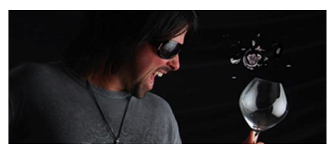
Helping students talk about evidence: A guide for science teachers

One of the central aims of science is to create explanations for events and processes that happen in the natural world. To be accepted in the scientific community, explanations have to be supported by evidence. Explanations and arguing from evidence are also important science practices for students to engage in—in fact they are featured in the *Next Generation Science Standards*.

As teachers, we often find it challenging to engage students in conversations about claims, evidence, and explanations. This is because we are unfamiliar with such talk ourselves. We may be unsure about "what counts" as a claim, as an explanation, or as evidence in a particular situation. This guide will help you understand the basics behind claims, evidence, explanations, and the reasoning that links these together. It will also help you envision how conversations about evidence and explanations can play out in your classroom, and provides tools you can use to support these conversations.

To anchor our descriptions about using evidence, we'll use some common scenarios that are part of science learning at the high school, middle school and elementary levels. We've chosen scenarios in which students use different types of data and information as evidence, and therefore construct different types of arguments.

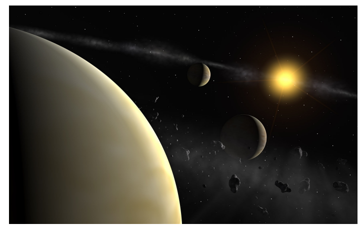


1. *Sound energy example*: This is a case from a 3rd grade unit on the physics of sound. In this scenario young learners were trying to figure out how a singer could break a glass with just the sound energy from his voice. They had just watched a video of this event and discussed how sound travels in waves. After this initial lesson, students became aware of sound in their everyday world. A day after the unit began, several of them came in from recess to share with the teacher that they could hear a soccer ball being bounced on the pavement no matter where they were standing. One student suggested that sound travels like waves on the surface of a lake, out from the source in all directions. Another student added that she thinks the waves travel equally quickly in all directions. These hypotheses became the basis for a round of experiments by the students on the playground. In upcoming sections of this guide we will refer to this round of experiments and how these 3rd graders used them to generate evidence-based explanations.

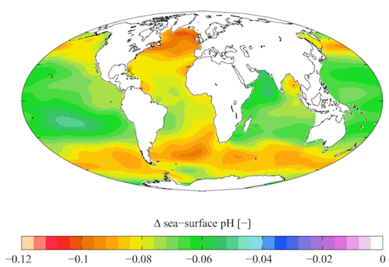
2. *Cellular respiration example*: During a 7th grade unit on cellular respiration, a teacher had her students mix dried yeast and sugar into a flask of warm water. They then affixed a balloon on the top of the flask. As students watched the balloon inflate, they hypothesized about what they were

seeing. One group of students, knowing that warm air tends to rise, believed that this was what's causing the inflation. Another group of students thought that somehow the yeast was giving off a type of gas. The teacher highlighted these two reasonable hypotheses and started a conversation about how these could be tested.

3. *Gravity example*: In a 9th grade unit from an earth and space science class, a teacher had his students exploring the way gravity shapes our solar system. The students had just learned about Newton's Laws of Gravitation, but were confused about whether small bodies of mass in our solar system could exert gravity on larger bodies of mass. They wondered, for example, whether the moon exerts a pull on the Earth. This became the basis for a series of thought experiments and web-searches for "models" of phenomena like this elsewhere in the universe.



4. *Ocean example*: Our final vignette is from an 11th and 12th grade AP class on humans and the environment. This class was project-based and a major portion of the year was devoted to the health and ecologies of our oceans. During this project, students learned that oceans are becoming more acidic over time. The focus of their explanations was why this is happening. Several students were trying to make the case that human-induced changes in the atmosphere have affected ocean acidification. The teacher is asking his students what type of evidence would convince them that this hypothesis is true or what evidence might convince them that some other mechanisms are affecting the ocean.



We'll use these scenarios as examples of how teachers prompt students to generate evidence and then ask students to support claims and explanations with that evidence.

Key concepts teachers should know about evidence and explanation

There is a vocabulary that scientists use to talk about explanation and argument. It's helpful to understand several key terms and we present these now. One important thing for us to make clear is that there is *not broad agreement* in the science education community, or even in the science community as to how claims, evidence, and explanations are defined. Despite this, we think it will be helpful to express what the disagreements are in the literature so you can make decisions for your classroom.

