ARGUMENTATION AND EXPLANATION

Tools for Using Them Together While Keeping Them Separate

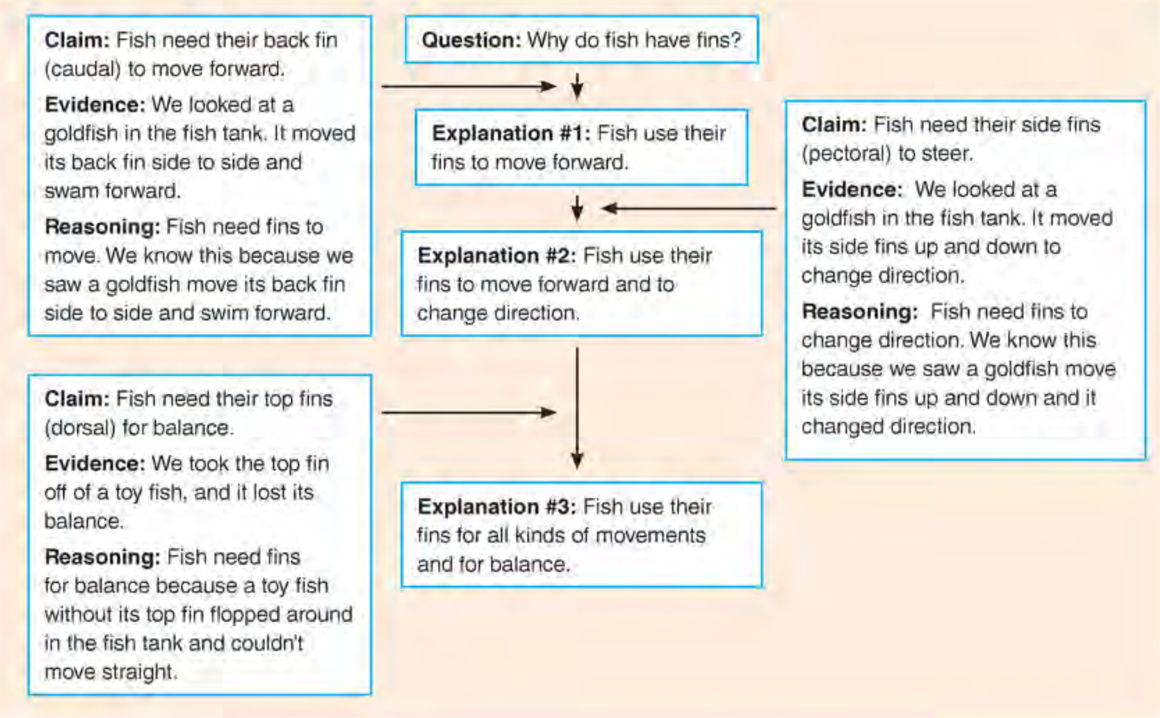
by Bryan Flaig

When the National Research Council's *A Framework for K–12 Science Education* was published in 2012, questions were raised about the need to distinguish between two of the science and engineering practices: Engaging in Argument from Evidence and Constructing Explanations. On one side, Osborne and Patterson (2011) argued that the distinction was necessary, saying that "a lack of clarity of fundamental concepts" in the practices could lead to confusion among teachers and students alike.

On the other side, a rebuttal by Berland and McNeill (2012) countered that:

> "… the jury is still out with respect to whether and how educators should differentiate between the scientific practices of explanation and argumentation in K–12 classrooms."

FIGURE 1 Arguing for evidence in an explanation



Since these papers were published, the lack of clarity and direction about how to use the two practices has created confusion among educators. Even though claims are a distinct feature of arguments (Osborne and Patterson 2011), it is not uncommon to find lessons promoted online where claims are equated with explanations in frameworks using claims, evidence, and reasoning (CER) (see Resources). One source of the confusion seems to stem from work by McNeill et al. (2006) in which they proposed using a framework called "scientific explanation" that purposely conflated the two practices of explanation and argumentation using CER. Later, McNeill explained the reasoning for conflating the practices this way:

> "We saw the overarching structure of the framework (CER) as being an argumentation structure, yet we wanted the students to use the framework when explaining phenomena. We chose to refer to the framework as scientific explanation instead of scientific argumentation…" (2009).

Here, the two practices were muddled into one. This same scientific explanation framework that conflated explanation and argumentation using CER was also the subject of a book by McNeill and Krajcik, *Supporting Grade 5–8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing* (2012). The book gained popularity among educators as an *NGSS* lesson-planning guide for using argumentation and explanation.

Problems and solutions

The purposeful conflation of the two practices has resulted in several problems for science education:

- professional development (PD) providers often use the tools and words associated with argumentation or explanation for similar purposes;
- teachers are confused about how to meet the goals of the National Research Council (NRC) *Framework* because they don't understand the definitions of *argumentation* or *explanation*; and
- students are unsure about how real-world science is done when they don't understand how the practices are actually used (Osborne and Patterson 2012).

