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Inquiry and Scientific Explanations: Helping Students Use Evidence and Reasoning

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Science is fundamentally about explaining phenomena by determining how or why they occur and the conditions and consequences of the observed phenomena. For example, ecologists may try to explain why species diversity is decreasing in an ecosystem, or astronomers may try to explain the phases of the Moon based on the relative positions of the Sun, Earth, and Moon. When scientists explain phenomena and construct new claims, they provide evidence and reasons to justify them or to convince other scientists of the validity of the claims.

To be scientifically literate citizens, students need to engage in similar inquiry. They need to understand and evaluate explanations that appear in newspapers, in magazines, and on the news to determine their credibility and validity. For example, a newspaper article may claim that stem cell research is important for human health and for treating diseases. Students need to be able to critically read that article by evaluating the evidence and reasoning presented in it. That capability allows students to make informed decisions.

Students should also support their own written claims with appropriate justification. Science education should help prepare students for this complex inquiry practice where students seek and provide evidence and reasons for ideas or claims (Driver, Newton, and Osborne 2000).

In this chapter, we describe the importance of scientific explanation in inquiry, common difficulties students have in justifying their claims, and a suggested instructional approach for supporting students in writing scientific explanations.

We then discuss five instructional strategies teachers can use to support students in scientific explanation, including transcripts from classroom discussions (collected during our research) to illustrate what these strategies look like in actual classrooms.

Why Scientific Explanation?

National science education standards (AAAS 1993; NRC 1996) and science education researchers (Sandoval and Reiser 2003; Windschitl, see Chapter 1) emphasize the importance of having students construct evidence-based scientific explanations as essential to scientific inquiry. For example, one standard described in *Benchmarks for Scientific Literacy* (AAAS 1993) states, "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" (p. 12).

Repeatedly, the National Science Education Standards (NSES) (NRC 1996) stress the importance of developing explanations using evidence. In a section on understandings about scientific inquiry, the NSES state, "Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations" (p. 148). These standards highlight the key role of explanation in scientific inquiry.

Engaging students in explanation and argumentation can result in numerous benefits for students. For example, creating and supporting their claims can help students develop a stronger understanding of the content knowledge (Zohar and Nemet 2002). When students construct explanations, they actively use the scientific principles to explain different phenomena, developing a deeper understanding of the content. Constructing explanations may also

help change students' views of science (Bell and Linn 2000). Often students view science as a static set of facts that they need to memorize. They do not understand that scientists socially construct scientific ideas and that this science knowledge can change over time. By engaging in this inquiry practice, students can also improve their ability to justify their own written claims (McNeill et al. 2006).

Although scientific explanation is an essential learning goal, students often have difficulty articulating and defending their claims (Sadler 2004). For example, they struggle to provide appropriate evidence for their claims and to provide reasoning that describes why their evidence supports their claims (McNeill and Krajcik In press-a). Instead, students tend to write claims without providing any justification for them. This is not surprising, since engaging students in justifying their claims is not often called for in science classrooms (Kuhn 1993), and curriculum materials do not provide teachers with concrete support on how to help students with this complex inquiry practice.

What Is Scientific Explanation?

In our work with teachers, we have developed an instructional approach to support students in writing scientific explanation (McNeill et al. 2006; Moje et al. 2004). This instructional approach builds on previous science educators' research on students' constructions of scientific explanations (Sandoval and Reiser 2003) and arguments (Bell and Linn 2000; Jiménez-Aleixandre, Rodríguez, and Duschl 2000; Norris, Phillips, and Osborne, this volume, Chapter 8), as well as Toulmin's (1958) model of argumentation. Although we built from research on both explanation and argumentation, we chose the phrase *scientific explanation* to align with the NSES, which the teachers we work with need to address.

