science writing, oral presentations, and classroom discussions. The framework can change students' understanding of what it means to create an explanation in science and in their science classroom. By making the implicit rules of science explicit, the framework helps students see how to justify claims in science. We developed it for a certain type of science writing and talking: to encourage students to answer a question or problem using data given to them or that they collected themselves.

To develop the framework, we adapted Stephen Toulmin's (1958) model of argumentation that has been used by other science educators to support students in both writing (Bell & Linn, 2000; Berland & Reiser, 2009) and talk (Erduran, Simon, & Osborne, 2004; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000). Toulmin's argumentation model is also used in other content areas, such as social studies and language arts, and is frequently used in composition courses. Although we use Toulmin's basic structure, we adapt the language to be more accessible for students. Our scientific explanation framework consists of four components: (1) claim, (2) evidence, (3) reasoning,[1] and (4) rebuttal.

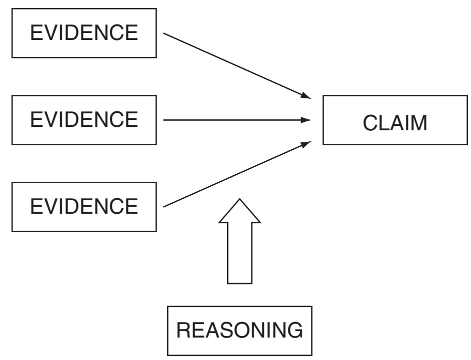
Depending on the experience, understanding, and age of your students, you may want to start by introducing your students to the first three components of claim, evidence, and reasoning. When your students have more experience, you may then add the final component of the rebuttal, which is the most complex part of constructing a scientific explanation. Figure 2.1 displays the relationship between the claim, evidence, and reasoning. This figure illustrates how the evidence supports the claim and the reasoning provides a justification for that link between the claim and evidence. We begin by discussing the claim, evidence, and reasoning as well as the relationship between these three components.

We then add on the fourth component, the rebuttal. We discuss the role of the rebuttal in scientific explanation in terms of how it considers and rules out alternative explanations for a scientific phenomenon.

---

[1]The reasoning combines Toulmin's warrant and backing.

FIGURE 2.1
Claim, Evidence, and Reasoning



Claim

The claim is a statement that expresses the answer or conclusion to a question or problem. Typically, we have found that this is the easiest part for students to include in their writing, though younger students can still find this aspect challenging. When provided with a question about data students have just collected or data that has been given to them, we ask them to construct a claim that addresses the question. For example, in Chapter 1 we discussed Brandon's two explanations about whether soap and fat are the same or different substances. In both Brandon's initial explanation and his revised explanation, he included an accurate claim that fat and soap are different substances. Table 2.1 shows the breakdown of Brandon's revised explanation in terms of claim, evidence, and reasoning. For some students in Brandon's class, the claim was actually all they wrote in their initial explanation. They simply stated a claim without any justification. Other times, particularly with younger students, students may write a claim, but it does not specifically answer the question posed. For example, in answer to the question posed to Brandon's class a student could write, "Fat and soap have different densities." Although this statement is true, it does not answer the original question of whether fat and soap are the same substance. Consequently, it is important to encourage students to look specifically at what the question is asking. The claim provides the conclusion or answer to that question. The other components of the scientific explanation framework provide the justification for that claim. Figure 2.1 illustrates how the other two components (evidence and reasoning) support the claim.

TABLE 2.1 Brandon's Revised Explanation as Claim, Evidence, and Reasoning

Component	Brandon's Revised Explanation
Claim	Fat and soap are different substances.
Evidence	Fat is off-white and soap is milky white. (#1) Fat is soft-squishy and soap is hard. (#2) Fat is soluble in oil, but soap is not soluble. Soap is soluble in water, but fat is not. (#3) Fat has a melting point of 47°C and soap has a melting point above 100°C. (#4) Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3. (#5)
Reasoning	These are all properties. Because fat and soap have different properties, I know they are different.

Evidence

Evidence is scientific data that supports the claim. Data are information such as observations and measurements that come from natural settings (e.g., behavior of birds) and results from controlled experiments (e.g., speed of objects falling). One of the key characteristics of science is its use of scientific data as evidence to understand the natural world (National Research Council, 2000). The accuracy or reliability of scientific data are often checked through multiple trials or by comparing different types of data. Students can either collect data themselves or be provided with data such as data tables, readings, or a database. When students are provided with data, this is sometimes referred to as secondhand data because the students did not collect the data themselves, rather, the data were collected by experts (Hug & McNeill, 2008). Secondhand data are often used when it is not possible for students to collect data themselves, such as when the phenomenon is too small (e.g., atoms and molecules), too large (e.g., the solar system), or takes too long of a period of time (e.g., evolution). Once students have reliable data, they need to make sense of that data. Students should use their data as evidence to come up with and support their claim to the original question or problem. Figure 2.1 illustrates how multiple pieces of evidence provide support for a claim.

When initially introducing the idea of evidence in a scientific explanation to your students, you may want to focus on the importance of using data, such as observations and measurements, to make and support claims. Instead of relying on evidence to support their claims, students often use their opinions, beliefs, and everyday experiences, even if they spent considerable time collecting and organizing their data. Students require support to understand the important role of evidence in answering questions in science. Any conclusion or claim they make about the natural world should be linked to specific and systematic evidence. As your students become more comfortable using evidence to support their claims, discussions about the characteristics of evidence may be deepened to include considerations about whether the data are *appropriate* and *sufficient* to justify the claim.

