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 event. 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 convince other scientists of the validity of the claims. In order to be scientific literate citizens, students need to engage in similar inquiry. Students need to understand and evaluate explanations that appear in newspapers, 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 treating diseases. Students need to critically read articles about science issues, such as stem cell research, by evaluating the evidence and reasoning presented in them. These capabilities allow students to make informed decisions. Students should also support their own claims in writing 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 & Osborne, 2000).

In this chapter, we describe the importance of scientific explanation in inquiry, common difficulties students have justifying their claims, and our instructional approach to help support students in writing scientific explanations. Then we discuss five instructional strategies that teachers can use to support students in scientific explanation including transcripts from classrooms discussions to illustrate what these strategies can look like in actual classrooms.
Why scientific explanation?

The national science education standards (AAAS, 1993, NRC 1996) and science education research (Sandoval & Reiser, 2003; Windschitl, this volume) 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* 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” (AAAS, 1993, p. 12). Repeatedly, the *National Science Education Standards* published by the National Research Council (NRC) stress the importance of developing explanations using evidence. In the NRC’s understandings about scientific inquiry they 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” (1996, 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 & Nemet, 2002). When students construct explanations, they actively use the scientific principles to explain different phenomena developing a deeper understanding of the content. It may also help change students’ view of science (Bell & 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 in justifying their own claims in their writing (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, students have difficulty providing appropriate evidence for their claims and providing reasoning that describes why their evidence supports their claim (McNeill & Krajcik, in press). Instead, students tend to just write a claim without providing any justification for it. Furthermore, engaging students in justifying their claims is often omitted from 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). The instructional approach builds off previous science educators’ research on students’ construction of scientific explanations (Sandoval & Reiser, 2003) and arguments (Bell & Linn, 2000; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Norris, Phillips & Osborne, this volume) as well as Toulmin’s (1958) model of argumentation. Although we build from research both on explanation and argumentation, we chose the phrase “scientific explanation” to align with the national science education standards, 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. The data need to be both appropriate and sufficient to support
the claim. By appropriate, we mean data that is relevant to the problem and helps 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 counts as evidence to support the claim. Often in order to make this link, students have to apply appropriate scientific principles.

In this chapter, we draw examples from one middle school science unit, *How can I make new stuff from old stuff? (Stuff)* (McNeill, Harris, Heitzman, Lizotte, Sutherland, & Krajcik, 2004), to illustrate students’ written explanations as well as instructional strategies that teachers use to support students. *Stuff* 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 the *Stuff* unit, other teachers have used the scientific explanation framework to successfully support students in other content areas and grade levels.

During *Stuff*, students complete many tasks where they are asked to construct scientific explanations. One of the items asks students to explain a particular phenomenon where they examine a data table and determine whether any of the liquids are the same substance (see Appendix A). Figure 1 is the response from one student for this question.

Insert Figure 1
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 to tell why her data counts 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. This illustrates how she used a general science principle in her reasoning to link her claim and evidence. Although this example provides a relatively simple scientific explanation, students can use the same framework to guide their responses in more complex writing tasks.

In order to help this student write a scientific explanation where she appropriately justified her claim, she experienced 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 use to support their students.

How can teachers support students in writing scientific explanations?

Teachers are essential for supporting students in scientific inquiry practices. In terms of scientific explanation, we found that the strategies teacher use in their classroom as well as the quality of those strategies can influence students’ ability to write scientific explanations (McNeill & Krajcik, in review). From recent research on learning and instruction (Bransford, Brown, & Cocking, 2000; Chiappetta, this volume) and our work with teachers, we have identified five
different strategies that can be used in classrooms to support students in creating scientific explanations (see Table 1).

Insert Table 1

Below we describe each of these instructional strategies in more detail as well as provide examples from six teachers who enacted the *Stuff* unit.

*Making the framework explicit.* When discussing scientific explanations, teachers can not assume that students understand what it means to create an explanation. Many of the teachers we work with explicitly discuss what an explanation is and the different components of an explanation (claim, evidence, and reasoning) with their students. They define the different components with their students and discuss what they 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 what is meant by evidence and reasoning to help students understand these components, which can then translate into students more accurately including these in their writing.

For example, when introducing scientific explanations to her class Ms. Nelson asked her class what they thought “evidence” meant. The class initially came up with the definition “the data that 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 or not for our claim.” Together as a class they developed a
definition of evidence including what counted as good evidence (i.e. sufficiency, accuracy, and
appropriateness) to support a claim.

Other teachers led classrooms discussions around the concept of reasoning. Mr. Davis
focused on how the reasoning “ties the evidence back up to the original claim – that is the
reasoning” while Ms. Parker focused more on “reasoning is the scientific principle or
justification for this answer.” Discussing the reasoning helped students understand that they
needed to explicitly write in their explanations what underlying scientific principle they were
using to select their evidence. Often students feel that the teacher already knows the scientific
principle (like what is a chemical reaction or what is biodiversity) so they do not need to include
it in their writing. Focusing on reasoning can help students include this justification.

**Modeling and critiquing explanations.** Besides defining scientific explanation, teachers
also need to model and critique explanations for students. Teachers can provide models of
explanations either through spoken examples or written examples. When providing examples,
teachers not only need to provide examples, they also need to explicitly identify the strengths and
weaknesses of the examples. Students can benefit from observing a strong example, such as an
example that clearly includes reasoning that uses a scientific principle to show why the evidence
supports the claim, as well as weak examples that need improvement, such as an example that
uses both opinion and data as evidence. Weak examples can also be used to highlight particular
difficulties or misconceptions a teacher may know that her students hold. Using these types of
examples can help students understand how to write quality explanations in different content areas and help students 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 example below 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? (gestures hands in the air) Why does that matter? Is fat – because it 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. 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? So what. That does not tell me if they are the same or different. Look at sentence three – They are both things we use everyday. Thank you for the information, but that does not help us - at all. That we use them everyday. We use a lot of things everyday. 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 (gestures hands in the air)… 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 to help them in their own writing.

