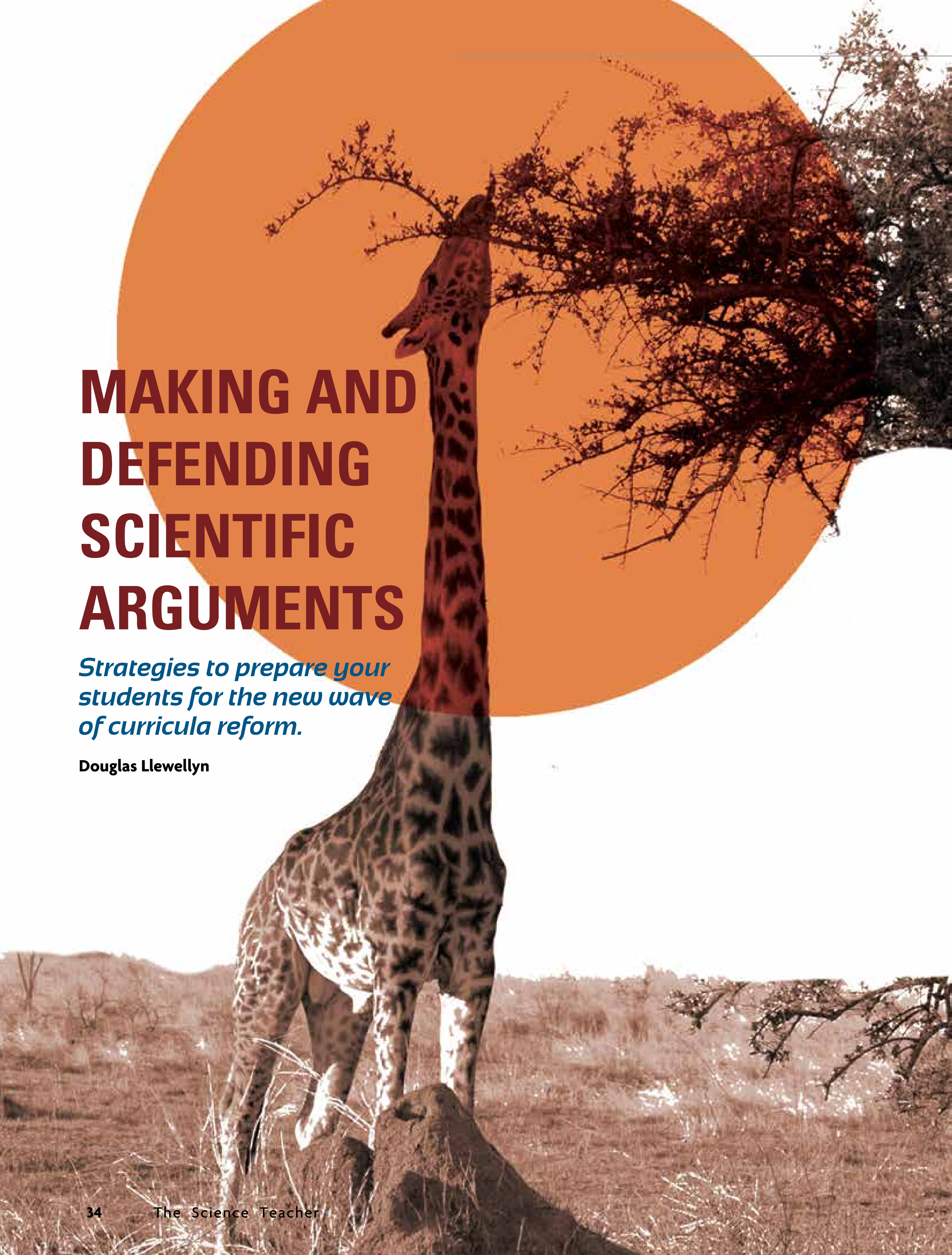


MAKING AND DEFENDING SCIENTIFIC ARGUMENTS

Strategies to prepare your students for the new wave of curricula reform.

