Assessing middle school students’ content knowledge and reasoning through written scientific explanations

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> *I think that probably one of my favorite components is writing the scientific explanations, because the kids actually have to think and they actually have to be scientific…They have to look at a data chart and pull the evidence out of there…You gotta know what you are doing in order to be able to complete it. It touches on the science, it touches on the writing skills, and it touches on critical thinking.*
>
> Ms. Hill, Practicing Middle School Teacher in a Large Urban Area

Science is fundamentally about explaining phenomena in the world. Explaining involves making claims and justifying those claims with appropriate evidence and reasoning. The National Research Council's (NRC) *National Science Education Standards* (1996) 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" (p148). Moreover, the NRC argues that it is important to engage students in a similar process of constructing and critiquing scientific explanations in science classrooms. Science education research has shown that when students construct scientific explanations that it may change students' image of science (Bell & Linn, 2000), foster deeper understanding of important science concepts (Zohar & Nemet, 2002), and help students write stronger explanations in which they justify their claims (McNeill, Lizotte, Krajcik, & Marx, 2006).

Besides the numerous benefits for student learning, students written scientific explanations can serve as an important assessment tool for teachers. Having students engage in this complex inquiry practice makes students scientific thinking and reasoning visible to teachers allowing them opportunities for assessment (Osborne, et al., 2004). By examining students' written scientific explanations, teachers can develop an understanding of how well their students apply and use scientific concepts to explain phenomena. In this chapter, we discuss an instructional framework for scientific explanations, provide a set of rubrics to assess student work, illustrate types of feedback to give students, and describe how to develop assessment tasks to assess students' written scientific explanations.

Instructional Framework for Scientific Explanation

Although scientific explanations are an important learning goal, students often have difficulty appropriately justifying their claims (Sadler, 2004). Consequently, we developed an instructional framework for scientific explanation based on both our experiences working with middle school teachers in Detroit and from the existing science education research literature (McNeill, Lizotte, Krajcik & Marx, 2006; Moje, Peek-Brown, Sutherland, Marx, Blumenfeld, & Krajcik, 2004). In other work, we discuss in more detail different instructional strategies teacher can use to introduce and support students in scientific explanation (McNeill & Krajcik, in press) and the connections between scientific explanations and literacy (Sutherland, McNeill, Krajcik, & Colson, 2006). In this chapter, we focus on issues relating to assessment.

Our instructional framework breaks down scientific explanation into three components: claim, evidence and reasoning. The *claim* is a statement or conclusion that answers the original problem or question that the students are trying to answer. We found that this is the easiest component for students to construct. The *evidence* is scientific data that supports the claim. The evidence can either come from investigations that the students complete or from second hand sources such as newspapers, books or the Internet. The evidence should be both appropriate and sufficient. By appropriate we mean it is directly relevant to the current problem and allows the student to figure out his or her claim. Sufficiency stresses the idea that students should not just rely on one piece of data, rather they should consider and use multiple pieces of evidence to support their claim. The *reasoning* is the justification for why their data counts as evidence to support their claim which often requires the use of scientific principles. Scientific principles can often help students determine what data does or does not count as evidence for a particular claim. We will illustrate this framework below with student examples.

Assessing students written explanations

We developed a general or base explanation rubric (see Appendix A) for scoring scientific explanations across different content and learning tasks (Harris, McNeill, Lizotte, Marx, & Krajcik, 2006; McNeill et al., 2006). It includes the three components of a scientific explanation and offers guidance to think about different levels of student achievement for each component. The base rubric needs to be adapted to create a specific rubric for a particular task. The specific rubric combines both the general structure of a scientific explanation with the appropriate science content for the particular task. Appendix B provides the specific rubric for the following chemistry assessment task (Figure 1) that is part of a middle school science curriculum unit that focuses on properties, substances, chemical reactions and conservation of mass (McNeill, Harris, Heitzman, Lizotte, Sutherland, & Krajcik, 2004).

Figure 1: Scientific Explanation Substance and Properties Assessment Task

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.