Appropriate data need to be scientifically relevant for supporting the claim. For example, in the soap and fat example in Brandon's initial explanation he included the fact that soap and fat are used for different things (washing and cooking) as evidence that they are different substances. This is not appropriate evidence for his claim because sometimes a single substance (e.g., aluminum) can be used for creating two objects with different functions (e.g., a soda can and a car). Consequently, what a substance is used for is not appropriate evidence for his claim. In his revised explanation, he uses color, hardness, solubility, melting point, and density as evidence. These are all appropriate pieces of evidence for his claim because all five characteristics are properties; properties are characteristics that are independent of the amount of the sample and can be used to identify substances. For example, the melting point of a substance (such as ice) will be the same whether one has a large amount or a small amount of the substance. Properties are scientifically relevant data for supporting the claim that the substances are the same or different and as such they are appropriate. Often in science we have a lot of data and need to determine which data we should and should not use to answer a particular question or problem. Determining what is and is not appropriate evidence can be challenging for students, yet it is a critical skill that students need to develop for scientific literacy in the world in which they live.

Sufficient data means a student has gathered enough data to support his or her claim. Typically in science, we collect, analyze, and use multiple pieces of data to answer a particular question or problem. Figure 2.1 illustrates three pieces of evidence supporting the claim, but in reality the number of pieces of evidence required will depend on the particular situation. For example, in Brandon's revised scientific explanation he includes five pieces of evidence to support his claim. Usually, one piece of evidence is not sufficient and students will need to figure out how many pieces of evidence to use to support their claim. This can be challenging for students, because they may want to focus on only one piece of evidence. Determining if there are sufficient and appropriate data for a claim are critical aspects of constructing scientific explanations and help build scientific literacy.

Reasoning

In terms of the first three components (claim, evidence, and reasoning), reasoning is the most difficult step in the framework because it involves providing a justification that links the evidence to the claim. This is why in Figure 2.1 we have the reasoning arrow pointing at that link between the claim and evidence. The reasoning explains why the evidence supports the claim, providing a logical connection between the evidence and claim. Typically, the reasoning requires the discussion of appropriate scientific principles to explain that link, because when you are picking or using scientific data you make your decisions based on your understanding of the scientific principles. The reasoning should articulate the logic behind that choice.

For example, in Brandon's explanation, he used color, hardness, solubility, melting point, and density as evidence that fat and soap are different substances. Someone could question him on why he chose that particular evidence. They might ask: Why didn't you use volume? Why didn't you use mass? Brandon's reasoning should explain why he chose that particular evidence. His revised explanation does provide some reasoning for his choice in that he wrote, "These are all properties. Because fat and soap have different properties, I know they are different." This provides some reasoning for his choice, but he could actually have described it in more detail. This is the logic behind his choice: *Color, melting point, solubility, and density are properties. Properties are characteristics of a substance that do not change even if the amount of the substance changes and can be used to determine if two things are the same substance. Since the properties are different, I know they are different substances.*

Students struggle with using scientific principles and describing their logic behind why their evidence supports their claim. Helping students learn how to articulate their reasoning can help them better understand their own thinking as well as develop a stronger understanding of the science content. Although it can be challenging for students, helping them develop sound reasoning skills is critical for their development of scientific literacy. It will not only help them develop better explanations, it will also help them analyze the flaws of other arguments such as those found in the newspaper or on the web.

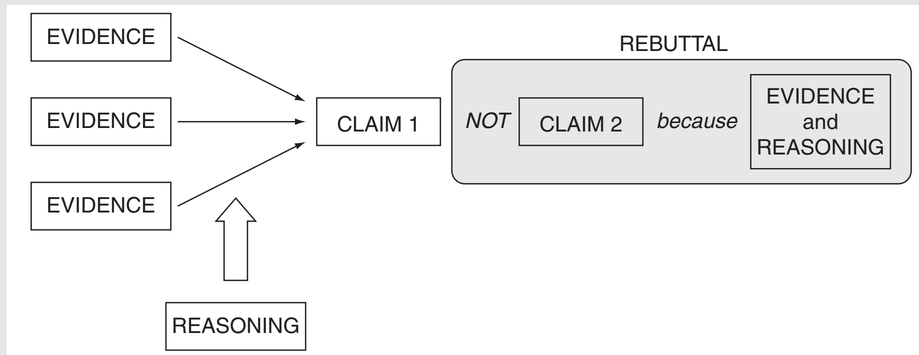
Rebuttal

The last component of the scientific explanation framework is the rebuttal. Figure 2.2 illustrates how the rebuttal connects to the other three components of claim, evidence, and reasoning. The rebuttal recognizes and describes alternative explanations and provides counter evidence and reasoning for why the alternative is not the appropriate explanation for the question or problem. Often in science there are multiple plausible explanations for how or why something has occurred. Scientists consider and debate these multiple possibilities. In critiquing alternative explanations, they go through a similar process as when they are creating an explanation. Scientists consider the alternative claim as well as the evidence and reasoning for that claim. In constructing their final scientific explanation, they will explain not only why they believe claim 1 is correct, but also why they believe alternative claim 2 is incorrect. For instance, they might argue that the evidence that is provided is inappropriate for supporting the claim. The rebuttal includes the explanation for why they believe claim 2 is not correct.

Most teachers introducing the scientific explanation framework do not initially include the concept of a rebuttal. For example, when Brandon's teacher initially introduced the framework for scientific explanation, he only discussed claim, evidence, and reasoning. When Brandon revised his explanation, he was asked to include those three components, but not a rebuttal. This idea that there can be multiple alternative explanations for the same question in science can be challenging for students as well as for teachers who do not have experience

FIGURE 2.2

Claim, Evidence, Reasoning, and Rebuttal



with taking into consideration alternative explanations. Consequently, depending on the experiences of your students you may want to begin with just claim, evidence, and reasoning and then add on the concept of rebuttal after students have become more comfortable with the first three components.