**Providing a rationale for creating explanations.** In order 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 do not understand the value and purpose of creating explanations. We identified two different types of rationales that teachers discussed with their students about scientific explanation. First, some teachers discussed that science is fundamentally about explaining phenomena. For example, Ms. Nelson talked to her students about how 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 that teachers used for engaging in scientific explanation is the idea of persuasion. When writing an explanation, students tend to just write a claim without providing
appropriate justification or support. Teachers talked to students about why just providing a claim does not persuade or convince others. Teachers helped students understand that providing evidence and reasoning creates a stronger case for the claim. For example, Mr. Kaplan discussed with his class that you want to include more than just a claim because you are trying to persuade or convince someone.

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 – 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 someone else of your claim. His students did not naturally understand this purpose of convincing someone else. Discussing the rationale behind an explanation can help students see the value and importance of the different components.

**Connecting to everyday explanations.** Just like 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 off their prior knowledge from their everyday experiences. Teachers provided students with different everyday examples, like discussing who is the best basketball player or how 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 used this written example to discuss the quality of the claim, evidence, and reasoning. She 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: Ahh 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: Yup.
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 - but it is a fact that I like it.
Student 1: It is not enough evidence.
Ms. Sutton: It is not enough evidence. What would be better evidence then?
Student 1: Having a vote.
Ms. Sutton: Ahh. Having a vote, taking a survey. What if I asked 100 people and 90 of them said that they like it? They like the Temptations.
Student 1: Than 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 put a 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 of 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 1 million members” and “They earned 4 gold records.” Ms. Sutton used this as an opportunity to discuss the difference between evidence and opinion and to stress the importance of including some reasoning that provides logic for 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 you are trying to persuade or convince someone of your 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 with 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.
Assessing and providing feedback to students. When students write scientific explanations it can help make their thinking visible both in terms of their understanding of the science content and their reasoning about data. Students specify how they analyzed their data and why they constructed their claim, which provides an avenue into their thinking. Consequently, many of the teachers we work with found students’ writing of scientific explanation as a valuable way to assess students’ understanding.

We developed a base explanation rubric to help teachers assess their students understanding. This is a general rubric for scoring scientific explanations across different content and learning tasks (see Appendix B). It includes the three components of a scientific explanation and offers guidance to think 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. Just telling students 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 frequently circulated around the room and provided students with feedback. He often pointed out the strengths and weaknesses of students’ explanations. After reading their explanations, Mr. Kaplan told one student, “Your claim said they were different. You need some evidence to show that” and another student “You don’t have your reasoning.” Another strategy
to provide effective feedback is offering suggestions on how to improve. Mr. Kaplan provided one student with suggestions on how to improve his evidence, “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.

**Concluding comments**

Constructing scientific explanations where 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 both 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 (Kuhn, 1993; Newton et al., 1999) 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 (McNeill & Krajcik, in review). In this chapter, we discuss five instructional strategies that teachers can incorporate in their science teaching across a range of content areas and grade levels to support students in writing scientific explanations in which they justify their claims with evidence and reasoning. Using these strategies can help make scientific explanation an essential and successful part of classroom inquiry. Furthermore,
over time 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 Norris et al., this volume; McDonald, Criswell & Dreon, this volume). For example, students can explain why the quality of the water in the river near their school is poor or good. Students can rule out alternative explanations by showing that there is not enough evidence to support a claim or there is counter evidence 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 such as those presented in popular culture, like in 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 where they successfully engage in scientific inquiry around explaining phenomena.
Acknowledgements

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References


Figure 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 substance. 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 properties are the same, 1 and 4 are the same substance.

Table 1: Instructional Strategies Supporting Scientific Explanation

<table>
<thead>
<tr>
<th>Instructional Strategy</th>
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<tbody>
<tr>
<td>1  Making the framework explicit</td>
</tr>
<tr>
<td>2  Modeling and critiquing explanations</td>
</tr>
<tr>
<td>3  Providing a rationale for creating explanations</td>
</tr>
<tr>
<td>4  Connecting to everyday explanations</td>
</tr>
<tr>
<td>5  Assessing and providing feedback to students</td>
</tr>
</tbody>
</table>
Appendix A: Substance and Property Explanation

Examine the following data table:

<table>
<thead>
<tr>
<th></th>
<th>Density</th>
<th>Color</th>
<th>Mass</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid 1</td>
<td>0.93 g/cm³</td>
<td>no color</td>
<td>38 g</td>
<td>-98 °C</td>
</tr>
<tr>
<td>Liquid 2</td>
<td>0.79 g/cm³</td>
<td>no color</td>
<td>38 g</td>
<td>26 °C</td>
</tr>
<tr>
<td>Liquid 3</td>
<td>13.6 g/cm³</td>
<td>silver</td>
<td>21 g</td>
<td>-39 °C</td>
</tr>
<tr>
<td>Liquid 4</td>
<td>0.93 g/cm³</td>
<td>no color</td>
<td>16 g</td>
<td>-98 °C</td>
</tr>
</tbody>
</table>

Write a **scientific explanation** that states whether any of the liquids are the same substance.
### Appendix B: Base Explanation Rubric

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