This assessment task requires that students apply the scientific principles that different substances have different properties and that a property (such as density, color and melting point) is a characteristic of a substance that does not change even if the amount of the substance changes. Below is an example from a seventh grade student who wrote a strong scientific explanation for this problem (Figure 2).

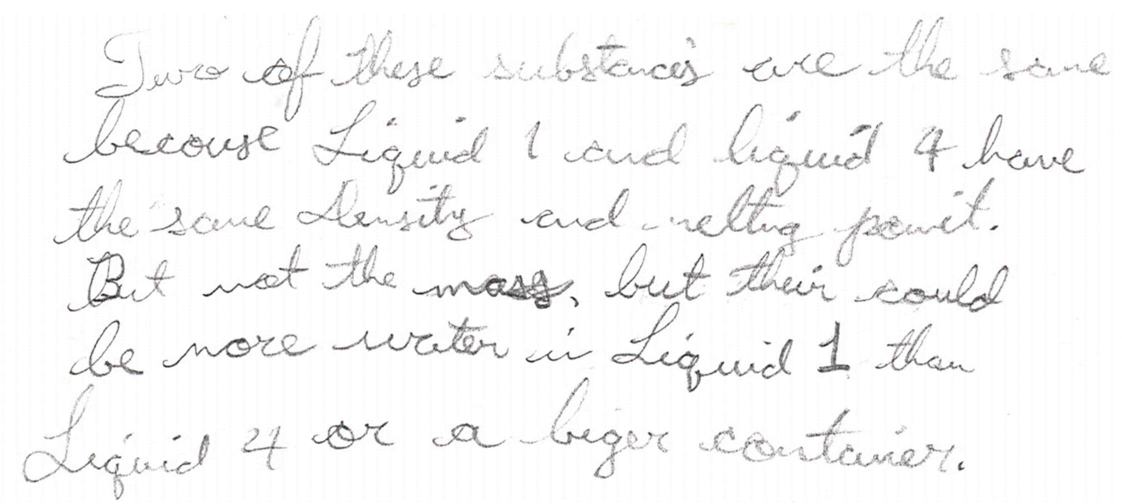
Figure 2: Student Example of a Strong Scientific Explanation

Write a **scientific explanation** that states whether any of the liquids are the same substance. Liquid 1 and 4 are the same substance. They both have a density of .93g/cm^3, have no color, and start to melt at -98°C. For substances to be the same, they must have the same properties. Since Liquids 1 and 4 have the same properties, they are the same substance. The other 2 Liquids are different substances because they have different properties.

We can use the specific scientific explanation rubric for this task in order to assess the student's response. The student would receive the highest score of a 2 for claim, because she provided an accurate and complete claim that "Liquid 1 and 4 are the same substance." She would also receive a 2 for evidence, because she provided three appropriate pieces of data as evidence by including density, color and melting point. Finally, she would receive a 2 for reasoning, because she links her evidence to her claim by discussing that same substance have same properties while different substances have different properties. She states, "For substances to be the same, they must have the same properties. Since Liquids 1 and 4 have the same properties, they are the same substance. The other 2 liquids are different substances because they have different properties."

The next example illustrates a seventh grade student who had more difficulty writing a scientific explanation for this task (Figure 3).

Figure 3: Student Example of a Weaker Scientific Explanation


Two of these substance's are the same becouse Liquid 1 and liquid 4 have the same density and melting point. But not the ~~mass~~, but their could be more water in Liquid 1 than Liquid 4 or a biger container.

Again, this student would receive a 2 for his claim, because he provides an accurate and complete claim. Yet, he has a more difficult time justifying or supporting his claim with appropriate evidence and reasoning. He provides two pieces of appropriate evidence, because he writes "Liquid 1 and liquid 4 have the same density and melting point." Since he does not also mention that they have the same color, he would not receive a 2 for his evidence. Consequently, we would give the evidence a score of 1, because it is not sufficient. Finally, we scored the reasoning a 0, because the student did not provide a link for why having the same density and melting point count as evidence to support the claim that Liquid 1 and 4 are the same substance. To receive points for reasoning, the student needs to discuss that samples of the same substances have the same properties. The student did provide a bit of a discussion of why having different mass might not be important in that he wrote "their could be more water in Liquid 1 than Liquid 4 or a larger container." Unfortunately, the first statement about there being more water in Liquid 1 than Liquid 4 is not a scientifically accurate reason for why the masses would be different, even if the two liquids were the same substance. If there was more water in one compared to the other, then the compositions would not be the same and the densities would also be different. The student's response provides the teacher with some insight into his thinking suggesting confusion about how to differentiate between substances or about the concept of mass. Teachers can also use the knowledge they obtain of their students' understanding to make decisions about future instruction.