The explanation framework includes three components: a claim, evidence, and reasoning. The *claim* makes an assertion or conclusion that addresses the original question or problem about a phenomenon. The *evidence* supports the student's claim using scientific data. This data can come from an investigation that students complete or from another source, such as observations, reading material, or archived data, and needs to be both appropriate and sufficient to support the claim. By *appropriate,* we mean data that are relevant to the problem and help determine and support the claim. *Sufficient* refers to providing enough data to convince another individual of the claim. Often providing sufficient evidence requires using multiple pieces of data. The *reasoning* links the claim and evidence and shows why the data count as evidence to support

the claim. Often in order to make this link, students must apply appropriate scientific principles.

In this chapter, we draw examples from our work (see McNeill et al. 2004) to illustrate students' written explanations and instructional strategies that teachers use to support students. This unit, which we call the "Stuff" unit, engages students in the study of substances and properties, the nature of chemical reactions, and the conservation of matter. In the Stuff unit, we contextualize the concepts and scientific inquiry in real-world experience, such as making soap from fat. Although our examples come from our observations of teachers using the Stuff unit, other teachers have used the scientific explanation framework to successfully support students in other content areas and at various grade levels.

During the Stuff unit, students complete many tasks in which they are asked to construct scientific explanations. One of the items asks students to explain a particular phenomenon. They examine a data table and determine whether any of the liquids are the same substance (see Appendix A, p. 134). Figure 11.1 is the response from one student for this question.

Figure 11.1. Example of a 7th-grade student's scientific explanation

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Liquid 1 and 4 are indeed the same substances. Looking at this data, the properties include Density, Color, and Melting Point. Mass is not a property. Density, color and M.P. are all the same for liquid 1 and 4. Since all of these propeties are the same, 1 and 4 are the same substance.

This example illustrates a strong scientific explanation from a 7th-grade student. This student provided an accurate claim that liquids 1 and 4 are the same substance. She included multiple pieces of appropriate evidence (density, color, and melting point) to support her claim. She also provided her

reasoning for why her data counted as evidence to support her claim. She wrote, "Looking at this data, the properties include density, color, and melting point. Mass is not a property." This tells why she used some data as evidence (density, color, and melting point) and did not use other data (mass). Then she articulated the general science principle (since properties are the same, they are the same substance) that allowed her to select her evidence and support her claim. Although this example provides a relatively simple scientific explanation, students can use the same framework to guide their responses in more complex writing tasks.

To help this student write a scientific explanation in which she appropriately justified her claim, she was given numerous supports and scaffolds in the curriculum during the Stuff unit and from her teacher. The remainder of this chapter focuses on different strategies teachers have used to support their students.

How Can Teachers Support Students in Writing Scientific Explanations?

Teachers are essential for supporting students in scientific inquiry practices. From recent research on learning and instruction (Bransford, Brown, and Cocking 2000; McNeill and Krajcik In press-b; also see Chapter 2 in this book) and our work with teachers, we have identified five different strategies teachers can use to support students in writing scientific explanations.

1. Make the framework explicit.
2. Model and critique explanations.
3. Provide a rationale for creating explanations.
4. Connect to everyday explanations.
5. Assess and provide feedback to students.

In the following section, these instructional strategies are described in more detail, along with examples from six teachers who enacted the Stuff unit.

Strategy 1. Making the Framework Explicit

When discussing scientific explanations, teachers cannot assume that students understand how to create an explanation. Many of the teachers we work with explicitly discuss what an explanation is and define the different components

of an explanation (claim, evidence, and reasoning) with their students. They discuss what the different components mean in science. Typically, they find that the claim is the easiest component for students to understand, while students have more difficulty with the concepts of evidence and reasoning. Teachers can have extensive conversations around the meanings of *evidence* and *reasoning* to help students understand these components, which can then translate into students more accurately including these components in their writing.

For example, when introducing scientific explanations to her students, one teacher, Ms. Nelson, asked her class what they thought evidence meant. The class initially came up with the definition "the data you have from actually doing something." The discussion continued with the class differentiating between data and evidence. They decided that not all data would count as good evidence and developed a more refined definition of evidence.