What is a claim? A claim is a statement about some event, process, or relationship in the natural world that you believe to be true. A claim, however, is not simply a statement about trends in data.

You can think of a claim as a small part of a larger explanation. For students just beginning to use evidence, it is easier to focus on using evidence to support a specific claim rather than supporting an entire explanation (which can be composed of several integrated claims). For example, in our 3rd grade sound scenario, a student might claim that "sound travels equally fast in all directions from its source." This claim is only a small part of the larger explanation. The full explanation for why students may all hear a soccer ball at the same time, if standing equally distant from it, would include several other ideas such as: how the soccer ball creates sound in the first place, how air acts as a medium for energy to travel and what that wave looks like at the molecular level, and what happens to the total amount of energy as it disperses outward. Out point here is that a good starting point for using evidence is to defend a smaller grain-sized claim rather than an elaborate explanation for a natural phenomenon.

In the 7th grade respiration example there are competing claims. Some students say the balloon inflated because of warm air and others believe the gas is given off by some biological process. In gravity example as we have described it, no claims have been made yet. In the ocean acidification example, a group of students is being asked to test the claim that human activity is responsible for ocean acidification.

A claim requires evidence (first or second hand data) to be supported and accepted by others in the class. Sometimes a claim can be supported by using logic and known science ideas without invoking new evidence. Although this technically can be considered part of an argument, we usually want our students to cite data, use logic, and use science ideas when they try to support a claim.

Think back now on the sound and the cell respiration examples. That claims made by students in these situations may be tested under controlled conditions and the conclusions may be more definitive. But in the ocean acidification example, the "human activity" claim would require many different types of studies and evidence, and even with substantial amounts of data one could never prove the claim—only support or question it to varying degrees.

Disagreements about what counts as a claim

Some science education researchers use a broader definition for "claim" than we have described above. For them, claims include position statements about social values in science. For example, one might make the claim that animals should not be kept in zoos or that countries should invest more in renewable forms of energy. These types of statements and the questions they generate are very much worth studying. Arguments for or against can be shaped by information and logical reasoning but they are also shaped by values. These claims are about "what should be done" rather than explaining why something happens. For the purposes of this document we will focus on claims as statements that theorize what might be causing particular natural phenomena (event or process).

As we have pointed out, a claim can be thought of a statement that is part of a larger explanation for why a phenomenon (the soccer ball sound, the balloon inflating, the movements of the planets, the shift in ocean pH) unfolds the way it does. It is possible to make and test claims that are not about a phenomenon. For example one could ask students to test the claim that water and vinegar are chemically different substances. Evidence could be used to support this claim, but such a claim is not part of a larger explanation for a phenomenon. We will not focus on these types of claims here, because they are not typically part of authentic science practice.

What counts as an explanation?
Scientific explanations account for natural phenomena by describing how unseen entities or processes cause observable events. Specifically an explanation is about some event, process, or structures that we cannot directly observe. In the sound example we cannot "see" the waves or their energy but we can gather evidence for how they behave. In the respiration example we cannot observe molecular-level interactions. In the gravity example we must rely on indirect evidence that planets exert an attractive force. In the ocean example there were no chemical tests conducted of the hydrosphere until the last two centuries, and in addition, any human effects on the atmosphere happen at such a large scale that, ironically, they are "invisible" to direct observation.

Teachers often ask students to produce descriptions of phenomena rather than explanations. For example, a description of condensation appearing on the outside of a cold glass of water differs from an explanation for condensation. The description emphasizes observable features of the phenomenon such as the cooler temperature of the water in the glass and the presence of droplets on the outside of the glass. In contrast, an explanation for condensation emphasizes unobservable processes such as molecular motion and energy, employs key scientific ideas and theories.

There is considerable ambiguity in the research literature and in classroom practice around the various meanings of explanation. This may be due to the ways the word "explain" makes its way from everyday conversation into the classroom. In the science education literature, it is common to see "explanation" used as a clarification for the meaning of a term or laying out of one's reasoning about a problem. For example, in science classrooms students are frequently asked to "explain their reasoning" while solving a problem ("Can you explain how you calculated the amount of force needed to lift that load with the pulley system?"), to "explain the meaning" of a technical phrase, or to "explain the results" of an experiment. These are not causal explanations. However, they are part of authentic communicative practice in the daily work of scientists who clarify ideas and findings for each other and for various audiences.