One way to help avoid the ongoing confusion is to develop a framework using graphic organizers and templates to separate the two practices, while still allowing them to serve one another. In this way, PD instructors can provide clear and useful tools for identifying and using the practices, teachers can design science lessons that align with the learning goals of the NRC *Framework*, and students can see how science is practiced while receiving valuable feedback about how they use argumentation and explanations, distinctly.

Argumentation and explanation work together but stay separate

In science, there are two ways that argumentation and explanation work together (Osborne and Patterson 2011). First, a question is asked in the form of "why" or "how," an explanation is proposed (hypothesis), and arguments are made (CER) about the strength or validity of information used to support the explanation. As the initial explanation gains acceptance, a clearer explanation can emerge (see Figure 1).

In the figure, notice that each CER is kept separate from the explanation. In this example, it's not hard to imagine that students could make claims about evidence that doesn't support the explanation. The role of the teacher would be to facilitate a classroom discussion (argumentation) and provide students with opportunities to defend their interpretations of the evidence.

The second way that argumentation and explanation work together in the science classroom

FIGURE 2 Arguing alternative explanations

Question: How do the planets move?

Ptolemaic Explanation: The Earth is the center of the universe, and the planets orbit the Earth.

Copernican Explanation: The Sun is the center of the universe, and the planets orbit the Sun.

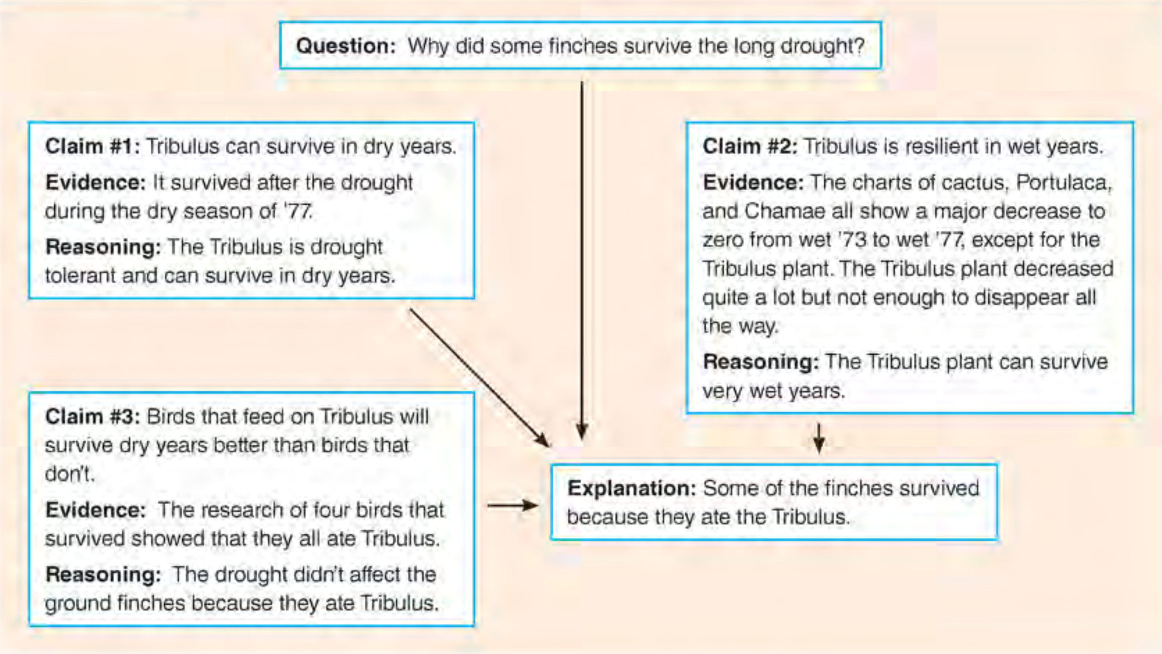
Claim: The paths of the planets around the Earth are circular, and they contain epicycles to account for retrograde motion.
Evidence: Ptolemy could predict the paths of the planets using his model. Epicycles show why some planets appear to move backward periodically.
Reasoning: The Earth is the center of the universe because Ptolemy's model successfully predicted the paths of planets using epicycles.

Claim: The planets follow circular paths around the Sun.
Evidence: Copernicus was able to predict the paths of planets with more precision than Ptolemy. His model did not require complicated features, like epicycles.
Reasoning: With the Sun at the center of the universe, Copernicus could predict the path of planets with a high degree of accuracy. His explanation also avoided complicated features like epicycles, making it easier to use.

