Fostering Argumentation Skills

Doing What Real Scientists Really Do

by Douglas Llewellyn and Hema Rajesh

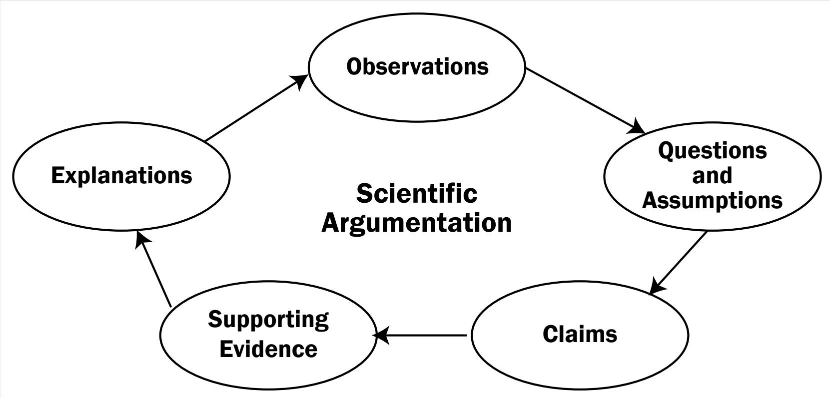
Elementary and middle school teachers often provide students with hands-on activities or even inquiry-based investigations that emphasize science process skills such as observing, classifying, identifying and controlling variables, hypothesizing, experimenting, and collecting and analyzing data. These activities and investigations are frequently accompanied by the teacher saying, "Wow, now you're acting like a scientist." Unfortunately, this type of comment often reinforces the misconception that the "scientific method" is the Holy Grail with which experts investigate the natural world. Without a realistic perception of the work of real scientists, there may be little hope of achieving national scientific literacy. The purpose of this article therefore is threefold: (1) to illustrate how scientific argumentation paints a more accurate picture of the work that scientists really do and, more importantly, (2) to demonstrate how teachers can foster argument-based science inquiries where students generate arguments to support their claims using relative and supportive evidence, and (3) to show how students can use scientific reasoning skills to analyze and communicate the findings of their investigations.

The case for argumentation is supported by the National Research Council's "Five Features of Science Inquiry" (NRC 2000), in which the NRC states that with science inquiry the learner

- engages in scientifically oriented questions;
- gives priority to evidence when responding to questions;
- formulates explanations from evidence;
- connects explanations to scientific knowledge; and
- communicates and justifies explanations.

From these points, two keywords stand out that reveal the true nature of science: *evidence* and *explanations*. This article will further describe how teachers of science can foster scientific reasoning skills at the conclusion of a lab by emphasizing scientific argumentation—a progression where students (1) investigate questions and assumptions from a puzzling phenomenon or event, (2) use the data from a self-designed investigation to make a claim and justify and defend the claim with supporting evidence, and (3) provide a scientific explanation based on the findings.

FIGURE 1 Scientific-argumentation cycle



What is the structure of a scientific argument?

The progression of a scientific argument frequently commences with an observable event (see Figure 1). This may be presented by the teacher in the form of a demonstration, a discrepant event, an initiating exploration, or any perplexing phenomenon that causes students to raise questions that they can later investigate. The process also involves students declaring what they already know about the event (their prior knowledge) and describing several assumptions as to the causes or promising solutions to the question or problem. In this case, the assumption is a statement that describes a natural phenomenon or a framework to construct a possible answer to the question being studied. It can lead to a tentative answer or solution (hypothesis) to the question.

Next, students design and carry out an investigation and then collect and analyze the data to look for patterns and relationships among the variables examined. From the data and patterns, one or more claims are constructed. The claim is an assertion or conclusion that attempts to answer the original question. The claim is then supported by evidence. The evidence is extracted from that data in the form of observations and measurements, which supports the legitimacy of the claim and is justified and defended via oral presentations or written argument-based lab reports. Finally, students structure explanations during the presentations or reports that account for the claims and evidence.