We provide these rubrics as a flexible tool for other teachers, administrators and researchers to adapt for their needs. In evaluating students' evidence for this particular task, another individual could decide that only having three levels (0, 1, and 2) is not enough to completely capture the students' understandings. We have also scored this task using four levels for evidence where a level 3 included three pieces of appropriate evidence, a level 2 included two pieces of appropriate evidence, a level 1 included one piece of appropriate evidence, and a level 0 included no evidence. There are tradeoffs between detail and depth of rubrics for assessments and how much time it takes to examining student work. The individuals using the tool should determine the right balance to meet their needs. But we have found the rubrics to be a helpful resource for ourselves and the teachers we work with in assessing students' ability to apply science concepts to explain phenomena.

Providing Feedback

Besides using scientific explanations to provide teachers with information regarding their students' understanding, they can also be useful to provide students with feedback to promote greater student learning. Providing students with feedback on their scientific explanations will help students improve on constructing explanations. Feedback that focuses on what needs to be done with the specific goal of helping students learn (compared to just being a rating of achievement) can improve student performance (Black, 2003).

Teachers can provide feedback both on explanations that students create as well as other examples. Teachers can use anonymous written student examples from other classes as a focus of classroom discussion to critique strengths and weaknesses and create a class consensus of a satisfactory response (Duschl, 2003). Teachers can also provide feedback on spoken explanations offered during class discussion or offer written comments on students' individual written explanations.

When providing feedback on scientific explanations, there are a variety of different features that teachers can comment. First of all, they can use the rubric to guide their comments on the different components of a scientific explanation (i.e. claim, evidence, and reasoning). In other cases, a teacher may find that a student's scientific explanation illustrates a particular difficulty a student is having with the science concepts. Then a teacher may choose to focus on the science content instead of the structure of the scientific explanation. Finally, it is important to realize that while we use the three components to help guide students' explanation construction our ultimate goal is that students write a coherent explanation and not three separate unrelated components. Consequently, teachers may comment on the holistic quality of a scientific explanation and how it hangs together as a whole.

Comments on students' explanations should offer explicit and clear feedback. Simply providing feedback such as "good work" or "needs more detail" is often not useful for a student. The student might not understand what was good about his or her explanation or what aspects need more detail. Specifically pointing out strengths and weaknesses can help students understand what to include in their writing. For example, for the second example (Figure 3) a teacher might say, "The explanation did a great job talking about density and melting point, but it did not include a discussion of color." For a particular weakness, it can also help students to provide suggestion on how to improve. In terms of color, a teacher might comment, "You should talk about whether the color of liquid 1 and 4 is the same or different and whether or not that piece of data is important for your claim." Finally, it can also help to ask students questions to promote deeper thought. With the student's reasoning in the second example, it might be beneficial to ask him questions to get a better sense of what he was thinking when he was writing the explanation. For example, a teacher could ask, "Why did you use density and melting point as evidence for your claim? Why are these pieces of data important? Do you think mass is important to determine if they are the same substance? Why or why not?" These types of questions can help the teacher better understand the student thinking as well push a student's own understanding about both the science content and their scientific explanation.

Creating Explanation Assessment Tasks

So far we have used an example scientific explanation task that we developed to assess students' understanding of substances and properties. Developing good assessment tasks that align learning goals or standards can be difficult. In this section, we describe the six steps that we go through in order to develop scientific explanation assessment tasks. These steps help ensure that the task is appropriate for having students construct an explanation in terms of combining both their understanding of the content and their ability to write scientific explanations. The steps also help align the task with the desired national science content standards and make certain that the task actually measures the desired content. Previously, we discussed a chemistry example. In this section, we focus on a middle school life science standard to help illustrate that students can engage in scientific explanations across different content areas.