Supporting students in making claims, using evidence and reasoning, and taking into consideration alternative explanations when writing scientific explanations is difficult for students to learn and challenging for teachers to help students understand. However, helping students learn this important practice will give them an invaluable tool to use throughout their lives.

Video Example—Introducing the Instructional Framework

We now use a video example to illustrate how you can introduce the framework to your students and what type of language makes sense for grade 5–8 students. The video for Chapter 2 on the DVD is from a seventh-grade science classroom where the teacher, Ms. Nelson, was introducing the framework for scientific explanation to her students. As the vignette in Chapter 1 illustrated, Ms. Nelson's students had been collecting water quality data from a local stream and are investigating the question: What is the water quality of our stream? In writing up the results from their investigation, Ms. Nelson planned for her students to make a claim about the quality of the stream and then write a justification for that claim using the data they had collected and what they had learned about water quality. Consequently, before she had them complete the write-up she devoted one lesson to introducing and discussing the framework for scientific explanation.

Video Example–Introducing the Instructional Framework

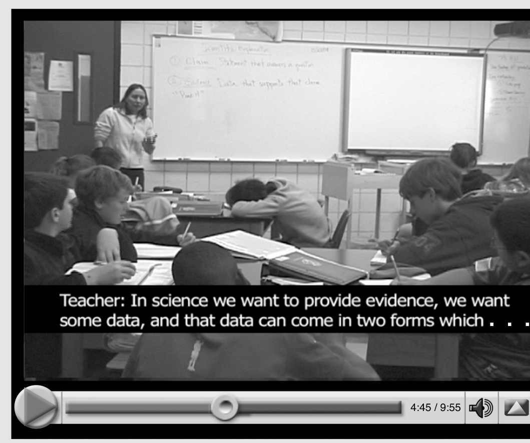
Ms. Nelson chose to introduce the first three components—claim, evidence, and reasoning—of the framework. Watch the 10-minute video clip from this lesson (video clip 2.1). Ms. Nelson uses a variety of strategies during the introduction of the framework to help students develop an understanding of claim, evidence, and reasoning and to link this framework to their prior experiences.

Introducing Claim

The clip begins with Ms. Nelson writing the word "Claim" on the board and she then asks her students, "Anyone have any idea what a claim is? What is a claim? In your everyday life." She has a number of students share their ideas before she combines a couple of them in the following definition of what claim is: "Statement that answers a question." Throughout this introduction of the scientific explanation framework, Ms. Nelson uses this technique of eliciting student ideas before providing them with the definition of each of the three components. She has in a binder (that you can see her look at a couple of times during the video clip) definitions that she wants the students to come up with as a class. Instead, she could very simply have written the three definitions on the board and the introduction would have been quicker. Rather, her strategy encourages student reflection and ownership of the framework and her technique encourages students to think about the words and connect them to their prior experiences. Ms. Nelson's strategy is student-centered. But although she encourages students to share their ideas, the focus is not to support student-to-student discussion of the ideas; student-to-student interaction is a strategy she uses at other times, which we will illustrate in Chapter 7.

VIDEO 2.1

Ms. Nelson Introduces the Framework



The Claim Answers a Question

After coming up with the definition of a claim, Ms. Nelson then focuses on the importance of the claim answering a question. Making sure the claim specifically answers the question instead of a different, but related, question can be very challenging for students. This conversation encourages Ms. Nelson's students to think about this important characteristic of the claim. Furthermore, she uses everyday examples to help students think about how the framework relates to their lives. She provides example claims such as "Brett Favre is the best quarterback that ever lived" and "We had a great field hockey game yesterday." Throughout the discussion of the other two components, she returns to everyday examples to help students understand the meaning of each component, because she wants to connect the framework to what students already know in terms of how to figure out or prove the answer to a question. Throughout the rest of the school year and during the next year in eighth-grade Ms. Nelson's students will have many opportunities to apply the framework to science examples.

Introducing Evidence

The next section of the video clip shifts to discussing the evidence component. Before introducing the word *evidence*, Ms. Nelson first elicits her students' ideas about how you prove or back up a claim in your everyday life as well as in science. Her students come up with the importance of using "facts" and "data," which Ms. Nelson then uses to introduce the term *evidence*. One of the students in her class then brings up another example and asks if this idea of claims and evidence is similar to what happens in the presidential debates.[2] This illustrates that the students are trying to make sense of these different components and connect them to their life experiences. As Ms. Nelson discusses the presidential example, she provides a definition of *evidence* that she writes on the board: "data that supports that claim." You will notice as she discusses the components she writes key terms and definitions on the board so that students have a visual representation as well as the classroom talk to support them in building an understanding. Furthermore, Ms. Nelson has asked the students to record these definitions in their science notebooks. The act of writing can help students remember the components and they will have a permanent record that they can return to when they are asked to write scientific explanations for their different science investigations in the future.

Different Characteristics of Evidence

After introducing the idea of evidence, Ms. Nelson continues to discuss different characteristics of evidence. First she asks students about different categories of data. Specifically, she has students come up with the idea that data can be either quantitative or qualitative. Then she asks students how much data they would want to include. One student responds, "You need to have enough so that you can prove it." Ms. Nelson builds on this idea to discuss the fact that you want to use multiple pieces of data as evidence to support the claim. Ms. Nelson's students are seventh-grade students who have had some experiences in the past using evidence in science. Consequently, this level of complexity works well with her students. As we will discuss later in this chapter (Table 2.3) there are a variety of different levels of

---

[2]This video clip was recorded in October 2008 during the John McCain and Barack Obama presidential debates.

complexity in terms of the framework that you may want to use with your students, depending on their prior experiences.