Douglas Llewellyn

Since 1996, science education has been guided by the National Science Education Standards (NRC 1996). But now there's a "new sheriff in town" as the *Common Core State Standards* and *A Framework for K–12 Science Education* together become the 21st century's torch bearer for curricula reform in science and other subject areas. A supposition runs through both documents: that for the United States to become scientifically literate, high school students must become proficient in (a) investigating phenomena, (b) collecting and analyzing data, (c) making claims from the findings, and (d) supporting such claims and explanations with evidence to justify and defend their assertions. In light of this new direction in science teaching, this article will address three questions:

- What is scientific argumentation?
- What do the *Common Core* and the *Framework* say about argumentation?
- How can science teachers effectively scaffold and prepare students to make and defend arguments?

Did a meteorite strike doom the dinosaurs?

What is scientific argumentation?

Although students are all too familiar with conventional arguments, scientific argumentation is different. It is a higher-level, critical-thinking skill that students use to propose, support, critique, refine, justify, and defend their positions about a specific (and sometimes controversial) scientific topic. The goal of a confrontational dispute is for one person's point of view to "win" over another's. In scientific argumentation, however, explanations (often in the form of models) are generated, verified, communicated, debated, and modified throughout the course of an argument-based discussion that is ultimately "win win" (Llewellyn 2013). The goal in scientific arguments is to refine and build consensus for scientific ideas. It's true that in a narrow sense, there can be winners and losers in scientific arguments; for example, in the rush to find the structure of DNA, scientists James Watson and Francis Crick—and their argument—clearly prevailed over that of Linus Pauling. But the broader point is that science itself "won" as a more accurate model of DNA emerged. With argumentation, the emphasis is on using empirical and experimental data to build consensus around a scientific phenomenon.

A scientific argument can be divided into six key parts:

1. *Question*: a point of uncertainty often derived from an observable phenomenon, a discrepant event, or a subject of dispute that sparks a discussion or investigation.
2. *Assumption*: using prior understanding to construct a possible answer or solution to the question being studied. At times, students use their *a priori* knowledge to construct a tentative explanation to the question; other times, prior assumptions are misconceptions that cloud analysis of the discussion or investigation.
3. *Claim*: an assertion or supposition generated from the data and findings of the investigation that attempts to conclusively answer the question being studied.
4. *Evidence:* consists of observations and measurements extracted from the data and findings that support the legitimacy of the claim.
5. *Explanation:* an oral or written summary based on the claim that provides an interpretation and justification of the evidence.
6. *Rebuttal:* a counterclaim provided by others as to the validity of the original claim and supporting evidence. At times, others may provide contrary evidence to rebut the original proposed claim.

An interesting question about arguments—similar to the chicken and the egg dilemma—is which comes first, the claim or the evidence? According to Llewellyn (2013), in the *formation* of the argument, selected evidence comes first and is used to generate a claim. In *communicating* the argument, however, the claim usually comes first, followed by corroborating evidence. That is, in forming the claim, students think inductively (parts to whole or specific to general); while in communicating the claim, they think deductively (whole to parts or general to specific).

What the *Common Core* and *Framework* say about argumentation

In 2010, two national standards-based documents were released after a decade of work: (1) the *Common Core State Standards* for English/Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects, and (2) the *Common Core State Standards* for Mathematics (NGAC and CCSSO 2010). The English/Language Arts document refers to scientific argumentation for grades 9–12 (CCSSO 2010, p. 64), stating that to be career- and college-ready by high school graduation, students should be able to

- introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence;
- develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns;
- use words, phrases, and clauses to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims; and
- provide a concluding statement or section that follows from or supports the argument presented.

Therefore, as state education departments and school districts across the country adopt and implement the *Common Core,* the teaching of argumentation skills will be fostered through both English and science, opening the door for teachers of these two subjects to work and plan collaboratively in fulfilling the national standards.

Similarly, the *Framework* (NRC 2012) identifies eight practices for becoming a "critical consumer" of scientific information. The words *argument* or *argumentation* appear 97 times in the 325-page *Framework*. That signals science teachers, curriculum developers, and those who plan professional development for science teachers that this new wave of standards emphasizes argumentation.

