Helping students write scientific explanations

by Ann M. Novak, Katherine L. McNeill, and Joseph S. Krajcik

Data analysis is one inquiry skill that my students find difficult to master. I found that my students' conversations and written analyses of data were rarely meaningful. Students were simply unable to "present a brief scientific explanation orally or in writing that includes a claim and the evidence and reasoning that supports the claim" (AAAS 2008) or "formulate explanations from evidence, connect explanations to scientific knowledge, and communicate and justify explanations" (NRC 1996).

I was very excited to learn of an instructional framework to assist students in developing scientific explanations (McNeill and Krajcik 2008, p. 101–16; McNeill et al. 2006; Moje et al. 2004, p. 227–51). The framework consisted of three components: *claim, evidence,* and *reasoning*. A *claim* is a statement that answers the question or problem that students are investigating. *Evidence* is the data, qualitative and/or quantitative, that supports the claim. *Reasoning* requires students to apply and use scientific ideas to explain the phenomena and show why their data count as evidence and how they connect to the claim.

I immediately saw the promise of this framework as a vehicle by which students could engage in thoughtful conversations about collected data. The framework would require students to use scientific ideas to explain phenomena. The framework would also make the complex practice of writing scientific explanations understandable to young learners.

Goals

Constructing explanations is an important scientific practice that brings meaning to all that scientists do. But just because it's important to scientists doesn't mean it's going to be important to students. I knew I needed to make the claim-evidence-reasoning framework explicit to students. I wanted to model the proper way to create explanations, share examples of strong and weak explanations, and give students the tools needed to critique explanations. Finally, I wanted students to move from novices and become more expert at writing evidence-based explanations.

Introducing the framework

To set the stage for introducing the framework, I explain that, in addition to designing and carrying out experi-

FIGURE 1 **Water-quality data collected by student**

Stream data–dissolved oxygen	Water quality standard*
Location A: 98%	excellent
Location B: 79%	good
Location C: 94%	excellent

*According to National Water Quality Standards (Stapp and Mitchell 1995) "good" and "excellent" indicate enough oxygen to support aquatic life. "Fair" and "poor" indicate problems with water quality and not enough oxygen to support life.

Student explanation

The dissolved oxygen level is good enough for most aquatic animals and it is in the excellent and good range [claim]. Location A is 98%, which is in the excellent range, Location B is 79%, which is in the good range, and location C is 94%, which is in the excellent range [evidence]. The 98% D.O. level might have happened because of two reasons. Lately, it had been raining a lot and there was a lot of stream flow that could trap lots of air. Second, there weren't a lot of dead organic waste except around location B, where there was a lot of dead cattail. The dead cattail gets decomposed by bacteria, and the bacteria use oxygen, the oxygen then drops [reasoning]. These results indicate that the D.O. level is just right for most aquatic organisms. I hope that they can just keep that high."

FIGURE 2 **Student's initial and revised explanations for a chemistry unit**

Write a scientific explanation stating whether fat and soap are the same substance or different substances.

Initial explanation

I believe that soap and fat are not the same substance. This is because all of their properties are different.

Revised and critiqued explanation

I believe fat and soap are not the same substance. **1.** Soap is white, while fat is transparent. **2.** Fat does dissolve in oil, but soap does not. **3.** The melting point for the fat was 29.7°C, while soap was over 100°C. **4.** Fat is squashy and soft and the soap is hard. **5.** The density of fat is 0.92 cm^2, and the density of soap is 0.84 cm^2. <u>Since soap and fat have very different properties, they are not the same.</u>

ments, scientists generate evidence-based explanations for science phenomena. Then I introduce the claim-evidence-reasoning framework to students using a non-science example and define each term. The following is a sample vignette.

Explanation vignette: Basketball

Sally has an awesome shot (claim)*! She scored 24 points in the game last night. She was 8 for 11 with four three-pointers. She was perfect from the line, making four out of four free throws* (evidence, several pieces). *One reason she's so accurate is that she has really good form. She jumps straight up, she extends her arms above her head, and she has really good follow-through. She also has lots of arc on her shot, so if it's not perfect it still has a chance to go in because it can bounce around on the rim and fall through. Another thing Sally has going for her is that she's always really focused. The crowd was so loud last night but Sally wasn't distracted by it. The player who guarded her was also very rough and trash talked, trying to take Sally away from her game. Sally was still able to focus on her game and really burned her* [reasoning—many reasons]. *I predicted that Sally would score 20 points because I've seen her shoot before and knew she had a good shot. I was pretty close even though she ended up scoring even more than I thought!*

Figure 1 shows actual water-quality data a seventh-grade student collected at a stream. The data are followed by his explanation related to the question, "Is there enough oxygen to support aquatic animals in the stream?" *Claim, evidence,* and *reasoning* are added to the student's explanation to highlight the explanation framework. I use the framework as a guide when assessing the student's explanation. In the example in Figure 1, the student presents a clear claim that answers the question and supports the claim by presenting quantitative data of the percentage of dissolved oxygen at each location, along with the water-quality standard as evidence. He also includes physical, qualitative data of observations he made at the stream when he presents his reasoning.