Introducing Reasoning

Finally, Ms. Nelson introduces the concept of reasoning. In discussing this component, she introduces a new everyday claim: "I could be an NFL quarterback." She uses this example because it is a claim that her students think is not accurate. As soon as she says it, some of the students smile and a couple of the students laugh. She provides evidence for this claim, but then goes on to talk about how the reasoning is faulty. She provides the following evidence: when she was younger she played football every Saturday, she was the quarterback, she had a 65 percent completion rate and has been watching football her entire life. Although this is all evidence around football and it shows that she was a quarterback, the evidence does not prove that she could be an NFL quarterback. This illustrates the importance of the reasoning for appropriately justifying a claim. She also provides a science example from a previous experience they had in class. Furthermore, Ms. Nelson defines the reasoning in terms of science: "Use the science ideas or concepts to show how the evidence supports the claim." Similar to the other two components of the framework, she has the students discuss and share their ideas before providing them with a concrete definition.

The claim, evidence, and reasoning framework is a lot for a grade 5–8 student to process in one 10-minute introduction or during one science class. But Ms. Nelson's goal is not that her students will have a complete and thorough understanding by the end of the period. Rather, it is an introduction to a complex framework they will revisit and build on throughout this school year and in future years. Students now have a new tool that they will be using over and over again across the year as they engage in science writing and discussion. She provides her students with a common framework and language that they can now use whenever they are trying to answer questions in their science classroom and in their everyday lives.

Examples of Scientific Explanations

To further illustrate the scientific explanation framework, we discuss examples from across the different science content areas—physics, chemistry, biology, and earth science. Table 2.2 provides each example broken down into the four components—claim, evidence, reasoning, and rebuttal. Table 2.2 also includes the question that the scientific explanation addresses. Each example increases in complexity from the physics example through the earth science example to illustrate the flexibility of the framework and how it can be used in different contexts. The most complex example we provide is in earth science; however, that is not to say that all earth science scientific explanations are going to be more complex than physics explanations.

TABLE 2.2 Examples of the Different Components for Scientific Explanations

Question	Claim	Evidence	Reasoning	Rebuttal
Physics Does mass affect how quickly an object falls?	No, mass does not affect how quickly an object falls.	The blocks had different masses—20 g, 30 g., 44 g, 123 g, and 142 g. But the average time for all five blocks was about the same—between 1.5 and 1.8 seconds.	Since the blocks had different masses but took about the same time to fall, I know that mass does not affect how quickly something falls.	Some people may think mass is important, because a piece of paper would fall slower than a baseball. But there must be another characteristic of the paper besides mass, which is why it falls more slowly.
Chemistry What type of process took place (mixing, phase change, or chemical reaction)?	A chemical reaction occurred.	Before, the penny was brownish in color, was not soluble in water, and had a density of 8.96 g/cm^3. After the experiment, the green solid was formed, soluble in water, and had a density of 1.88 g/cm^3. The color, solubility, and density changed.	Color, solubility, and density are all properties. Since the properties changed, I know a new substance was made, which means a chemical reaction occurred. Chemical reactions create new substances that have different properties from the old substances.	Another explanation could be that a mixture was created or a third explanation could be that a phase change occurred. Since there is a new substance, it cannot be a mixture or a phase change. A mixture would just be a combination of the old substances and a phase change would be the same substance in a different state.
Biology What will happen to the shark population if the phytoplankton population dies out?	The shark population will die out.	The shark eats other fish such as the ocean fish and the lantern fish. The ocean fish and the lantern fish eat other organisms such as shrimp and copepods. The shrimp and copepods eat the phytoplankton.	Phytoplankton are producers and they make their own food using energy from the sun. All the other organisms in the food web depend on the phytoplankton, even if they do not directly eat them. If the phytoplankton die, primary consumers (shrimp and copepods) will die because they will have no food, which will cause the secondary consumers (ocean fish and lantern fish) to die, which will cause the shark to die.	You might think the shark population would not change, because they do not eat the phytoplankton. But they will actually die out because they eat organisms that eat organisms that eat the phytoplankton.
Earth Science How was the Grand Canyon formed?	The Grand Canyon was mainly formed by water cutting into and eroding the soil.	The soil in the Grand Canyon is hard, cannot absorb water, and has few plants to hold it in place. When it rains in the Grand Canyon it can rain very hard and cause flash floods. The flash floods come down the side of the Grand Canyon and into the Colorado River.	Water moving can cause erosion. Erosion is the movement of materials on the earth's surface. In terms of the Grand Canyon, the water moved the soil and rock from the sides of the Grand Canyon into the Colorado River where it was then washed away.	Some people may think the Grand Canyon was caused by a large earthquake, but the Grand Canyon is not near any tectonic plate boundaries. Furthermore, earthquakes in Colorado are rare and do not tend to be very large—largest earthquake on record had a magnitude of 6.6.

We could have used any of the four different content areas to illustrate either the simplest or most complex example. We wanted to illustrate the range so you could consider what level of complexity might be appropriate to introduce this framework to your students. In the next chapter, we discuss how to design these and other learning tasks to provide students with the opportunity to construct scientific explanations.