What is the difference between data and evidence?
Evidence is data that is used to support a claim or explanation. This can be data generated by a single observation (a ball bouncing on the playground from our 3rd grade

scenario), it can be the result of an experiment, or it can be the result of other kinds of systematic measurements or observations. Observations (data are observations that are systematically collected for a specific purpose) can be taken by using one of your senses directly (sight, sound, touch, smell, taste) or by using an instrument that extends your senses (a microscope, pH paper to test if something is acidic or basic, a thermometer, satellite imagery). This is a good place to repeat that data only becomes evidence when it is used to support a claim.

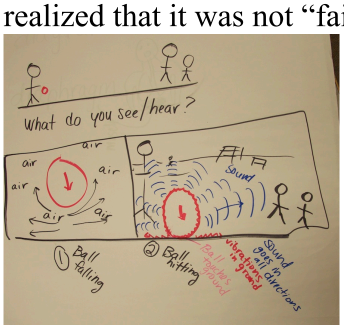
Observations do not have to be data that is collected by you, you can use "second-hand" data that was collected by someone else. With the Internet, it is now possible to access a great number of data tables and graphs that are quite reliable and suitable for use in K-12 science classrooms.

When you analyze data, it means that you have organized it so that you can see patterns in the observations. Analyzed data can take the form of a graph, a table of data, or a pictorial representation of observations. Sometimes when you engage in scientific argument you have to discuss whether the way you collected data will allow you to see accurate patterns or whether you have collected the right kind of data in the first place. Perhaps there were not enough observations to draw conclusions, or the data was collected inaccurately. These all can undermine the credibility of your data when you use it as evidence.

How students can generate different kinds of data to be used later as evidence for their claims

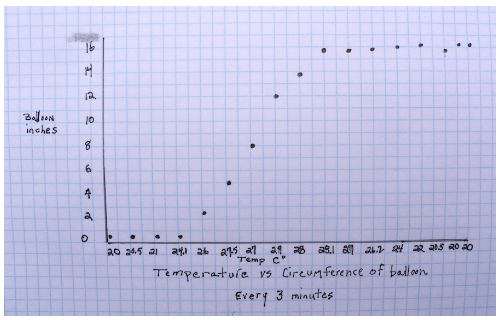
To illustrate the variety of observations that can be generated or used in testing a claim, we return to our four cases.

The 3rd grade classroom is an example of first-hand data collection from a single event (not a traditional experiment with a control group and a comparison group). The teacher discussed the idea of a fair test with students. If some students think sound waves go out in all directions with equal speed, how could we test that with the soccer ball on the playground? Some students suggested that one of them stand in the middle of the playground with the soccer ball and bounce it once. The rest of the students would stand in different places and shout when they heard the bounce. The teacher knew the limitations of this but allowed the students to try it out. On the playground the students realized that it was not "fair" because some students were close to the ball and others

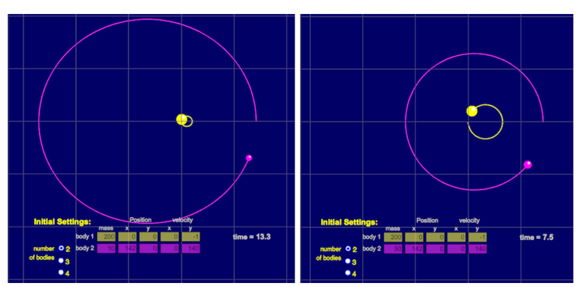


were farther away. After several trials and discussions, they settled on a more controlled test. They formed a large circle about 50 yards in diameter with the student bouncing the soccer ball at the center. With their eyes closed they quickly raised their hands when they each heard the bounce. Two students were recording when the students raised their hands. When they went back into the classroom the students decided to represent the data as a drawing, which showed who raised their hands earlier than others and who raised them later, to see if there were any real differences in the direction or speed of sound.