Step #1:Identify and Unpack the content standard. The first step involved in writing an assessment task is to identify the content standard you wish to assess. Unfortunately, there are often far more ideas in one content standard than you might initially think. It is important to closely examine and unpack the content standard to determine the science ideas that you are trying to help students learn and assess. When interpreting standards it can be helpful to: 1. decompose the standard into related concepts, 2. clarify the different concepts, 3. consider what other concepts are needed, and 4. make links if needed to other standards. For example, one of the American Association for the Advancement of Science (1993) benchmarks for life science is listed below. We will use this standard to develop an explanation assessment task.

Figure 4: The interdependence of life benchmark

Two types of organisms may interact with one another in several ways: They may be in a producer/consumer, **predator/prey**, or parasite/host **relationship**. Or one organism may scavenge or decompose another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other. AAAS, 1993, 5D: M2

This benchmark includes a variety of different ideas. One important aspect of this content standard focuses on the predator and prey relationship (in bold), which we decided to focus on for this assessment task. Addressing this idea meant that we needed to clarify the meaning behind the bold components of the standard "organisms may interact" and "predator/prey relationship." We clarified their meaning in the following manner. A biological interaction is a relationship between two species in the natural world. One type of relationship that two organisms can have is a predator and prey relationship. A predator is an animal that captures and consumes other organisms for food while the prey is the organism that is captured and consumed for food. This relationship can result in stable populations for both species. However, if a predator enters a new environment it can cause the population size of a prey to drop even possibly resulting in no more prey in that environment.

It is also important to consider what prior knowledge students will need to understand this concept as well as what non-normative ideas or misconceptions they may have about the content. You may decide to include some of the misconceptions in your design of the assessment task. For example, the clarification we provided before assumes that students are already familiar with the concepts of organism, food, and populations. One misconception students may have is differentiating or understanding the link between the death of one organism and the change in a population size over time.

Step #2: Unpack the scientific inquiry practice. It is important to consider what you are looking for in terms of the scientific inquiry practice (e.g. design, models, scientific explanation). In this chapter we specifically focus on scientific explanation, which we unpacked into three components: claim, evidence and reasoning. This unpacking corresponds to the base rubric discussed above and clearly articulates what you are looking for in terms of the assessment task (see Appendix A). Unpacking the scientific inquiry practices specifies what it is that you will want students to do with their understanding of the science content. If you create an assessment task for a different scientific inquiry practice (e.g. design of investigation), you would need to unpack the inquiry practice and create a corresponding base rubric.

Step #3: Create learning performance. The scientific explanation assessment task measures both students' understanding of the science content and the scientific inquiry practice. In order to help us think about what it means to combine the content and inquiry practice, we create learning performances. Learning performances specify what students should be able to do with the content knowledge. We do not simply want students to memorize the content standard and recite it back to us. Rather, we want them to apply the content as they engage in scientific inquiry. You can think of a learning performance as a cross between the content standard and an inquiry practice. The learning performance clarifies how the content knowledge is used in reasoning about a scientific phenomenon. Figure 5 is an example learning performance. It combines the content learning goal (i.e. predator/prey) with the scientific inquiry learning goal (i.e. scientific explanation).

