ARGUMENTATION IN SCIENCE EDUCATION

HELPING STUDENTS UNDERSTAND THE NATURE OF SCIENTIFIC ARGUMENTATION SO THEY CAN MEET THE NEW SCIENCE STANDARDS

Victor Sampson, Patrick Enderle, and Jonathon Grooms

A *Framework for K–12 Science Education* (NRC 2012) and subsequent *Next Generation Science Standards* (Achieve Inc. 2013) will substantially influence the teaching and learning of science in the United States. The *Framework*, for example, calls for students to learn about several practices related to scientific argumentation. These practices—arguing from evidence (practice #6) and obtaining, evaluating, and communicating information (practice #8)—are embedded throughout the *Next Generation Science Standards* (*NGSS*). Many teachers, as a result, need to re-focus their curriculum and methods to teach these practices. This article will help teachers understand the nature of scientific argumentation so they can help students reach the new benchmarks. It will also explain challenges students face when they participate in scientific argumentation and will list resources teachers can use to help students learn from and about scientific argumentation in the classroom.

What counts as an argument in science?

In scientific argumentation, individuals attempt to support, challenge, or refine a claim on the basis of evidence (Norris, Philips, and Osborne 2007). Claims include conjectures, conclusions, explanations, models, or an answer to a research question. Scientists often rely on evidence to support their claims. To generate a compelling argument, however, scientists must also convince others that their evidence is relevant and of high quality. Scientists, as a result, spend a great deal of time assessing, critiquing, and defending the evidence used to support or challenge claims when they engage in scientific argumentation.

Students must also learn how to construct an evidence-based argument and evaluate the evidence presented by others. We developed an argument framework (Figure 2, p. 32) to help students understand what counts as evidence in science and how to construct and evaluate a scientific argument. In this framework, an argument consists of a claim, evidence, and a justification of the evidence.

The claim, as described earlier, is a conjecture, conclusion, explanation, principle, or some other answer to a research question. Evidence is data or findings from studies. Note that in this framework, data and evidence have different meanings. Scientists collect data or gather findings from other studies then transform the data or findings into evidence. To do this, they must first analyze the data or findings (e.g., by making comparisons between groups, looking for trends over time, identifying relationships between variables, or synthesizing available literature), and then they provide an interpretation of their analysis. Finally, in this framework, they justify the evidence, explaining its importance by making the specific principle, concept, or underlying assumption that guided the analysis of the data (or findings) and the interpretation of their analysis explicit.

To clarify, let's examine the argument made by James Watson and Francis Crick in one of the most important scientific papers in history. In their groundbreaking article, "A structure for Deoxyribose Nucleic Acid" (1953), they set out to describe a "radically different structure" (p. 737) for the DNA molecule. Their claim was complex, describing not only the helical chains of DNA and the directions they run in relation to each other but also how the purine and pyrimidine bases hold the two chains together:

> …only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine). In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. (p. 737)

Watson and Crick then provided evidence based on the findings of other scientists:

> It has been found experimentally [citations] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid. (p. 737)

This evidence reflected their analysis of findings from two different studies (one by Chargaff and one by Wyatt) and their interpretation of their analysis of the available literature. Watson and Crick then provided a justification of most, but not all, of the evidence they decided to include in their argument:

> The previously published x-ray data on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments. (p. 737)

As part of their justification of their evidence, Watson and Crick explained some of the assumptions underlying their analysis and interpretations. They also explained why they didn't use some other findings (x-ray data) in their argument. Note, however, that this article was short (less than 900 words) and omitted some of the assumptions underlying their analysis and interpretations. Accordingly, Watson and Crick included this caveat at the end of their article:

FIGURE 1

The effect of weights on pendulum speed.