Based on the *Framework,* the *Next Generation Science Standards (NGSS)* also fosters reasoning skills through argumentation. Rather than focusing solely on core ideas, professional developers will need to help bring high school science teachers up to speed with the practice of scientific argumentation so they can plan units of study that meet the goals of the new standards.

Developing a plan of action

Each day television, the internet, and other media bombard us with claims about how to lose weight or stop smoking, the effects of global warming, and why one political candidate is better than another. The media make it possible for flimflam artists to distort the truth and mislead the foolhardy (Llewellyn 2013). Students must be taught to distinguish deceptive claims from those grounded in substantial evidence. Fostering scientific argumentation is challenging, however, since students often struggle with proposing, supporting, critiquing, refining, justifying, and defending a position. These skills, much like scientific inquiry, must be explicitly taught and nurtured through concrete experiences and teachers' prompts. The following strategies offer ways for scaffolding students toward weighing the wonder of inquiry with a slight sense of skepticism. The strategies, though sequenced from simple to more involved, can be used in any order, separately or together.

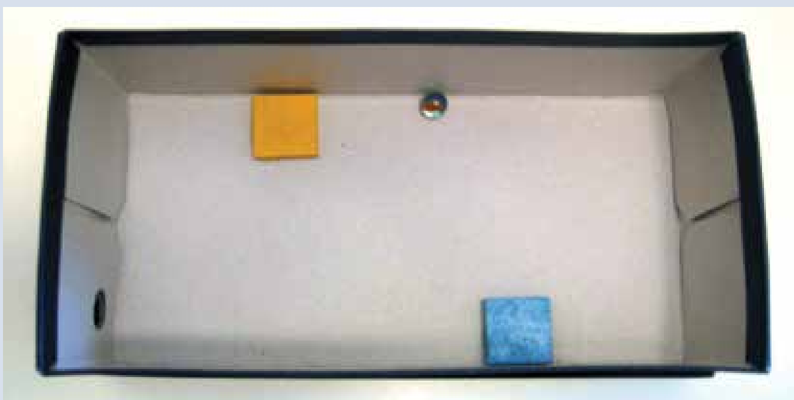
Strategy 1. Making an inference from observations

Teachers ask students to draw inferences based on their observations of several situations. In the first situation, stu-

FIGURE 1

Mystery Box

The "mystery box," containing wooden blocks and a loose marble, is sealed so students can't look inside. Students use other senses to model the inside of the box.



dents observe a "mystery box." This is a cardboard shoe box with two wooden blocks glued to the inside bottom (see Figure 1) and holding a loose marble. The box is taped shut so students cannot look inside. By tilting the box, students can use their hearing and touch (as the marble rolls around) to determine where the blocks are. Then they draw an illustration (or model) to infer the location of the blocks within the box. You can make a variety of mystery boxes by altering the number of blocks and their locations. Alternatively, many varieties of mystery boxes are available commercially.

In a second situation, "Track Stories," students are presented with three frames of animal tracks (see "On the web") and asked to infer how the tracks were made and what kind of animals might have made them. In the end, each student tells a story about how the tracks were formed.

In the Strategy 1 activities, students learn how observations lead to inferences and model building. In these examples, inferences are an ideal introduction to the understanding of claims because they are both assertions and conclusions based on observable evidence.

Note: Readers may already be familiar with mystery boxes as well as the track stories activity for teaching science process skills. Here, however, the activities demonstrate how making observations and inferences lead to understanding the fundamentals of argumentation.

Strategy 2: Agreeing or disagreeing with a statement

Students are presented several scientific statements (or misconceptions) with which they can agree or disagree. Examples include:

- The giraffe got its long neck by stretching for leaves at the top of trees.
- A meteorite hitting the Earth caused the extinction of dinosaurs.
- Frequent use of cell phones can cause brain cancer.
- The table you are working on is mostly empty space.

For each statement, students research evidence to support or rebut it. Starter sentences can help students state their positions. For example:

"The statement argues that ________. I agree with the statement because ______."