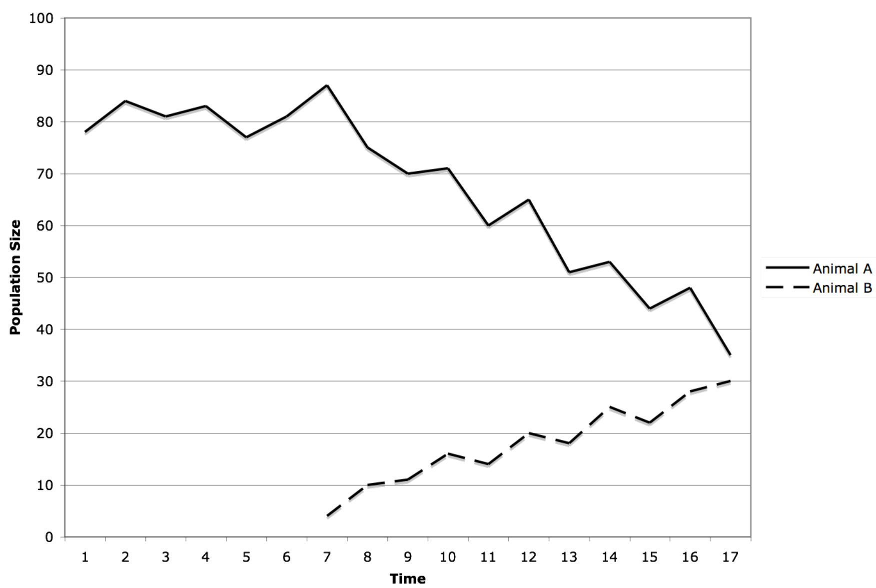
Figure 5: Developing Learning Performances

Content Standard X	Scientific Inquiry Standard =	Learning performance
Two types of organisms may interact with one another in …a predator/prey relationship. AAAS, 1993, 5D: M2	Develop…explanations… using evidence. (NRC, 1996, A: 1/4, 5-8) Think critically and logically to make the relationships between evidence and explanation. (NRC, 1996, A: 1/5, 5-8)	Students construct a scientific explanation that includes a claim about whether two organisms have a predator/prey relationship, evidence in the form of the characteristics of the organisms and their populations, and reasoning that predators consume prey and that when predators enter a new environment they can cause a drastic decrease in the prey population size.

Step #4: Write the assessment task. Next we design an assessment task that would result in students applying both their content and scientific explanation understandings to create the desired product. We do this by aligning the assessment task to the learning performance that we previously created. Figure 6 shows the assessment task that we created for the predator and prey scientific explanation learning performance.

Figure 6: Scientific Explanation Assessment Task for Predator and Prey

Animal A lives in a grassland area where it eats grasses, roots and weeds. Animal A lives in small tunnels it creates under the soil. At time point 7, Animal B moves into that environment. Animal B is a much larger animal and eats small animals, insects, and reptiles.



Write a scientific explanation that tells what type of relationship these two animals have with each other.

Step #5: Review assessment task. After creating the assessment task, we use three questions adapted from the Project 2061's assessment framework (DeBoer, 2005) to review our task: 1. Is the knowledge needed to correctly respond to the task? 2. Is the knowledge enough by itself to correctly respond to the task or is additional knowledge needed? 3. Is the assessment task and context likely to be comprehensible to students? These questions help us reflect on whether our assessment task aligns with the desired learning goal and whether or not it will be accessible to the students.

Step #6: Developing Specific Rubrics. We next use the base scientific explanation rubric to create a specific rubric for the particular assessment task by determining what would count as appropriate and sufficient claim, evidence, and reasoning. As discussed above, the specific rubric differs from the base rubric in that it is specific to a task and shows clearly what content knowledge the students should apply. Appendix C provides the specific rubric for the predator and prey task.

Concluding Comments

Developing scientific explanation tasks and specific rubrics is challenging. Yet once developed the tasks and rubrics can help you better assess students' understanding of the science content as well as students' reasoning behind their understanding of phenomena. Moreover, engaging your students in constructing scientific explanation helps them develop an understanding of science and the scientific practice of explanation. As discussed in the National Science Education Standards (2000) students constructing explanations is one of the essential features of doing inquiry. Providing specific feedback is critical for supporting students in developing this understanding.