Physics Example

Physics provides many opportunities for students to collect data, analyze data, and write scientific explanations in which they make sense of the data and justify their claims. A variety of topics in physics lend themselves to students conducting first-hand investigations where they either collect data or are provided with data to make sense of such as force, friction, gravity, air resistance, motion, electricity, magnetism, light, and energy. The physics example in Table 2.2 comes from an investigation to answer the question: Does mass affect how quickly an object falls? In this investigation, students drop five blocks that are all the same size and shape but have different masses.[3] This example in Table 2.2 illustrates a simpler scientific explanation for a couple of different reasons. First, there are only two possible claims—either that mass does or does not affect how quickly objects fall. In this case, the correct claim is that mass does not affect how quickly an object falls. The students then have two different types of evidence to support their claim: (1) the mass of the different objects and (2) how quickly the objects fall. The reasoning then links the claim and evidence without having to draw from students' understanding of the scientific principles outside of this specific investigation. They can answer this question by analyzing the data they have just collected. For example, a student's reasoning might state: *Since the blocks have different masses but took about the same time to fall, I know that mass does not affect how quickly something falls*. Finally, the rebuttal brings up a counterclaim, but does not refute it in depth: *Some people may think mass is important, because a piece of paper would fall slower than a baseball. But there must be another characteristic of the paper besides mass, which is why it falls more slowly*. In order to provide a strong rebuttal, the student would need to do further investigations exploring other characteristics of the objects. This is an example where you could choose not to have students include a rebuttal, but rather focus on the claim, evidence, and reasoning.

The main reason we classified this as a simple scientific explanation is because the question is very focused. If you want to have students write a more complex scientific explanation around the same science concepts, you could use a more open question such as: What characteristics of an object affect how fast it falls? or Why does a piece of paper fall slower than a baseball? Both of these questions could result in multiple possible claims (not just two), a range of evidence looking at

[3]The blocks have different masses because they are made of different substances. For example, students could have five blocks made of wood, plastic, aluminum, iron, and copper.

different characteristics of objects, reasoning that includes science concepts such as gravity and air resistance, and a more complex rebuttal that explicitly refutes other potential explanations.

Chemistry Example

Chemistry also offers a variety of opportunities for students to write scientific explanations. In grades 5–8, students can conduct investigations or be provided with data around topics such as substances, properties, chemical reactions, phase changes, states of matter, mixtures, and conservation of matter. The example in Table 2.2 is a scientific explanation for an investigation in which students are answering the question: What type of process took place (mixing, phase change, or chemical reaction)? They have placed a penny in a container with vinegar overnight. The next day there is a green solid on the penny. Students use data about the two solids (penny and green solid) to determine whether the green substance was the result of a chemical reaction, a phase change, or mixing. In the physics example, there were two basic claims that a student could construct. The wording of this question expands the possible claims to include three scientific processes. The correct claim is that a chemical reaction occurred. The evidence is the color, solubility, and density data that is different for the two substances. The reasoning in this example is more complex than the physics example. In this example, the student needs to explain what a chemical reaction is (i.e., a process that creates new substances) and why they know a chemical reaction occurred (i.e., the properties changed, which means that a new substance was created). In order to provide the link between the evidence and claim, the student needs to explain the scientific principles they used to make sense of the data. Finally, the rebuttal explains why the investigation was a chemical reaction as opposed to mixing or a phase change by providing reasoning that describes the scientific ideas around these two processes: *Since there is a new substance, it cannot be a mixture or a phase change. A mixture would just be a combination of the old substances and a phase change would be the same substance in a different state*. Similar to the physics example, you can decide whether or not to ask your students to include the rebuttal depending on their experience and expertise with scientific explanations.

Biology Example

Scientific explanations in biology can occur after students conduct controlled experiments, but they also may focus on explaining observations of living organisms. Scientific explanations in the life sciences may focus on topics such as needs of living things, life cycles, adaptations, animal behavior, population dynamics (e.g., predator/prey relationships), organ systems, diseases, and heredity. For instance, the example in Table 2.2 is based on an activity where students examined data about the eating patterns of organisms in a marine ecosystem. Students were asked to write a scientific explanation answering the following question: What will happen to the shark population if the phytoplankton population dies out? Phytoplankton are the only producers and the shark is the top consumer in the marine food web. In this example, there are numerous potential claims that students could make, such as the population of shark will stay the same, increase, decrease, or die out. The correct claim is that the shark population will also die out. The evidence in this example consists of the data about which organisms eat other organisms in the marine ecosystem. This is different evidence than the physics and chemistry examples that consisted of results from an experiment. Here the evidence is observations about the behaviors of organisms. Furthermore, those observations, such as a shark eating an ocean sunfish, are not directly observable by students so they need to rely on data collected by other individuals (i.e., secondhand data). Students use information from readings and texts to gather evidence about the behavior of the organisms. In order to make sense of this evidence, students may first want to create a food web using the information to create a representation of the data. Representations play a key role in science. In other activities, students may want to create a table or graph of their data before writing their scientific explanations. Different ways of organizing and representing data can help students make sense of that data before they formulate their scientific explanation. The reasoning in this example is complex, because it explains not only the role of the phytoplankton as producers in the food web, but also how removing the phytoplankton will influence the other links in the food web. Finally, the rebuttal discusses why the shark population would not stay the same, which could be assumed because the sharks do not eat phytoplankton.