One student said, "You have to have more than one piece of evidence." This comment introduced the idea of providing sufficient evidence. Classroom conversation continued to include other characteristics of evidence, such as accuracy and appropriateness. Ms. Nelson summarized their discussion by saying, "So not only does the evidence have to be accurate and we have to have enough of it, but we also need to decide if the evidence is pertinent for our claim." As a class, the students developed a definition of evidence, including what counted as good evidence to support a claim (i.e., sufficiency, accuracy, and appropriateness).

Other teachers lead classrooms discussions on the concept of reasoning. Mr. Davis focused on how the reasoning, in his words, "ties the evidence back up to the original claim." Ms. Parker focused more on the idea that "reasoning is the scientific principle or justification for an answer." Discussing the reasoning helps students understand that they need to write explicitly in their explanations what underlying scientific principle they are using to select their evidence. Often students feel that the teacher already knows the scientific principle (like what a chemical reaction is or what biodiversity is), so they do not need to include it in their writing. Focusing on reasoning can help students include this justification.

Strategy 2. Modeling and Critiquing Explanations

Besides defining scientific explanation, teachers also need to model and critique explanations for students. Teachers can provide models of explanations through either spoken examples or written examples. Teachers need to explicitly identify

the strengths and weaknesses of those examples. Students can benefit from observing a strong example of reasoning that clearly includes a scientific principle to show why the evidence supports the claim. They cannot benefit from weak examples that need improvement, such as an example that uses both opinion and data as evidence. Weak examples can be used to highlight particular difficulties or misconceptions teachers may know that their students hold. Using these types of examples can help students understand how to write high-quality explanations in different content areas and how to be more critical of their own writing.

During one lesson of the Stuff unit, students write scientific explanations about whether fat and soap are the same or different substances. The curriculum materials suggest that teachers show the students examples of strong and weak explanations and model how to critique them. The following example is from Ms. Henry's classroom. After placing the written example on the overhead, she asked her students to critique it:

> *Fat and soap are both stuff, but they are different substances. Fat is used for cooking and soap is used for washing. They are both things we use everyday. The data table is my evidence that they are different substances. Stuff can be different substances if you have the right data to show it.*

The class agreed that this was a weak example of a scientific explanation. They then had the following conversation about the appropriateness of the evidence for the claim.

Ms. Henry: Look at the second sentence—fat is used for cooking and soap is used for washing.

[Students laugh.]

Ms. Henry: Who cares? Why does that matter? Because fat is used for cooking, is that what makes it fat?

Students: No.

Ms. Henry: No. OK. That does not mean anything to me. Is use—how something is used—is that a property?

Students: No.

Ms. Henry: No. Soap is used for washing. So what? That does not tell me if they are the same or different. Look at that

sentence there: "They are both things we use every day." Thank you for the information, but that does not help us at all. We use a lot of things every day. Next sentence. Did they give us some good evidence?"

STUDENTS: No.

MS. HENRY: They say the data table is my evidence.

[Students laugh.]

MS. HENRY: What about the data table? I don't know [gestures hands in the air]. What on the data table? I don't know… you did not give me any data to prove anything.

Although her class quickly agreed that the explanation was weak, Ms. Henry took time to discuss the weaknesses of the evidence. She talked about how use is not an appropriate piece of evidence because it is not a property. She also indicated that just referring to the data table is not appropriate evidence. She next showed a strong explanation, which included specific data about density, melting point, and solubility to further model what is and is not appropriate evidence for this claim. By modeling and critiquing examples, she helped her students understand what is and is not a good example of a scientific explanation.

Strategy 3. Providing a Rationale for Creating Explanations

To effectively create scientific explanations, students should understand why they need to engage in this inquiry practice. Otherwise, using the scientific explanation framework (i.e., claim, evidence, and reasoning) can become too procedural or algorithmic and students may not understand its value and purpose.

In our observations, we identified two different types of rationales for scientific explanation that teachers discuss with their students. Some teachers discuss how science is fundamentally about explaining phenomena. For example, Ms. Nelson discussed with her students that science is about explaining phenomena. She told her class, "Explaining is probably the most important part of figuring out what is going on in science. It is what scientists do the most." She often talked about how her students were scientists and that they engaged in real science through inquiry such as explaining phenomena.