Claim: Earth is not the center of our Solar System.
Evidence: Galileo's observations of the moons of Jupiter showed that they orbit Jupiter and not Earth.
Reasoning: Since Galileo showed that some moons orbit other planets and not Earth, the Earth is not the center of our solar system, or the universe.

Final Argument:
Claim: The planets in our solar system orbit the Sun.
Evidence: The Copernican model accurately predicts the positions of planets with the Sun at the center. The model does not require epicycles, so it is the simpler model. Galileo's observations helped confirm that objects in our Solar System do not orbit the Earth.
Reasoning: Since the Copernican explanation of the motion of planets can predict the location of planets, is less-complicated, and is supported by evidence from Galileo, the Copernican explanation is a better explanation.

FIGURE 3 Separating arguments from explanations



is in arguing alternative explanations for a single phenomenon. One historical example is the Ptolemaic and Copernican explanations for the motions of planets in our solar system (Osborne and Patterson 2011) (see Figure 2).

What happens when practices are conflated? A graphic fix!

Let's examine the consequences that result when argumentation and explanation are combined into a "scientific explanation" framework. In the following example from Berland and Reiser (2009), students were trying to explain or argue about why some birds survived during a drought on the Galapagos Islands.

> "We believe that the reason some of the finches survived was because they ate the plant that was able to survive without water called Tribulus. The charts of cactus, Portulaca, and Chamae all show a major decrease to zero from wet '73 to wet '77, except for the Tribulus plant. The Tribulus plant decreased quite a lot but not enough to disappear all the way. It survived after the drought in the dry season in '77. The research of four birds that survived showed that they all ate Tribulus. Which means that the drought didn't effect [sic] the Tribulus plant, which didn't effect the ground finches that ate it. According to the information we found, our hypothesis is correct. They both said that the Tribulus was the best surviving plant of the drought in '77, which didn't effect those who ate it."

The first sentence acts as a claim ("We believe that") and as an explanation (Osborne and Patterson 2012). Notice, later, the phrase, "... our hypothesis was correct." It seems to indicate that the students were referring to their claim as a hypothesis, but it is unclear. If the previous example were organized graphically, students' intentions and use of the practices would be easier for a teacher to understand (see Figure 3).

In Figure 3, the CERs are distinct arguments that contain separate pieces of evidence to support the explanation. One thing that is much easier to see when the "scientific explanation" is broken up is that claim 1 is not well-supported by evidence. In addition, claim 2 is only vaguely connected to the explanation. When students' understandings and misunderstandings are made visible, the teacher can provide constructive feedback for achieving clear learning goals and for clarifying how science is practiced in the real world.

Working with professional-development providers

During an argumentation and explanation PD workshop that I attended in the summer of 2015, the instructors also used a framework in the style of "scientific explanation." No distinction was made between the two practices. Their "explanation" template followed this outline:

Question: What is the question you are trying to answer through explanation?

Evidence: What have you observed? What data have you collected?

Scientific principles: What scientific principles does your evidence refer to?

Claim: Answers the question based on your evidence.

Explanation: Explains how the evidence answers the question.

Here is how it was used by teachers in a density investigation:

Question: Why do things sink or float?

Evidence: Density blocks sank and floated, depending on their masses. Some blocks were attached with rubber bands to one another, and in general, the ones with larger volume floated. Mass didn't seem to be a factor. When data were plotted, mass versus number of blocks in the raft, the graph showed a positive correlation between mass and number of blocks.

Scientific principles: The relative densities of materials determine whether they sink or float, where $d = m/v$.

Claim: Objects sink or float because of the relative densities of materials.

Explanation: The relative densities of the two materials will determine which one sinks and which one floats. For our "rafts," we had a three-cube raft of 82.3g that sank, while a six-cube raft of 92.5g floated. This evidence supports our claim because it disproves mass alone as a factor. In addition, the density of all the rafts and cubes that floated is less than $1 g/cm^3$, which is the density of water, and the density of cubes that sank is greater than $1 g/cm^3$.

In this example, the claim is really a *hypothesis*, or a tentative attempt at an explanation of density. There is little doubt behind this claim because it can be directly observed and is, therefore, not arguable. Different pieces of evidence are combined, such as mass, volume, and graphical data. The reasoning for using the evidence is buried in the explanation. The final explanation, at the bottom of the template, begins to steer us toward a definition of density.

Later, teachers were asked to apply this explanation template to a lesson they created. It quickly became apparent that the teachers did not understand the differences between the tools of argumentation or explanation. Here is an example lesson presented by one of the teachers:

Big bang theory CER

Background: Students have already learned about the steps of the big bang theory.

Question: Does the evidence help support the big bang theory?

Evidence 1: Edwin Hubble's discovery that galaxies were moving away from the Milky Way.

Evidence 2: The ratios of hydrogen and helium in the universe matched what you would expect to see if the universe acted like one giant, exploded star.