"The statement contends that _________; however, I disagree with the statement because ______."

"On one hand I agree with the statement about ______ because ______ ; on the other hand, I disagree with it because ________."

As an extension of strategy 2, teachers turn their classrooms into courtrooms by having students present two sides of a controversial argument in science. Through this activity, students become aware of the sequence of a scientific argument. In addition, they can role-play to present two sides of the argument, while the rest of the class acts as a jury to decide a verdict based on the preponderance of the evidence. Three examples of topics for these arguments include:

- Ptolemy's geocentric universe versus Copernicus' heliocentric universe
- Light as a particle versus light as a wave
- Pluto is a planet versus not a planet

Strategy 3: Testing another person's claim

Students are presented with a claim and then asked to provide evidence to support or rebut the claim. Testing another's claim can begin with framing the claim in the form of a question, such as: "Is Bounty really the quicker picker-upper?" Or, as suggested by Plankis, Vowell, and Ramsey (2011): "Do Double Stuf Oreo cookies really have double the cream filling inside?" These questions form the basis for introductory investigations to establish the validity of a claim.

In another example, Science Take-Out (see "On the web"), students test the optimum temperature for hatching "sponge eggs" (small sponges enclosed in a gelatin capsule). In Part 1 of the lab, students test how water temperature (cold, room temperature, and hot) affects sponge egg hatching. This initial inquiry serves as an introduction to Part 2, in which students design a controlled investigation to test the claim that adding a product called "HatchFast" to water makes the sponge eggs hatch more quickly. Although students don't know that the HatchFast granules are actually just red-colored sugar, they soon collect enough evidence to confirm that HatchFast has no effect on hatching speed and to rebut the company's claim.

Strategy 4: Making your own claim

At this point, students are now familiar enough with the process of scientific argumentation to design their own investigations and draw claims and assertions from the data collected. The data are then used to provide evidence to support the validity of their claims and explanations. Students can communicate their findings and explanations in an oral or written argument.

In an argument-based oral report, students

- state the original question,
- state the method used to test the question,
- state the findings and results of the investigation,
- make a claim from the findings,
- state the evidence to support the claim,
- summarize the assertion and provide an interpretation of the newly acquired knowledge, and
- respond to possible rebuttals from the audience.

In a traditional lab report, students may write many or all of the following:

- title of the lab
- hypothesis to be tested
- materials used
- safety measures
- procedure
- data tables and/or graph
- conclusion

These elements are similar to those in an argument-based lab. However, an argument-based lab report is often graded more heavily on (a) analysis of the data, (b) how the claim is supported by the evidence, and (c) the explanation. While a traditional lab report identifies a hypothesis, the argument-based report includes assumptions and prior knowledge the student brings to the lab. And instead of listing procedures step by step, the alternate report describes methods in a more narrative form. A typical organization and grading point distribution for an argument-based lab report may include:

1. Background on the observed phenomenon (10 pts.)
2. Question or problem being investigated (5 pts.)
3. Assumptions and/or tentative explanation (5 pts.)
4. Variable tested (5 pts.)
5. Method used to investigate the question (10 pts.)
6. Data and findings (15 pts.)
7. Analysis (25 pts.)
   - Describe the relationship among variables (10 pts.)
   - State a claim with supporting evidence (15 pts.)
8. Explanation and discussion (25 pts.)

Fostering scientific argumentation can be challenging. Nonetheless, by scaffolding activities from simple to complex, students can attain the communication skills embraced by the *Common Core, Framework,* and *Next Generation Science Standards.* Adjusting to this reform requires science teachers to shed "old skins" and tweak the emphasis of their time-honored labs. This will require ongoing professional development. Now is the time for teachers and leaders to work together to embrace this new wave of reform. ■

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On the web

Animal tracks activity: "Proposing Explanations for Fossil Footprints," in *Teaching About Evolution and the Nature of Science,* pp. 87–89. Free PDF: *www.nap.edu/catalog.php?record_id=5787*

Science Take-Out: *www.sciencetakeout.com*

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