Another rationale teachers used for engaging in scientific explanation is that students need to be able to persuade others that their claims are justified. When writing an explanation, students tend to write a claim alone, without providing appropriate justification or support. Teachers can help students understand that providing evidence and reasoning creates a stronger case for the claim. For example, Mr. Kaplan held the following discussion with his class:

Mr. Kaplan: If you are really trying to convince somebody of something, do you want to be as specific as possible?

Student: I wasn't convincing anybody.

Mr. Kaplan: Well, that is what you want to convey. You want to convince someone of the claim. Your claim is that these two things are different substances. The evidence that you are using or choosing supports that.

Mr. Kaplan tried to help his students understand that the goal of the scientific explanation was to convince others of their claim. His students did not naturally understand this goal. Discussing the rationale behind an explanation can help students see the value and importance of the different components.

Strategy 4. Connecting to Everyday Explanations

Just as in science, in everyday life people try to convince each other of claims. Discussing this similarity between science and everyday life may help students understand the purpose behind scientific explanation and build on their prior knowledge from their everyday experiences. Teachers can provide students with different everyday examples (like discussing who the best basketball player is or ways to convince your parents that you deserve a higher allowance) to discuss how the claim, evidence, and reasoning framework can be used. Drawing on what students know about evidence or justification in their everyday lives can help them understand those same concepts in science.

For example, Ms. Sutton placed the following example on the overhead as a journal topic when students entered the classroom.

Evaluate the scientific explanation below:

The Temptations are the best band ever. They have a popular song and I like it. Therefore, they are the best band ever.

Ms. Sutton then asked students how they evaluated the explanation, which resulted in the following conversation.

STUDENT 1: You did not have enough evidence to back it up.

MS. SUTTON: Ah, so you are saying I can go around making this claim, but I don't have the kind of evidence that I would need?

STUDENT 1: Yes.

MS. SUTTON: What, I have not convinced you with this?

STUDENTS: No.

MS. SUTTON: This evidence is not good enough—they have a popular song and I like it?

STUDENTS: No.

MS. SUTTON: What else is there? I like it.

STUDENT 1: It is your opinion.

MS. SUTTON: Oh, it is my opinion. And that is not good for evidence?

STUDENTS: No.

MS. SUTTON: But it is a fact that I like it.

STUDENT 1: It is not enough evidence.

MS. SUTTON: What would be better evidence then?

STUDENT 1: Having a vote.

MS. SUTTON: Ah. Having a vote, taking a survey. What if I asked 100 people, and 90 of them said that they like the Temptations?

STUDENT 1: Then that is enough evidence.

MS. SUTTON: That is better evidence. Does anyone else have an idea of where I can get some good evidence to back up my claim? [Points to a student.]

Student 2: You did not include reasoning.

Ms. Sutton: I do not have any kind of reasoning. I have no logical reason why I said that. I just throw it out there that they have a popular song and I like that and I hope that you accept it. I need some reasoning—some kind off logic to back that up.

The class continued to discuss what would count as good evidence and good reasoning. They decided that good reasoning includes a general principle about why a band could be considered the best band ever. Specifically, they decided the reasoning should be, "In order to be the best band, you must have millions of fans and sell millions of records." Then they determined that their evidence would be, "The Temptations fan club has one million members," and "They earned four gold records." Ms. Sutton used this opportunity to discuss the difference between evidence and opinion and to stress the importance of using logic to support why your evidence supports your claim. She used this everyday example to help students understand the claim, evidence, and reasoning framework, as well as the idea that students are trying to persuade or convince someone of their claim.

Although scientific explanations have similar features as everyday explanations, the two types of explanation can also differ substantially. Besides talking about similarities with everyday examples, it can also be important to talk about differences. When people use the word *explain* in everyday talk, they are often not asking for someone to provide evidence and reasoning for a claim. For example, someone might ask you, "Can you explain to me where the grocery store is?" In this case, the meaning of *explain* corresponds more closely to *describe* than to the scientific explanation framework of claim, evidence, and reasoning. Students can develop a more complete understanding of scientific explanation if they understand how it is similar and different from everyday explanations.