Evidence 3: The discovery of cosmic microwave background radiation.

Claim: Almost all astronomers agree on the theory of the big bang. The entire universe started as a singularity and is still spreading apart, with distant galaxies spreading out in all directions.

The idea for the lesson makes sense—to justify the evidence used to explain the big bang theory—but the execution is a mess. It is not the teacher's fault. She was trying to use the muddled "explanation" template presented in the workshop. First, the question she used does not fit easily into an explanation format. (Remember, explanations are best designed around questions asking why or how.) Her question is more appropriate for a claim, which could be argued. Second, where she writes "Claim," we see an explanation—sort of. It would have been better to simply provide the existing big bang theory (explanation) in place of this confusing claim and have students argue about the evidence. However, the "explanation" template does not provide clear instruction about how to structure this concept for students. Let's try to fix that.

What if we looked at the lesson using a historical lens and examined each piece of evidence as a separate CER? For her question, the teacher could have asked, "How did the universe begin?" Then, students could argue claims for each piece of evidence that supports the big bang theory. Alternatively, students could have looked at the explanations scientists used

FIGURE 4 An explanation template

The Big Bang Theory	
Question: How did the universe begin?	
What information did scientists use to argue for the big bang theory as an explanation to the question? Include: Data, investigations, experiments, observations, and examples from your life.	**Scientific Principles** What scientific principles are being used that also strengthen the arguments?
1. **Claim:** The universe is expanding. **Evidence:** Hubble's data shows that galaxies are moving away from each other. **Reasoning:** Since galaxies are moving away from each other, it's likely they began moving from the same location at some point.	Objects in motion remain in motion unless acted on by an opposing force.
2. **Claim:** The universe started out like an exploding star. **Evidence:** When we measure the ratios of hydrogen and helium in the universe, we see similarities to the ratios that exist in exploding stars. **Reasoning:** Since the ratios of hydrogen and helium in the universe match those found in exploding stars, the universe must have started as an explosion from a single place.	Stars generate consistent ratios of hydrogen and helium through nuclear reactions.
3. **Claim:** Cosmic background radiation shows that the source of heat from the big bang is still radiating energy. **Evidence:** Measurements of microwave energy are consistent with the energy left over from an explosion deep in the universe. These measurements are the same no matter where you point a microwave antenna in space. **Reasoning:** Since we detect cosmic background radiation coming from all directions in space, and the amount is consistent with a large energy source, there must have been an explosion that started the universe.	Microwaves are a measure of energy. Explosions radiate energy in all directions.
Explanation for the origin of the universe: The universe likely began as an explosion from a single point (singularity) that spread matter and energy in all directions. We see evidence for this explanation in galaxies that are moving away from each other, the ratio of gases in the universe, and in the background radiation emanating in all directions from deep space.	

before the big bang theory, such as the static universe, and compared them to the big bang theory. The teacher could have helped students examine evidence for each explanation (similar to the Ptolemaic/Copernican example).

By examining the historical uses of argumentation and explanation, we can address a key concern from Berland and McNeill (2012) about "*HOW* educators should differentiate between the scientific practices" (emphasis added). The past provides good models. In the previous big bang theory example, a teacher might create lessons to show how evidence was collected over several decades and eventually built to a clear explanation. Each new piece of evidence had to be argued as to whether it was credible and supported the emerging explanation. Darwin's theory of evolution is another example. *On the Origin of Species* explains an answer to the question of why we see such a variety of species on Earth (1869). The chapters of the book can be viewed as CERs supporting key pieces of evidence. Eventually, Darwin develops his explanation that all life on Earth is just "descent with modification through a common ancestry," an explanation that we accept as a theory today (Gould 2001).

An explanation template using CER

In place of a graphic organizer, an explanation template can also help students organize their ideas in a way that separates arguments from explanations while showing the historical uses of these science practices. Figure 4 shows a completed form that students might create using an explanation template for the big bang theory.

By avoiding the conflation of argumentation and explanation and developing useful tools for teachers, we keep the practices more clearly defined and aligned with the goals of the NRC *Framework*. These tools, in the form of graphic organizers or templates, can help teachers better organize lessons with structures that provide students with more authentic experiences and provide teachers with opportunities to offer constructive feedback to students. I think we should be moving in the direction of clarity and away from accepting conflation. It is my hope that attempts at these types of strategies can generate more ideas and discussions to improve science education. ■

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Resources

A web search on the words "CER and explanation" turns up lessons that often conflate argumentation and explanation and can create confusion about how to use the practices correctly. The two links below are prime examples:
http://tinyurl.com/kbe2qor
http://tinyurl.com/o8lvnuw

Bryan Flaig (*bflaig@sbcglobal.net*) is a former middle school science teacher. He is currently a science curriculum specialist with Lawrence Hall of Science in Berkeley, California.