The illustration in Figure 1 poses an interesting quandary—which comes first, the claim or the evidence? Similar to the chicken-or-the-egg dilemma, in the *formation* of the claim, data and evidence are used to generate the claim. However, in the *communication* of the claim, the evidence supports the claim and is usually followed by the statement of the claim.

Data versus evidence

The difference between data and evidence is sometimes confusing. Simply, *data* are the information and measurements from an investigation. *Evidence* is a particular subset of data an investigator uses to support or refute a claim. Because many students are already familiar with forensic science by way of crime shows such as *CSI*, an example for students is the crime scene, which is usually loaded with data. In the legal system, the prosecutor or district attorney uses the data to make one claim based on selected evidence, while the defense lawyer extracts evidence from the same set of data to make a contrary claim. It is then the jury's responsibility to decide which claim is best proven based

FIGURE 2 Comparing data and evidence

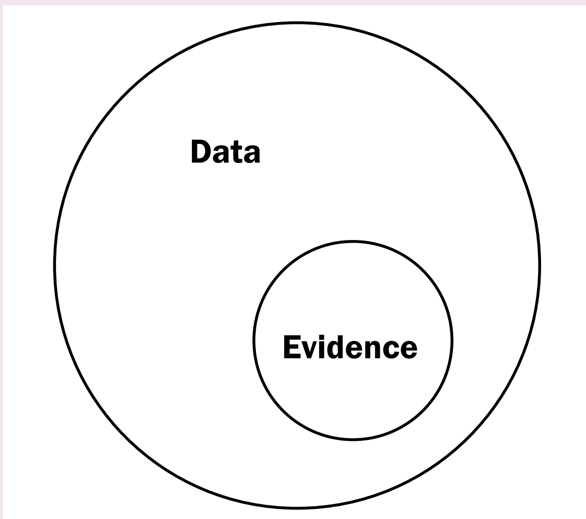
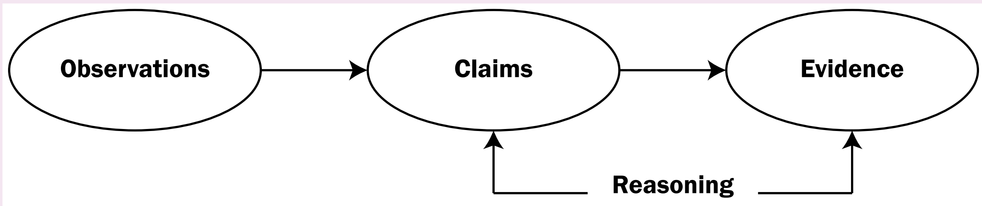


FIGURE 3 Reasoning links claims to evidence



upon the preponderance of the evidence. Hand et al. (2009) provide a clear relationship between data and evidence, showing that all the data collected during an investigation may not be relevant to the question being investigated (see Figure 2). See "Data Versus Evidence: Investigating the Difference" in this issue for additional information on this topic.

Argumentation in everyday life

Whether we realize it or not, we are constantly bombarded with claims by today's media. We hear claims about how to lose weight, how to stop smoking, the effects of global warming, the benefits of herbal medicines, or how to make sound financial investments. During the months leading up to an election, claims by political candidates are repeated in infomercials and flyers that fill mailboxes. Deciding which candidate is telling the truth with accurate and relevant evidence can be a daunting decision. Thus, understanding the connection between claims and evidence becomes a skill extending beyond the science classroom.