# of weights	# of swings (in 10 seconds)
None	0
2	3
4	6
5	6
6	7
7	7
8	6

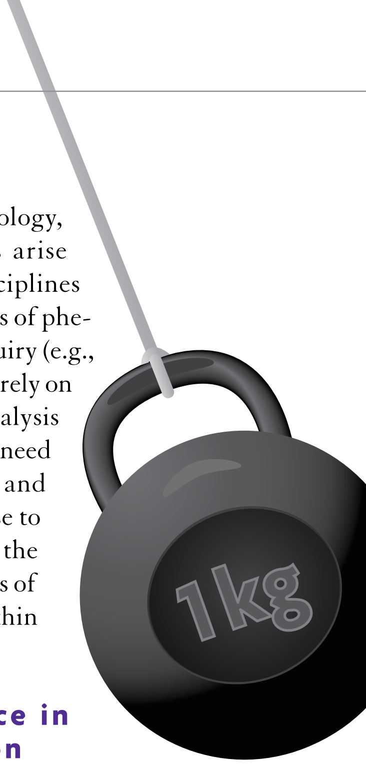
Student claim: The optimal number of weights was 6 or 7 because with 8 weights, the pendulum's speed slowed by about 1 swing per section. This proves that the pendulums swing faster depending on the amount of weight.

> Full details of the structure, including the conditions assumed in building it, together with a set of coordinates for the atoms, will be published elsewhere. (p. 737)

As this example illustrates, scientists must argue from evidence to support their claims. They must make clear the assumptions underlying their analysis of data and their interpretations of the analysis to convince others that the evidence they used was relevant and valid. The framework in Figure 2 offers students guidance about what to include in a scientific argument.

Students also need to learn the criteria (Figure 2) that scientists use to evaluate and critique the arguments developed by other scientists. We describe these criteria as either empirical or theoretical. Empirical criteria are used to evaluate how data was collected and analyzed and how well the claims fit the evidence. Theoretical criteria, in contrast, address how consistent the claim is with accepted scientific knowledge and the appropriateness of the theoretical framework that was used to guide the interpretation of the results.

What counts as quality in these two categories of criteria can vary from discipline to discipline (e.g., physics, biology, chemistry) and across fields within a discipline (e.g., cell biology, evolutionary biology, biochemistry). These differences arise because scientists in different disciplines and fields investigate different types of phenomena, use different modes of inquiry (e.g., experimentation vs. fieldwork), and rely on different theories to guide their analysis and interpretation of data. Students need to understand that the empirical and theoretical criteria that scientists use to evaluate arguments are shaped by the theories, modes of inquiry, and ways of communicating that are valued within a discipline or field.



Challenges students face in scientific argumentation

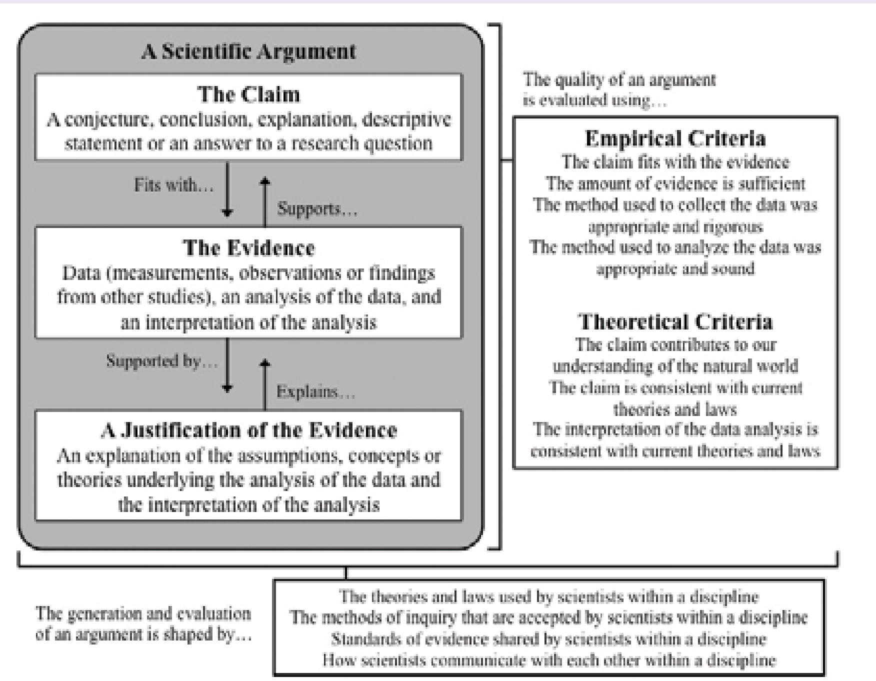
Students often encounter challenges when asked to craft an evidence-based argument in science (NRC 2012). Many students don't understand the difference between data and evidence so only include data in their argument. Other students struggle with transforming data into evidence and therefore inappropriately analyze their data or misinterpret the results of their analysis. Some students have a confirmation bias and only seek out data (or findings) that support their ideas and ignore the rest. Others make hasty generalizations based on limited information.

