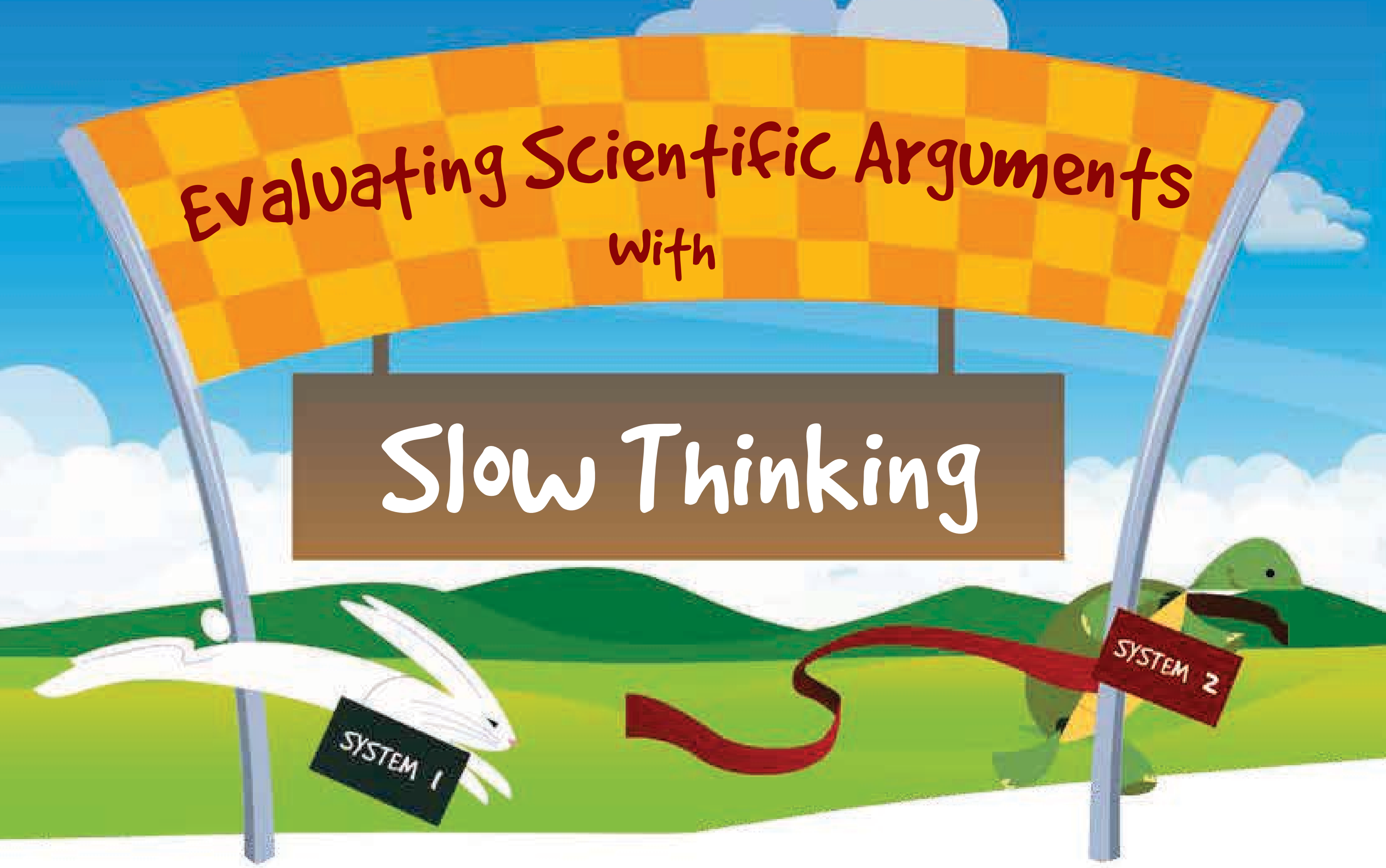
Evaluating Scientific Arguments with Slow Thinking



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To an increasing degree, goals for K–12 science education reflect the need for all citizens to understand and be able to use science in decision making. For instance, Practice 8 from the *Next Generation Science Standards* highlights the importance of students being able to evaluate the validity of scientific information and communicate ideas (Achieve Inc. 2013). Children in school today will need to act as informed citizens in both public roles (e.g., voter, advocate) and private roles (e.g., consumer, worker, learner). Thus, as science educators, we need to prepare students for the decisions they will make in those roles. We, the authors of this article, are particularly interested in how K–12 science education can prepare students to use science understanding and practices to inform their decisions regarding environmental issues such as climate change, freshwater resources, and biodiversity.

This does not imply advocating a particular political position, but it does mean that citizens should be able to understand and evaluate scientific arguments about environmental issues and use scientific understanding to inform their decisions. Scientific knowledge alone is not sufficient for making informed decisions about these issues, which also have political, economic, and ethical dimensions. However, in this article, we focus primarily on scientific understanding.

System 1 and System 2 thinking

We all agree that people should make decisions about environmental issues in deliberative and rational ways, but we have plenty of evidence that this is easier said than done. One reason for this has to do with the ways that humans, over millions of years, have evolved to think and make decisions. We can't be deliberative about every decision we make (for instance, whether that rustling in the bush is a lion or your mother), so we have developed abilities to make most decisions very rapidly.