In the 7th grade life science classroom, students collected first-hand data from a set of "proof-of-concept" experiments. One group of students believed that the balloon on the top of the flask was inflating due to warm air rising. Another group believed it was due to the yeast giving off some kind of gas. The teacher decided to arrange students in groups of four, two of whom believed the "warm air" hypothesis and two who favored the "yeast-gas" hypothesis. The teacher asked them to consider "How do you know it is the warm air and not some gas being given off by the yeast?" Over the next couple of days, the class read more about cellular respiration by fungi and the students who favored the yeast-gas hypothesis reasoned that the gas might be carbon dioxide. When the groups of four got together again they asked each other "how would we know if it is carbon dioxide?"

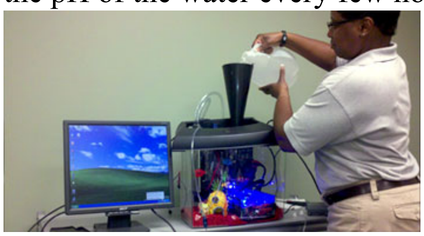


The students then came up with two experiments. The first was to test the warm air hypothesis. They placed a two-holed rubber stopper on top of a flask with a small thermometer in one of the openings, suspended above the mixture of yeast, sugar and warm water. They placed the balloon over the whole apparatus and recorded the air temperature as the balloon inflated. They continued with the readings to see if the balloon would remain inflated even after the air temperature had dropped back to normal levels. The students conducting the warm air experiment found that the balloon remained inflated long after the air in the flask had dropped to room temperature. They repeated the experiment several times and had the same outcomes. The second group wanted to know if the gas in the balloon was carbon dioxide. They learned that carbon dioxide was heavier than room air and that, if it was in the balloon, it could be captured, then poured carefully into the bottom of a flask. They could then place a burning wood splint into the flask to see if it would go out. Students doing the yeast-gas experiment released the gas into the balloon into a flask, then inserted a burning wood splint at the bottom of the flask. The flame was extinguished as soon as it was placed in the flask. These students also repeated this experiments several times.



In the earth and space science classroom students knew that they could not do any kind of "hands-on" experiment with planets and stars. But they could collect data in a systematic way with a computer model. They found a simulation developed by a well-regarded university astrophysics department that would allow them to create their own solar system and designate how much mass each body had, how far planets would be from the host star and the speed of the orbits. They then collected data on the movement of the star as planets of various sizes orbited. They found that under certain conditions, the star appeared to be pulled in a small elliptical orbit. This seemed to be most noticeable when there was a planet of large mass that passed closely to the star.

In the humans and the environment class, the students decided to collect data in two different ways, in order to test the claim that ocean acidification was linked to human activity. One group of students looked up historical data on how the oceans have become increasingly acidic and compared that against other tables and graphs of data showing the total amount of greenhouse gasses in the atmosphere over the past 100 years. Another group of students decided to create a small model of the ocean by using an aquarium. They filled it with water and recorded its pH. They then placed a lid on the tank and pumped small amounts of carbon dioxide into the space above the water. They recorded the pH of the water every few hours for about a week and found that the water did become more acidic over time. They were not sure if this was due to something other than the carbon dioxide. They then conducted a parallel trial with the same equipment but without the carbon dioxide. They found no increase in the acidity of the aquarium water.



When we look at all four classrooms we see a wide variety of legitimate strategies for collecting data. Note that this last type of data collection with the aquarium was the only one of our examples that could be considered a controlled experiment. In the table below the different strategies for generating data are summarized.

Strategies for generating data to be used as evidence

Scenario	How data was generated or used
Sound energy unit	First-hand data collected, each students' response to sound treated as a data point.
Cellular respiration unit	First-hand data collected from "proof of concept" activities
Solar system gravity unit	Data generated by a computer model of a real system
Ocean acidification unit	Second-hand historical data gathered. First-hand data gathered by using a physical model in a controlled experiment

What kinds of reasoning is used when arguing from evidence?

Reasoning is a way of talking about how your evidence supports a claim—it connects the evidence with the claim. You can't just say "This data is evidence that supports that claim." This is one of the most challenging conversations you can have in a science classroom. Why? Students have to be able to:

- articulate what their claim or explanation is
- describe the data or observations and the conditions under which they were gathered
- describe why that data (evidence) supports the explanation or claim.