Sometimes students will intertwine evidence and reasoning, bounce back and forth as they present ideas, and then explain them. The goal is to have a coherent story. The order of the evidence and reasoning is flexible. In Figure 1, the student presents two reasons to explain the results. These reasons are from the science ideas we studied in class (fast-flowing water captures oxygen from the atmosphere and organic waste contributes to oxygen depletion). The student clearly illustrates an understanding of the science by applying science to connect the evidence with the claim. For example, the student connects that location B has lower dissolved oxygen than the other two locations, that dead cattails are present at location B, that organic waste is present, and that organic waste is consumed by bacteria. Bacteria consume oxygen, which causes oxygen levels to drop.

Students need guidance and practice to be able to provide a complete and thorough explanation. For example, during a chemistry unit, students learn that different substances have different properties by conducting five activities to collect data on soap and fat. Prior to a discussion of explanations, students are asked to write what they think a scientist might write, stating whether fat and soap are the same or different substances (McNeill et al. 2004). The top half of Figure 2 is representative of what many students initially write before I introduce the explanation

FIGURE 3 **Scientific explanations**

Claim = Red, Evidence = Blue, Reasoning = Purple

Explanation #1

Fat and soap are both stuff, but they are different substances [correct claim]. 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 [incorrect evidence]. Stuff can be different substances if you have the right data to show it [incomplete or vague reasoning].

Explanation #2

Fat and soap are different substances [correct claim]. Fat is off-white and ivory is milky white. Fat is soft squishy and soap is hard. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47° C and soap has a melting point above 100° C. Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 (correct evidence). These are all properties. Because fat and soap have different properties, I know they are different substances. Different substances always have different properties (correct reasoning).

Explanation #3

Fat and soap are different substances *(correct claim)*. Fat is off white and ivory is milky white. Fat is soft squishy and soap is hard. Fat and soap have different solubility. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47°C and soap has a melting point above 100°C. Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 [correct evidence]. Because the color, hardness solubility, melting point, and density are different, I know they are different substances [correct, but incomplete reasoning].

framework. This student presents a clear claim followed by reasoning that properties are different. What is missing is any evidence to support the claim, and therefore the evidence is not connected to the claim.

After students write their initial scientific explanations, the explanation framework can be introduced. As a class, we discuss and define the three different components (e.g. claim, evidence, and reasoning). Next, I project examples of three different scientific explanations so that we can critique the examples as a class. The science explanations vary; one is complete, another is missing evidence and has inappropriate evidence, and a third is missing reasoning. As a class, we discuss each science explanation and decide which one is the strongest and why the other two are weak, using the explanation framework as our guide. After discussing the three examples, I then project the second overhead, where the three components are identified and color coded (see Figure 3).

After we've discussed several examples of explanations, I ask students to rewrite their chemistry explanations using the framework. Once students finish their new and improved explanations, they switch papers with a partner and critique each other's explanations using the following criteria: (1) circle the claim, (2) number each piece of evidence, and (3) underline any reasoning. The lower portion of Figure 2 presents the student's revised explanation with critique. The student's claim is circled. The student presented all five pieces of evidence (the student partner has written a number by each piece of evidence), and the reasoning is underlined. Comparing this student's initial (Figure 2, top) and revised (Figure 2, bottom) explanations shows a tremendous improvement.

When students critique each other's explanations using the explanation framework, they see another student's work and how it needs to be modified. The first time, not all students will report all of the data. Others will forget to include reasons. By critiquing each other's work and sharing complete explanations with the entire class, students begin to get a clear understanding of the expectations for any scientific explanation. I assess the students' writing by looking for all three components, the quality of each component in terms of scientific accuracy and completeness, and the coherency of the scientific explanation as a whole. With continued practice and with feedback from other students and me, students' explanations get better and become a common scientific practice for students.

Concluding thoughts

Getting students to engage in meaningful conversations to make sense of data by applying science ideas is an essential goal for middle school science (AAAS 2008; NRC 1996), but it is also a challenge. The explanation framework of claim, evidence, and reasoning, however, assists my students in moving beyond simply reiterating data. Learning to write good explanations is a process where students need support and plenty of practice. Constructing explanations is an intellectual process and finished explanations provide me with valuable information to assess where students are in their learning.

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