Using rubrics can allow you to determine students' strengths and weaknesses, which can inform your future instructional design. For example, if you find that your students are having difficulty differentiating between evidence and opinion or that they are having a hard time with a particular science concept, like understanding that mass is not a property, this can help focus your future lesson plans. Using the same base rubric across different content areas can also help you develop a richer sense of students' ability to engage in particular scientific inquiry practices. You can use the base rubric across content areas and time to develop an understanding about how students' ability to engage in scientific explanations is developing. Furthermore, providing your students feedback on their scientific explanations can push their thinking and help them develop a richer understanding. As the quote from Miss. Hill at the beginning of the chapter illustrates, engaging in scientific explanation with your students has multiple benefits in terms of both learning and assessment because "It touches on the science, it touches on the writing skills, and it touches on critical thinking."

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Appendix A: 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 counts 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 scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Appendix B: Scientific Explanation: Substance and Properties

<table>
<tr><th rowspan="2">Component</th><th colspan="3">Level</th></tr>
<tr><th>0</th><th>1</th><th>2</th></tr>
<tr><td>Claim –
A conclusion that answers the original question.</td><td>Does not make a claim, or makes an inaccurate claim.

States none of the liquids are the same or specifies the wrong solids.</td><td>Makes an accurate but incomplete claim.

Vague statement, like “some of the liquids are the same.”</td><td>Makes an accurate and complete claim.

Explicitly states “Liquids 1 and 4 are the same substance.”</td></tr>
<tr><td>Evidence –
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).

Provides inappropriate data, like “the mass is the same” or provides vague evidence, like “the data table is my evidence.”</td><td>Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.

Provides 1 or 2 of the following pieces of evidence: density, melting point, and color of liquids 1 and 4 are the same. May also include inappropriate evidence, like mass.</td><td>Provides appropriate and sufficient evidence to support claim.

Provides all 3 of the following pieces of evidence: density, melting point, and color of liquids 1 and 4 are the same</td></tr>
<tr><td>Reasoning –
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.

Provides an inappropriate reasoning statement like “they are like the fat and soap we used in class” or does not provide any reasoning.</td><td>Repeats evidence and links it to the claim. May include some scientific principles, but not sufficient.

Repeats the density, melting point, and color are the same and states that this shows they are the same substance. Or provides an incomplete generalization about properties, like “mass is not a property so it does not count.”</td><td>Provides accurate and complete reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Includes a complete generalization that density, melting point, and color are all properties. Same substances have the same properties. Since liquids 1 and 4 have the same properties, they are the same substance.</td></tr>
</table>

Appendix C: Scientific Explanation: Predator and Prey

<table>
<tr><th rowspan="2">Component</th><th colspan="3">Level</th></tr>
<tr><th>0</th><th>1</th><th>2</th></tr>
<tr><td>Claim –
A conclusion that answers the original question.</td><td>Does not make a claim, or makes an inaccurate claim.

States that they do not have a relationship or that they have the wrong relationship like a parasite and host relationship.</td><td>Makes an accurate but incomplete claim.

Less explicit statement like “Animal B caused the population size of Animal A to decrease.”</td><td>Makes an accurate and complete claim.

Explicitly states “Animal A and B have a predator and prey relationship.”</td></tr>
<tr><td>Evidence –
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).

Provides inappropriate data, like “both lines go up and down a lot” or provides vague evidence, like “the graph is my evidence.”</td><td>Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.

Provides 1 or 2 of the following pieces of evidence: 1. When Animal B entered the environment, the population of Animal A decreased. 2. The two animals eat different food so they are not competing for food. 3. Animal B eats organisms like Animal A so it could be eating Animal A.</td><td>Provides appropriate and sufficient evidence to support claim.

Provides all 3 of the following pieces of evidence: 1. When Animal B entered the environment, the population of Animal A decreased. 2. The two animals eat different food so they are not competing for food. 3. Animal B eats organisms like Animal A so it could be eating Animal A.</td></tr>
<tr><td>Reasoning –
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.

Provides an inappropriate reasoning statement like “they are different animals” or does not provide any reasoning.</td><td>Repeats evidence and links it to the claim. May include some scientific principles, but not sufficient.

Repeats the evidence. Or provides an incomplete generalization about predator and prey relationships, like “predators eat other animals.”</td><td>Provides accurate and complete reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Includes a complete generalization that predators consume prey and that when predators enter a new environment they can cause a drastic decrease in the prey population size.</td></tr>
</table>