We will state the basic framing of an argument here, but our generic example is actually harder to understand than the examples from the classrooms we describe later. In the box we see a more extended argument than you might expect to hear in the classroom, but we wanted to include as many dimensions of an argument as possible. Within a class setting, students would be challenging each other at any point in the argument, perhaps offering different interpretations of what should be included in the sentence frames shown below.

> *Our claim can help us explain data that we see—it "fits" the data.*
>
> *Here is my claim* […we believe that X is caused by ….OR we believe that Y has a role in how Z happens…].
>
> *If this claim or explanation is true, then when I look at this data I would expect to see* [this particular result or this outcome].
>
> *The reason I'd expect to see this is because I collected data from a situation that is really close to the real thing we are studying, and if we had these outcomes it would mean that* [state a brief causal chain of events—this chain has to be consistent with known science ideas/facts].
>
> *We did see the data pattern we expected. We believe this supports our claim.*
>
> *If our claim was* **not** *true, then I'd expect to see* [a different set of patterns the data or a particular outcome]. *But we didn't see that outcome so this reasoning also supports my claim.*
>
> *There may be other explanations for the data, such as ______, or ______, but this does not seem likely because __________.*

A well constructed argument does not have gaps, or places where you need to make big inferences about what happened or why. You don't have to assume too much for events that we don't have direct evidence for. If we now take our cases one at a time, we can fill these blanks in with reasonable responses.

In the 3rdgrade unit on sound, the sentence frames listed above may be filled in this way (with a lot-lot-lot of scaffolding by the teacher).

> *Our claim*: Sound waves go out in all directions from the source at the same speed.
>
> *If this claim is true:* then when we did the soccer ball test, we would expected to see that all the students would raise their hands no matter what direction they were from the soccer ball. Also, they would raise their hands at the same time. We did see this.

> *Here's the reason I'd expect this*: sound waves travel out like the waves on a pond. The soccer ball makes the sound. If it goes equally fast in all directions then the wave should get to each person at the same time. But only if they were the same distance away from the source.
>
> *If our claim was not true*: then sound would only go in one direction and only a couple people would raise their hands, or they would raise their hand first, but that did not happen.
>
> An alternative explanation for all students raising their hands at the same time? It could be that some students were not keeping their eyes closed as we asked them to, and they just responded when others put their hands up. But this is unlikely because we tried it once with our backs to the middle where students could not easily see each other, and they still all raised their hands at the same time. So this explanation is not a very good one.

If we use our 7th grade cellular respiration unit, the argument for the "hot air" claim may go like this:

> *Our claim*: Hot air was expanding the balloon, which is less dense than cool air, so it was rising.
>
> *If this claim is true*: We would expect that the balloon would inflate when we put warm water in and deflate as the water cools.
>
> *Here's the reason I'd expect this*: The warm water is in contact with the air. The air molecules would begin to move faster and become less dense, causing the balloon to inflate. When the water cools, the air would become more dense, like the room air. This would make the balloon deflate.
>
> *If our claim was not true*: The balloon would stay inflated even after the water and air cooled.
>
> This is what we saw: The balloon stayed inflated, so the data does not support out claim.
>
> *There may be other explanations* for the data, such as the yeast giving off a gas and this is more likely of a claim because the balloon would remain inflated with the new gas, no matter what the temperature (experienced teachers will note here that students will not give up on their claims this easily, this is an idealized kind of reasoning that we are presenting).

For the 9th grade earth and space science unit, the argument about gravity might go like this:

> *Our claim*: Small planets do exert a gravity pull on larger planets or stars.
>
> *If this claim is true:* Then when we looked at the computer simulation we would expect to see the larger planet or star being pulled toward the smaller body and the larger body would travel in a tiny circle or ellipse over time.
>
> *Here's the reason I'd expect this*: Because the small body has a small mass, and mass always exerts some gravity, there would be a small constant pull on the larger body. Because the pull is toward the smaller body, then as the small body orbits the bigger one, it would pulling in different directions over time. This is what we actually saw in the data.
>
> *If our claim was not true*: then there would be no movement of the larger body over time. But we did not see this.
>
> *There may be other explanations* for the data, such as the star just being "wobbly" but this does not seem likely because there are no forces we know of that would make a star wobbly.