Earth Science Example

Similar to biology, earth science examples can be based on data from controlled investigations or from observational data over time. Students could write scientific explanations around a variety of topics such as weathering, erosion, types of rocks, weather patterns, plate tectonics, movement of the planets, and phases of the moon. The earth science example in Table 2.2 answers the question: How was the Grand Canyon formed? This question is very open and allows students to provide a variety of claims. It is also a question for which students cannot directly collect data. Furthermore, the Grand Canyon has formed over the last 5 to 6 million years. Consequently, there are no human records dating back to the beginning of the Grand Canyon's formation, which makes it more difficult to use evidence to answer this question. Yet the formation of the Grand Canyon is a question that scientists have investigated and debated alternative explanations. Just like scientists, students can look at current data about the Grand Canyon to develop a potential explanation of how it was formed. For example, students can examine photos and videos to look at features of the canyon and the impact of severe weather. They can also examine data about the characteristics of the soil, topography of the land, and the path and characteristics of the Colorado River. After examining all this secondhand data, students can construct an explanation using evidence about how they think the Grand Canyon formed. In Table 2.2, the claim that is provided is that the Grand Canyon was mainly formed by water cutting into and eroding the soil. The claim is justified using evidence about the characteristics of the soil, rain, and topography of the Grand Canyon. The reasoning explains how water can cause erosion and links the characteristics of the area to water moving the soil and rock to form the Grand Canyon. Finally, one potential alternative explanation, that the Grand Canyon was formed by an earthquake, is refuted in the rebuttal. This particular example could be extended with much more detail in terms of the evidence, reasoning, and rebuttal. The actual process that formed the Grand Canyon is more complex than that described in Table 2.2. Also, your students may have many alternative ideas about how the Grand Canyon was formed. Students can research the question, collect secondhand data, and form a scientific explanation arguing for how they believe the Grand Canyon was formed. In Table 2.2, this example is the most complex of the four examples, because it occurred millions of years ago and scientists have debated multiple explanations. There are other examples in earth science that are much simpler explanations for students to construct, such as writing a scientific explanation about the identity of an unknown mineral using properties such as streak, hardness, and luster. In Table 2.2, we show you a range of examples both from different content areas and with a range of complexities to illustrate how you could have students construct a variety of different explanations based on the particular needs and experiences of your students and the science content you currently address in your curriculum.

Increasing the Complexity of the Framework Over Time

As we discussed the framework for scientific explanation, we described aspects that you can make more or less complex depending on the level and needs of your students. In Table 2.3, we present four different ways you could introduce the framework to your students. The four variations have different levels of complexity in terms of both the number of components (three or four) and the description of each component. You should consider your students' backgrounds in deciding which variation to first use to introduce the framework. After your students have written scientific explanations and had some success in this writing, you may want to then increase the complexity of the framework. You could also make a school or districtwide decision. For example, the different grade levels (grades 5–8) could each focus on a different variation of the framework in order to support students in building a more in-depth understanding over time. In order to illustrate the different variations of the framework, we provide example student scientific explanations that all relate to the overarching question: What do plants need to grow? Although all

TABLE 2.3 Variations of the Instructional Framework for Scientific Explanation

Level of Complexity	Framework Sequence	Description of Framework for Students
Simple	Variation #1 1. Claim 2. Evidence 3. Reasoning	Claim • a statement that answers the question Evidence • scientific data that supports the claim Reasoning • a justification for why the evidence supports the claim using scientific principles
↓	Variation #2 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning	Claim • a statement that answers the question Evidence • scientific data that supports the claim • data needs to be appropriate • data needs to be sufficient Reasoning • a justification for why the evidence supports the claim using scientific principles
↓	Variation #3 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning • Multiple components	Claim • a statement that answers the question Evidence • scientific data that supports the claim • data needs to be appropriate • data needs to be sufficient Reasoning • a justification for why the evidence supports the claim using scientific principles • each piece of evidence may have a different justification for why it supports the claim
Complex	Variation #4 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning • Multiple components 4. Rebuttal	Claim • a statement that answers the question Evidence • scientific data that supports the claim • data needs to be appropriate • data needs to be sufficient Reasoning • a justification for why the evidence supports the claim using scientific principles • each piece of evidence may have a different justification for why it supports the claim Rebuttal • describes alternative explanations, and provides counter evidence and reasoning for why the alternative explanation is not appropriate.

four examples address this question, each example increases in complexity in both the structure of the scientific explanation as well as the science content used in the explanation.

Variation #1: Claim, Evidence, and Reasoning

The first variation focuses on the three components (claim, evidence, and reasoning) and provides simple definitions of each component. This variation may be appropriate for your students if you are working with younger students or if your students have had limited experiences with this type of talk and writing. When you introduce this variation, even though you mention all three components, you may want to focus your discussion on claim and evidence. If your students are not experienced with writing and talking in this format, these two components can be quite challenging for students. Once they have developed a stronger understanding of claim and evidence, you can then shift your focus to the reasoning component and emphasize that it is also important to explain why the evidence supports the claim. In terms of the plant-growth example, a potential student explanation would state:

> *The plant that received more light grew taller (CLAIM). The plant with 24 hours of light grew 20 cm. The plant with 12 hours of light only grew 8 cm (EVIDENCE). Plants require light to grow and develop. This is why the plant that received 24 hours of light grew taller (REASONING).*

This example provides a simple claim that focuses on one variable that plants need to grow—light. The student then provides evidence to support the claim from an experiment that focused solely on comparing plants that received 24 hours of light with those that received 12 hours. The actual data the students have to answer the question is not complex; rather, it is limited to support them in the sense-making process and in writing their scientific explanations. The reasoning is also fairly simple, but it encourages students to begin thinking about why their data counts as evidence to support the claim and why they would not use different evidence or construct a different claim from this data.