Strategy 5. Assessing and Providing Feedback to Students

When students write scientific explanations, their thinking may become more visible, both in terms of their understanding of the science content and their reasoning about data. We developed a base explanation rubric to help teachers assess their students' understanding as revealed in their writing. This is a general rubric for scoring scientific explanations across different content

and learning tasks (see Appendix B, p. 134). It includes the three components of a scientific explanation and offers guidance for thinking about different levels of student achievement for each of those components. Teachers adapt the base rubric for a particular task by taking into consideration the content knowledge needed to respond to the task as well as considering what counts as appropriate evidence and reasoning.

When assessing students' explanations, teachers need to provide explicit and thorough feedback. Telling students only that their explanation is "good" or "weak" does not necessarily provide them with any guidance on how to improve. Teachers can provide specific feedback on a variety of different aspects, such as the components of the explanation (i.e., claim, evidence, and reasoning), the science content of the explanation, and the holistic quality of the explanation. In providing feedback, teachers need to point out strengths and weaknesses. For example, Mr. Kaplan circulated around the room and provided students with feedback, often pointing out the strengths and weaknesses of students' explanations—for example, "Your claim said they were different. You need some evidence to show that."

Another effective feedback strategy is offering suggestions on how to improve. Mr. Kaplan provided one student with suggestions on how to improve his evidence as follows: "Now, you have to be more specific—the color changed from this to this; this changed from this to this…. Be as specific as possible." A third feedback strategy is to ask questions that promote deeper thinking. For example, in order to encourage one student to revise her reasoning, Mr. Kaplan asked her, "What scientific principle explains this?" Using these different feedback strategies can help students revise their current scientific explanations, as well develop a deeper understanding of both the content and how to write an explanation.

Conclusion

Constructing scientific explanations in which students support their claims with appropriate evidence and reasoning is an important element of scientific inquiry (AAAS 1993; NRC 1996). Engaging in explanation can help students develop a deeper understanding of the science content and become more adept at writing and critiquing explanations. Yet this complex inquiry practice is rarely a part of classroom instruction, and students often have difficulty supporting their scientific claims (Sadler 2004).

The role of teachers and the different instructional strategies they incorporate into their classroom instruction is important for students' success at writing

explanations and building students' understanding of the content. Using the strategies discussed in this chapter can help make scientific explanation an essential and successful part of classroom inquiry. Furthermore, as students become more successful at writing scientific explanations, teachers can introduce more complex tasks. Students can analyze data from phenomena where there are multiple possible explanations (see Chapters 4 and 8). Students can rule out alternative explanations by showing that there is not enough evidence to support a claim or there is counterevidence for a claim. After analyzing the data and constructing their explanations, they can debate the strength of their explanations. These tasks are important for helping students become scientifically literate where they critically evaluate scientific claims presented in popular culture (e.g., newspapers and magazines).

Although we have focused on written explanations, these strategies can also encourage scientific talk in the classroom where evidence and reasoning are valued. The goal is to help students become critical thinkers and successfully engage in scientific inquiry to explain phenomena.

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Appendix A:
Substance and Property Explanation

Examine the following data table:

	Density	**Color**	**Mass**	**Melting Point**
Liquid 1	0.93 g/cm^3	no color	38 g	-98 °C
Liquid 2	0.79 g/cm^3	no color	38 g	26 °C
Liquid 3	13.6 g/cm^3	silver	21 g	-39 °C
Liquid 4	0.93 g/cm^3	no color	16 g	-98 °C

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Appendix B: Base Explanation Rubric

Component	**Level**		
	0	**1**	**2**
Claim—A conclusion that answers the original question.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence—Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (evidence that does not support claim).	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning—A justification that links the claim and evidence. It shows why the data count as evidence by using appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link evidence to claim.	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some—but not sufficient—scientific principles.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.