For the AP Humans and the Environment unit, the argument may be like this:

> *Our claim*: Human activity has acidified our oceans to a significant degree.
>
> *If this claim is true:* I would expect to see that when we look at historical data, there would be a correlation between the rise of industrial activity by humans and a rise in ocean acidity.
>
> *Here's the reason I'd expect this*: because industrial activity releases carbon dioxide in the atmosphere as a result of burning fossil fuels. The atmosphere is in contact with the vast surface of the ocean and can be absorbed by the ocean. We know that carbon dioxide is soluble, meaning that it can dissolve into liquids. Then carbon dioxide is absorbed into water, it creates ions that acidify the water. We do these patterns across the past few hundred years, which supports our claim.
>
> *If our claim was not true*: we would expect to see no correlation or an inverse correlation, but we did not see this so it supports our claim.
>
> *There may be other explanations* for the data, such as natural variations in ocean chemistry, but this does not seem likely because there are no known ways for acidity to happen on a global scale, and if we have natural

variation, we'd probably see cycles over time of acidity going up and then back down. We don't see those cycles.

It is worth noting again at this point that these are highly idealized arguments, students would need all possible forms of support for doing this kind of intellectual work. This would including the teacher modeling, providing examples and counter-examples of arguments, using discourse guides for talking in these ways, using guides to describe civil kinds of interactions among students who disagree or have different views about the validity of evidence or how arguments are stated. We expand on these ideas in the next section.

Helping students to reason with each other about evidence

Getting students to reason like this is challenging. We recommend that you start talking about evidence early in the school year. Take some vignettes from authentic science situations such as the ones we've described, where hypothetical students in these scenarios use evidence to support ideas. Have your students analyze what counted as an explanation, what was used as evidence, how students in the scenario argued with that evidence. You may want to model this kind of talk for students. Be explicit and point out what moves makes a good argument and what parts of the argument a person is using.

It will take time for students to understand the vocabulary of claims, evidence, reasoning, etc. And it will take time for them to understand the expectations that you have for their conversations about explanation and argument. Later you can do a relatively straightforward science demonstration for which there might be different hypotheses generated. This should be done after students have had some science content knowledge to use in generating data, using evidence, and creating explanations. You can ask how you might collect data to help answer a question of theirs or test a hypothesis, or you can define specific ways to conduct observations. After they have collected and analyzed the data, or accessed and made sense of second-hand data, provide sentence frames for students to work with that simply ask them to state their claim, then cite the evidence that they feel supports the claim. You then have to verbally walk them through your own reasoning process about why that claim fits with the data.

So, here are some suggested strategies to use in combination with one another:

- Start with an authentic but understandable case where scientists gathered data to test a claim. Discuss how data was gathered, then used as evidence.
- Model (think out loud) how you might dissect evidence based arguments.
- Be explicit about language like data, observations, claims, reasoning, explanations, argument, etc. Use these words in context whenever possible.
- Provide sentence frames to support written and spoken attempts at argument.
- Allow students frequent practice with these kinds of reasoning and talk.
- Let students create public artifacts of their reasoning so that other students can learn from them and respond to them.
- Create tools like public records of students' claims and evidence so as a group you all have something to refer to. One poster that has helped students judge the

quality of claims is called "How good is your hypotheses?" Students refer to these four criteria all throughout the unit to get conversations going. By the way, a hypothesis in this case is very much like a claim. We realize that there are "official" ways that these terms get used in science, but for learning situations in classrooms the distinctions do not always matter. There's what's on the poster:

How good is your hypothesis?

Does it pass this test? ***"The likelihood test"***
How likely is it that the events in your hypothesis can actually occur? Are there parts of your hypothesis that depend on really unlikely things happening?

Does it pass this test? ***"Fits with all data patterns"***
Can the hypothesis explain most or all data patterns?

Does it pass this test? ***"Based on known science"***
Is the hypothesis itself based on well known science knowledge like facts, laws, theories?

Does it pass this test? ***"Based on reliable data"***
The hypothesis has to be based on data that really measures what is important, the data has to be reliable and credible.

Summary

The *Next Generation Science Standards* features evidence-based explanations (pretty much the same thing as argumentation). But these conversations are complex and unnatural ways of talking in a classroom It requires teachers to work together in collaboration to find out what will work for students, what kinds of tools will need to be developed and in what sequence of experiences will work for students. Perseverance on your part will be a key ingredient for success!