Variation #2: Using More Complex Evidence

Variation #2 also includes the three components, but here the definition of evidence is expanded to encourage students to think about different characteristics of the plants. Specifically, the evidence now includes the ideas of whether the evidence is appropriate and sufficient for their claim. The plant-growth example increases in complexity:

> *The plant that received more light grew more (CLAIM). On average, for the six plants that received 24 hours of light, they grew 20 cm, had six yellow flowers, had fifteen leaves, and they were all bright green. On average,*

> *for the six plants that received 12 hours of light, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still bright green, but they were smaller and with fewer flowers and leaves (EVIDENCE). Plants require light to grow and develop. This is why the plant that received 24 hours of light grew more (REASONING).*

The claim is still limited to focus on light, but the scientific explanation example now includes multiple pieces of evidence. Furthermore, the evidence includes both quantitative measurements (e.g., average height, number of flowers, and number of leaves) and qualitative observations (e.g., color of flowers and leaves). Obviously, the data that the students collected in this case was more complicated and required greater analysis before they could construct their initial claim.

Variation #3: Providing More Complex Reasoning

Variation #3 focuses on the three components, but we expand the reasoning component to become more complex. The reasoning piece can become more complex in its use of scientific principles or it can become more complex in that different pieces of evidence require different reasoning to articulate how the evidence supports the claim. In the plant-growth example, not only does the reasoning become more complicated, but the claim that students are justifying has also become more complex:

> *Plants need water, carbon dioxide, and light to grow (CLAIM). On average, for the six plants that received constant light, carbon dioxide, and water, they grew 20 cm, had six yellow flowers, had fifteen leaves, and they were all bright green. On average, for the six plants that received 12 hours of light, limited carbon dioxide and water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still bright green, but they were smaller and with fewer flowers and leaves (EVIDENCE). Photosynthesis is the process during which green plants produce sugar from water, carbon dioxide, and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide, and light grew the most (REASONING).*

In the previous examples, the claim focused on how light affects plant growth. This example becomes more complex in that students are being asked to determine multiple variables that impact plant growth. This question requires a greater understanding of the science concepts related to plant growth and that water, carbon dioxide, and light are necessary for photosynthesis to occur. Although we are just illustrating in these examples the writing that students would be producing, these variations would also require an increase in complexity in terms of the question being asked and the data being collected or provided to the students.

Variation #4: Including a Rebuttal

The final variation includes a specific focus on the rebuttal. In the rebuttal students articulate why another claim would not be more appropriate to answer a question or problem and provide counter evidence and/or reasoning to support that rationale. The only difference in this example for plant growth is the last section of the explanation focused on the rebuttal:

> *Plants need water, carbon dioxide, and light to grow (CLAIM). On average, for the six plants that received constant light, carbon dioxide, and water, they grew 20 cm, had six yellow flowers, had fifteen leaves, and they were all bright green. On average, for the six plants that received 12 hours of light, limited carbon dioxide and water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still bright green, but they were smaller and with fewer flowers and leaves (EVIDENCE). Photosynthesis is the process during which green plants produce sugar from water, carbon dioxide, and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide, and light grew the most (REASONING). Our experimental design just limited the amount of air the plants received, not specifically the amount of carbon dioxide. So you could argue that plants need water, air, and light. But we know that the process of photosynthesis requires carbon dioxide and not another gas (like oxygen), which is why we concluded specifically that the carbon dioxide was required for growth. If we could limit just the carbon dioxide in our design, we would have better evidence for this claim (REBUTTAL).*

This example does not require a more complex learning task in terms of the question or the data set. Rather, the complexity increases because of the expectation that the students should be including a rebuttal in their response where they refute other potential explanations.

Other Potential Variations

These are only four examples of how you could adapt the framework. There are of course multiple other possibilities as well. We see the framework as a tool that you should adapt to meet the needs of your students. For example, in working with one bilingual middle school, the teachers in the school decided to change the framework from claim, evidence, reasoning, and rebuttal (CERR) to claim, evidence, reasoning, and other explanation (CERO). They made this change for two different reasons. First, they decided to have all the middle school teachers across the content areas (math, English, social studies, and science) use the same framework. The teachers in the other content areas felt that "other explanations" were more appropriate for their content areas than the term "rebuttal." The second reason they made the change was because *cero* means "zero" in Spanish. They decided to use this to remind their students to use CERO if they did not want to get a zero for their writing. This is just one example. But the point is that there are other ways to adapt the scientific explanation framework beyond the four variations in Table 2.3. The framework is a tool for you to adapt and use to better support your students in science writing and talk.

Benefits of the Framework for All Learners

Engaging students in talking and writing scientific explanations across different science content areas can help all students achieve greater success in science as well as develop a deeper understanding of explanations and arguments that they encounter in their daily lives. Using the instructional framework can help support a variety of different students, including students with culturally and linguistically diverse backgrounds and students with special needs. In this chapter, we focus specifically on the role of the framework, while in Chapters 3 and 4 we will discuss other classroom supports and teaching strategies for supporting all students in constructing scientific explanations.

Students with Culturally and Linguistically Diverse Backgrounds

From a young age, students learn how to effectively communicate in their homes and everyday lives, yet these ways of communicating can differ compared to the academic language and academic ways of thinking that is prioritized in schools (Rosebery & Hudicourt-Barnes, 2006). Specifically, science has its own ways of knowing, talking, and writing that can be challenging for all students, particularly those from culturally and linguistically diverse backgrounds. The use of evidence, construction of explanations, and consideration and weighing of alternative explanations play key roles in science, yet they may vary from how students construct knowledge claims or create explanations in their everyday lives. Two effective strategies that can help all students are: (1) Connect students' everyday ways of knowing with scientific ways of knowing and (2) make the implicit rules of science discourse explicit (Michaels et al., 2008).