Fostering scientific reasoning skills

If scientific inquiry asks, "What if…?," then scientific reasoning asks, "Why…?" Scientific reasoning is the logic behind scientific inquiry. Becoming scientifically literate implies being able to use scientific reasoning skills. In argumentation, students use scientific reasoning skills when explaining how the claim and the evidence are connected. In their oral defenses, students link the claim to supporting evidence by using reasoning skills (see Figure 3). But, like inquiry, we should not expect that reasoning skills develop implicitly. Initially, students need to be explicitly taught and nurtured through concrete experiences of simple, observable discrepant events, where teachers use questions and prompts to elicit "evidence-based" explanations. Before engaging students in scientific argumentation, several pre-activities promoting scientific argumentation can be tapped

FIGURE 4 Day-by-day plan

Day 1	Introduction and discussion of a soil profile.
Day 2	Discussion about the factors that promote soil fertility. Students walked around the school campus to observe the rich biodiversity there and identified rationales about what promoted growth. Safety procedures reviewed.
Day 3	In groups of four, students collected soil samples from different areas throughout the school.
Day 4	Using the school library and online resources, students researched and discussed procedures to analyze the soil samples.
Day 5	Students collected the required materials from the laboratory and started to test their soil samples.
Days 6 and 7	Students completed the test and analysis. Students completed their QCEE sheets.
Day 8	Students prepared charts for their argument-based presentations.
Day 9	Using the QCEE sheets, groups presented their claims and evidence while the rest of the class pointed out strengths and limitations of the findings, often offering alternative explanations and counterclaims.

as students struggle with the task of proposing, supporting, critiquing, refining, justifying, and defending a position. These activities center on students making observations and inferences. Later, through additional practice, they will become more adept at linking claims to evidence.

In one activity (Llewellyn 2007), students are presented with six small, sealed juice or milk containers; each contains a common object such as a battery, a rubber ball, a Styrofoam ball, several marbles, a domino or wooden block, or a penny. Each of the same objects is placed in a clear, plastic baggie so students can easily see it. Students then shake each closed container, make observations using the senses of hearing and touch, and infer which object in the container matches the object in the bag. The container remains closed after students have made all of their inferences. Students need to rely on their observations to make justifiable inferences and conclusions.

FIGURE 5 QCEE template

Question	
Claim	**Evidence**
Explanation	

A second activity (Llewellyn 2007) involves a typical black box model. Here, students are presented with a sealed shoe box containing two wooden blocks glued to the bottom of the inside of the box and a marble. Like with the juice boxes, students make observations to infer the location of the wooden blocks by sliding the marble back and forth inside the box. By drawing an illustration, students can make a model as to the location of the two blocks—hereby making a claim based on the evidence collected.

Mystery Hands is a third activity that is simple to do. The teacher tapes a sheet of butcher paper across the opening of an open door frame. Two holes, about 15 cm (6 in.) in diameter, are made side by side near the center of the paper. A "mystery person," in the hallway side of the door, places his or her hands through the openings. The mystery person can be an adult from the school or another student. Students on the classroom side of the paper approach the hands, make observations about the hands and fingers, and draw inferences about the person on the other side. Is the mystery person a male or a female? How old is the person? What kind of work does the person do?

Similar activities, such as the familiar Track Stories, can be used to have students make observations and inferences (AGI 1984). These basic science process skills serve as rudimentary scaffolding for making claims and citing supporting evidence.

Flaws in scientific reasoning

It is often said that middle school students are good at school-yard arguing, but not at using the skills of argumentation and scientific reasoning. Without explicit instruction, students often make claims based on their opinions and previously held, naive conceptions. Students' lack of prior experiences and opportunities initiates many of their claims and explanations. To help students develop skills in argumentation and reasoning, we need to provide sufficient "think time" for students to give their explanations. This means allowing students to complete their thoughts and responses without interruptions from other students or the teacher. In our fast-paced, time-constrained curriculum, this is a paramount challenge to rise above.

Flaws in students' reasoning can also be overcome by teachers' questions and prompts that promote scientific argumentation. Verbal prompts include the following:

- What assumptions can you make about the observation?
- What is the basis for your claim (or inference)?