The biggest challenge for students, however, is justifying their evidence. Most students don't understand the value of making their assumptions explicit to others, or they fail to discuss the theory, law, or concept that guided their analysis of the data they collected and the interpretation of their analysis. Many students, as a consequence, provide an interpretation of their results to justify their evidence or they just declare that their evidence proves their claim.

To illustrate some of these challenges, we offer a sample argument typical of students who haven't yet learned about scientific arguments in school. At the start of the school year, students were directed to develop an argument consisting of a claim, evidence, and justification of the

FIGURE 2

A framework that illustrates the components of an empirical scientific argument and some criteria that can be used to evaluate them.



evidence to answer the question: "Why do some pendulums swing faster than others?"

After designing and carrying out an investigation to gather data (Figure 1, p. 31), the group produced the following argument: "Some pendulums swing faster depending on the amount of weight because of the balance between the inertia of the pendulum and the gravity acting upon it."

These students did not meaningfully analyze their data or interpret their analysis. They also showed a confirmation bias, collecting data about only one factor (the mass of the bob) and making an inaccurate generalization based on their limited information. They failed to justify the "evidence" they used to support their claim, simply declaring that their data proves their claim. Teachers need to be mindful of these pitfalls when students try to argue from evidence.

Students also struggle when asked to evaluate the conclusions of others in the science classroom (NRC 2012). Many, for cultural or other reasons, consider it disrespectful to question the ideas of their classmates, or they are inhibited by existing relationships with their peers. Other students see little value in discussing the merits of an idea, preferring to wait for the teacher or friends to reveal the right answer. When students do engage in argumentation with their classmates, they often don't argue from evidence but use personal attacks, an appeal to authority figures, or personal experiences or beliefs to support or challenge an idea. Most students, then, need more opportunities to learn how to participate in argumentation consistent with the norms and values of the scientific community.

Conclusion

The focus of the science curriculum needs to change so students can learn how to participate in the practices of science. Teachers must emphasize "how we know" as much as "what we know" (i.e., the scientific concepts outlined in most state standards). Teachers need to provide students more opportunities to craft scientific arguments and participate in discussions that require them to support and challenge claims based on evidence. Teachers need to help students learn how to use the same criteria that scientists use to evaluate an argument. Finally, teachers need to give students a reason to discuss alternative claims, the available evidence, and their underlying assumptions during a lesson. These tasks can be difficult, but help is available (see "Resources").

We hope this article will spark discussions about the varied ways to help students learn how to argue from evidence and evaluate information in the context of science. These types of practices are key features of the *Framework* and the *NGSS*. It's time for all of us to focus our efforts on helping students learn about these new practices. ■

Victor Sampson (victor.sampson@gmail.com) *is an assistant professor of science education; Patrick Enderle* (patrick.enderleadi@gmail.com) *and Jonathon Grooms* (grooms.fsu@gmail.com) *are assistants in research, all at Florida State University in Tallahassee.*

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Web-based Inquiry Science Environment (WISE): *http://wise.berkeley.edu.* This free learning environment includes projects related to arguing from evidence. Includes project overviews and information on how the project aligns with content standards.