The use of evidence to support a claim can be different from how claims are supported in everyday talk. For example, some cultures prioritize storytelling as a cultural way of talking and communicating (Bransford, Brown, & Cocking, 2000).

Constructing a story has a very different format than constructing a scientific explanation. Storytelling can prioritize communication that is more of a narrative or description and draws from experience and knowledge outside of the science context. Although storytelling is a very effective way to communicate in certain contexts, scientific explanations take on a different format. This is why it is important to understand your students' everyday meanings and uses of terms like *evidence* and *explanation*. By developing an understanding of your students' ideas about these terms and practices, you can better support them to understand how constructing explanations and using evidence are similar and different in their everyday lives compared to their lives in the science classroom.

For example, explanation may have a different connotation for students because they may think of explaining as telling a story. In Table 2.2, we discussed a physics example in which students conducted an investigation testing the effect of mass on how quickly an object falls. If students thought writing a scientific explanation about the investigation involved telling a story, they might write a more personal narrative such as, "Our group had a lot of fun testing the different blocks. We used a timer and five different blocks during our investigation." This is a very different format than stating a claim, "Mass does not affect how quickly an object falls," and then supporting that claim with evidence from the investigation. Consequently, you may need to discuss with your students how writing a scientific explanation is different from other ways of communicating, such as telling a story. In terms of evidence, students may have some initial ideas about evidence such as from television shows or movies that focus on forensic investigations. Building on these initial ideas can help students understand that "what counts" as evidence in science is different, though in both cases evidence is used to answer a question or a problem. Students' everyday knowledge can serve as a resource that can be explored and built on to enable students' greater success in constructing scientific explanations.

In addition to understanding students' prior ideas, it is also important to make the expectations of science clear to students. The scientific explanation framework makes explicit how claims are created and supported in science by breaking down this complex practice into the different components: claim, evidence, reasoning, and rebuttal. Simplifying this complex practice into the different components can help provide greater access to all students. The framework provides an entry point that allows students to better understand expectations and how to justify claims in science. Introducing and using the framework with your students can provide them with a valuable tool to enable them greater success in this complex practice.

Specifically, in terms of English language learners (ELLs) engaging in science investigations and making sense of that data through talking, listening, reading, and writing can support students in learning both science content and academic discourse. Similar to other students, ELLs need explicit support in science writing in terms of specific objectives and support to make the expectations clear and limit the complexity of the task (Maatta, Dobb, & Ostlund, 2006). Furthermore, it is important to build from their everyday knowledge and ways of knowing

(Rosebery & Hudicourt-Barnes, 2006). These recommendations align with the Sheltered Instruction Observation Protocol (SIOP) model for teaching content to English learners (Echevarria, Vogt, & Short, 2008). The SIOP model encompasses multiple recommendations for instruction, including clearly defining and displaying content and language objectives, explicitly linking concepts to students' background experiences, and using an instructional model that provides explicit teaching, modeling, and practice (Echevarria et al., 2008). Using the CER framework provides an instructional model that can be used as a tool to integrate these instructional strategies into science classrooms for ELLs and other students with culturally and linguistically diverse backgrounds.

Students with Special Needs

Currently, many students with special needs are mainstreamed in general science classrooms and may have a variety of disabilities including learning disabilities, intellectual disabilities, behavioral disorders, attention deficits/hyperactivity, and language impairments (Steele, 2005). Individual accommodations and modifications need to be made for each student with special needs. The use of the instructional framework for scientific explanation is a strategy that can benefit all students. The scientific explanation framework can provide structure, repetition, and practice for a key way of knowing in science. Students with learning disabilities can have difficulty organizing what they have learned, making connections, and expressing their ideas (Steele, 2005). The claim, evidence, and reasoning structure can support students with these aspects. Furthermore, the framework breaks down this complex task into simpler components, which can help make this way of talking and writing more accessible to all students. Finally, the reasoning component highlights the important science concepts, which can help students understand the concepts as well as encourage them to apply the concepts to different contexts. As such, the scientific explanation framework provides a heuristic that can benefit all learners. In the next two chapters, we will discuss additional strategies that can be used in conjunction with the framework such as visual organizers, picture cues, and modeling to help all students succeed in constructing scientific explanations.

Check Point

At this point, we have described why scientific explanation is important for science classrooms as well as introduced a framework that you can use with your students. The components of the scientific explanation framework include: claim, evidence, reasoning, and rebuttal. The framework can be adapted to meet the needs of your particular students and it can increase in complexity over time as students develop a stronger understanding. In this chapter our goal was to describe what the framework looks like across science content areas and illustrate what it might look like to introduce the framework to your students. At this point, you should hopefully feel like you have a general understanding of the scientific explanation framework. In future chapters, we will describe how to integrate this framework into your classroom in order to support students in constructing scientific explanations in both writing and in classroom discussions. We will focus on how to design and use learning and assessment tasks as well as different teaching strategies you can use to support all students in this complex scientific practice.

Study Group Questions

1. Look at Table 2.3. What variation of the framework would you use in your classroom? Why? Do you think the variation you will use will change over the course of the school year? Why or why not?
2. Describe how you will introduce the scientific explanation framework to your students. Watch the video of Ms. Nelson's classroom again. How would your introduction be similar and different from how Ms. Nelson introduced the framework to her seventh-grade students?
3. Introduce the scientific explanation framework to your students (consider videotaping the introduction and then watching the lesson). What worked well? What challenges did you face? How would you introduce the framework differently next time?