- What evidence did you collect that supports your claim, your idea, or your hypothesis?
- Why do you think this is so?
- What do you mean by…?
- Does the evidence support or refute your claim?
- Are the data biased? Are the data reliable?
- How would you interpret the data and evidence?
- What is the relationship between the independent and dependent variables?
- What do the data say or imply?
- What conclusions can you draw from the evidence?
- How does the evidence support or refute your claim?
- How is one variable dependent upon another?
- What explanation can you propose from the evidence collected?
- How do the results support what you expected?
- How do the results support what you already knew about the phenomenon?
- Can you develop an explanation from the results?
- Can you construct a model to support your explanation?
- Were your original assumptions about the question correct?
- How will you defend your findings?

FIGURE 6 Student QCEE template 1

Question: Will this soil sample support good vegetation?

Claim	Evidence
The area from where the soil was taken was arid; it will not be able to support vegetation. The soil has too much sand and gravel.	Gravel = 20% Humus = 7% Clay = 7% Coarse sand = 6% Fine sand = 60%
The humus layer in the soil is low because it formed a smaller layer while the soil was sediment.	Humus content = 7%
The pH would be 7 or 8, as we do not use chemicals that would be either acidic or alkaline on the soil or on plants at the school campus.	pH = 8
We think the water retention of the soil would be low, as the soil has low humus content.	30% per 10 g of the soil
The soil may have some nutrients present because the soil is not disturbed.	The soil has nitrates, sulfates, and iron.

Explanation

From the evidence, we can infer that the soil cannot support heavy vegetation as the humus content is very low. 60% of the soil is sand, which makes it difficult to support the growth of plants. The pH of the soil is 8, so it can support good vegetation. But the humus content is low, so the soil is not fertile. The water-retention capacity is high. This may be due to the presence of clay in the soil, or we might have taken wrong readings. Therefore, we can say that our soil has ideal pH, but other factors are not suitable to support thick vegetation. Maybe over the course of time, humus may enrich the soil due to the biological degadation by the microbes.

One teacher's story

In this section, coauthor and science teacher Hema Rajesh recounts her first experience in integrating argumentation into inquiry investigations at the TVS Academy in Hosur, India. Here is Hema's story:

In grade 9 at the TVS Academy in Hosur, India, students study the factors that promote soil formation. Instead of having them do typical laboratory experiments and write a report, I wanted a different approach that would make the class lively and enable students to justify their results through arguments—just like real scientists do. I was motivated when I read the article "Generate an Argument: An Instructional Model" by Victor Sampson and Jonathon Grooms in *The Science Teacher* (2010). After an introductory soil lesson, I asked students to observe the biodiversity in our school campus, which is filled with over a hundred flowering plants. Students immediately stated an assumption that because the soil supported a great number of plants, it was rich in humus content. This assumption set the ball rolling. The big question students came up with was "What promotes soil fertility?" To explore this aspect of the soil, students decided to identify the pH of the soil, humus depth (along with other layers in the soil), humus content in percentage, water-retention capacity, and qualitative estimation of mineral ions (such as sulfates and nitrates) as variables that impact soil fertility. The timeline for the nine-day lesson is found in Figure 4.

Students first divided themselves into seven groups comprising four members per group. They then chose various locations on the school campus from where they took soil samples for analyses. **Safety note:** Safety glasses and gloves must be worn when collecting soil samples and testing soil. Collection sites must be screened by the teacher for biological and chemical contaminants. The soils were taken from areas where the vegetation was high, moderate, and low. From learning about soil factors in the lower grades, they initially assumed that the humus content varied. Students also came up with another assumption: that the pH of the soil would range from 6 to 8 because the soil was free from chemical pollution that would alter the pH, and because they saw plants growing luxuriantly on the school campus. In regard to safety measures, the proper handling of acids was given prior to the procedure. In addition, while digging in the soil for samples, students were supervised by the teacher and the school gardener.

From the data, students were able to relate that clay and humus content in the soil increased the water-retention capacity of the soil. If the soil appeared red to dark brown, it indicated the presence of iron in the soil. To help students summarize their data as follow-up claims and evidence, I provided them with a question-claim-evidence-explanation (QCEE) template (see Figure 5).

When the groups analyzed the data and documented their claims on QCEE templates (see Figures 6 and 7), they were able to determine whether the findings were concordant or not. For instance, Group 3 had reported that the humus content was only 0.14%, which was very low for the soil. After hearing counterarguments from peers, students in the group agreed that they had made a mistake, repeated their

FIGURE 7 Student QCEE template 2

Question: Is the soil fertility high or low?

Claim	Evidence
The area from where the soil was taken was undisturbed with royal palm trees. Since the soil is undisturbed, we think the humus layer would be high in terms of depth of the soil.	Gravel = 44% Humus = 16% Sandy soil = 40%
The percentage content of humus in the soil would be high.	Humus content = 8%
The pH of the soil must be neutral or slighty basic.	pH = 7
The water-retaining ability of the soil will be low.	4% per 10 g of the soil
The soil may have some nutrients.	The soil contains nitrates, sulfates, and iron.

Explanation

The soil shows only three well-marked zones. Clay is totally absent and the depth of the humus layer is very small. The humus content is medium. The sample does not have clay, which would be helpful in retaining water. As the water is supplied externally, the plants are able to grow. But as the soil is neutral, it is ideal for supporting good vegetation. To enhance fertility we can supply organic manures to the soil so that pH balance is not disturbed. As the nutrients are present in the soil, organic manures will further increase the nutrient concentration in the soil.

experiment, and found that the humus content was 2.6%. During their oral defenses, students were able to argue as to how the soil promoted growth even though the water-retention capacity and clay and humus content were not very high. Each group came away with a justification as to how its soil promoted plant growth in the locality. Later, students decided to extend their study of soil by further analyzing the mineral nutrients in the soil sample and also comparing their sample with soil samples taken from an organically farmed area and an inorganically farmed area.

As the teacher/facilitator in the argumentation process, I had immense satisfaction seeing students negotiate meaning through argumentation while truly working like scientists. Instead of merely conducting the investigations with set procedures and stating the results, students looked for patterns and relationships among the variables and made oral arguments justifying their claims and evidence. Many students have also extended their findings into further investigations. I link up the class with the Soil Research Centre, where they are exposed to new techniques and have access to sophisticated instruments for soil testing and analysis. This gives them an opportunity to work in a well-established laboratory, side by side with professional scientists. In the end, the entire process of generating an argument as an instructional model helped me to modify a traditional lab activity into a highly dynamic process that led to fostering scientific reasoning while promoting the real work of real scientists.

Conclusion

Science teachers should be mindful that two new standards projects, the Common Core State Standards (*www.corestandards.org*) and the Conceptual Framework for New Science Education Standards (to later evolve into the Next Generation Science Standards, see *www7.nationalacademies.org/bose/Standards_Framework_Homepage.html*), emphasize having students develop skills and competencies in scientific argumentation. This places argument-based inquires on the horizon for science-curriculum and professional developers. Thus, in getting ahead of what's to come, science leaders should initiate opportunities where teachers learn to modify their existing inquiry labs into a format where students develop precise claims supported by evidence and justify and defend such claims in oral and written arguments to their peers. During these arguments, other students will be encouraged to pose counterclaims and consider alternative evidence and explanations. Throughout this process, students will gain a realistic view of the nature of science and develop proficiencies in reasoning and communication.

The ability to question, inquire, discover, and express new ideas is a key critical competency for the 21st century. Developing sound scientific argumentation and reasoning skills in school will lead to proficient decision making later in life. According to Carl Sagan, "Both skepticism and wonder are skills that need honing and practice. Their harmonious marriage within the mind of every schoolchild ought to be a principal goal of public education" (1996, p. 306).

Lastly, transformation through scientific argumentation involves shedding outmoded skins and altering our understanding of the dimensions of scientific literacy and the actual work of scientists. Moreover, it reconstructs our attitudes and beliefs about what motivates authentic student learning and the true nature of science inquiry. ■

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