In his book *Thinking, Fast and Slow*, Daniel Kahneman (2011) explores how and why people think in irrational ways. He describes two systems the human mind uses for processing information. System 1 (thinking fast) involves instantly and subconsciously fitting what we see into our preconceived frameworks for how the world

FIGURE 1 Features of System 1 and System 2 thinking (adapted from Haidt 2001)

System 1 thinking	System 2 thinking
Fast and effortless	Slow and effortful
Unintentional, runs automatically	Intentional and controllable
Process is inaccessible, we're only aware of results	Process is consciously accessible
Does not demand attentional resources	Demands attentional resources, which are limited
Thought is metaphorical and holistic	Thought is analytical

works. In contrast, System 2 (thinking slow) involves using conscious effort to question and modify instant perceptions and conclusions that get switched on by System 1. Figure 1 shows contrasting features of these systems.

Humans rely on System 1 thinking for most of our day-to-day decisions, and in general that's a good thing. System 1 enables us to take quick and decisive action using incomplete information, and there are many times when quick action is better than slow or no action. For example, our ancestors who successfully hunted and defended themselves from attacks were generally the ones who acted quickly. Likewise, successful entrepreneurs and athletes are usually the ones who believe they will be successful, not the ones who have made the most accurate calculations of the odds of success and failure. But System 1 can fail us, too (see Figure 2).

For example, when we make decisions that have environmental impacts, such as what kind of car to buy or how to vote on an environmental ballot issue, we need to avoid common System 1 errors by:

- looking beyond surface appearances to avoid WYSIATI (what you see is all there is) errors;
- identifying important underlying questions rather than substituting easier ones that we can answer readily;
- considering data, and the patterns in data, not just appealing stories;
- avoiding confirmation-bias and false-certainty errors by not believing claims just because we initially agree with them; and

FIGURE 2 Characteristics of System 1 thinking that lead to errors in judgment

WYSIATI (what you see is all there is)	System 1 makes use of information at hand to construct perceptions and stories, without asking whether other critical information might be missing.
Substituting an easier question	When confronted with a complex, difficult question, System 1 supplies an answer to an easier, related question.
Stories, not statistics	System 1 is very good at fitting patterns we see around us into story lines but is not able to see and interpret statistical patterns in data. In other words, we see the world in stories, not statistics.
Confirmation bias	We give greater credence to sources, information, and arguments that agree with our personal perceptions and narratives.
False certainty	System 1 does not recognize uncertainty. It produces instant conclusions that seem wholly true based on available information without evaluating the quality of the information. Only System 2 involves doubting, hesitating, or qualifying.
Source amnesia	System 1 makes use of available information without questioning whether the source it came from is reliable, and quickly forgets the source entirely.

FIGURE 3 Examples of System 1–type errors common among students

WYSIATI (what you see is all there is)	**Students rely on their firsthand experiences to make sense of the world, often neglecting that there may be additional information that is important to consider.**
Example: When one student was asked if she thought that building a well to extract water for a bottled-water company could affect trout living in a nearby stream, she responded, "No, not really. Since groundwater is a separate system from river water, it really won't harm the trout." This student's lack of experience with the connected nature of surface-water and groundwater systems (these connections are hidden from our everyday view) led her to the conclusion that these systems are not connected at all.	
Substituting an easier question	**When confronted with a challenging question such as "How strong is the scientific evidence provided for this argument?" students sometimes answer the easier question of whether or not the argument makes sense to them.**
Example: Many times when we asked students to comment on how adequate the evidence provided by different stakeholders was regarding whether or not building a mall would affect water quality and biodiversity, students answered a different question instead. In particular, students often provided responses indicating that the evidence was adequate because the conclusion made sense. For example, one student responded, "I think the evidence is adequate because a natural environment like a park would be more beneficial to the environment."	
Confirmation bias	**Students often give greater credence to sources, information, and arguments that agree with their personal perceptions and narratives, regardless of the evidence.**
Example: Students often answered the question asking them to evaluate the adequacy of evidence about the mall scenario by articulating personal inferences: • "[The evidence is] very adequate due to my experience and observations of driving past large malls." • "I believe that this evidence is adequate and supports my prediction. The mall is trying to make their promise to the economy more beneficial than it actually is."	

- paying careful attention to sources of information and giving more weight to reliable sources to avoid source-amnesia errors, where information is used without questioning or remembering the source it came from.

In our research (exploring how middle school students make sense of scientific arguments and evidence), we have seen many students demonstrate patterns of System 1–type judgment errors. This research has been conducted using several scenarios presented to students, including considering whether a bottled-water company should be allowed to drill wells near a trout stream and whether to allow a shopping mall to be built on a site that is currently a city park. Several typical examples of System 1–type judgment errors are shown in Figure 3.

While the innate bent toward relying on System 1 thinking is strong, it's not the only processing system available to humans. System 2 thinking can help us consider more substantial and complex issues that we want to make decisions about (e.g., to what extent are humans contributing to global climate change? Will taking acetaminophen increase a child's risk of developing asthma?). Scientific norms for argumentation and verification are designed to make sure that System 2 has its say and that scientific knowledge claims are subjected to careful scrutiny that avoids errors common in System 1 thinking. Figure 4 shows some practices of scientific thinking that we can develop norms for in science instruction to counteract limitations of System 1.

A unit to introduce System 2 thinking practices

In a National Science Foundation–supported partnership that involves middle schools, high schools, and

FIGURE 4 Scientific practices that address limitations of System 1 thinking

System 1 characteristics	System 2 scientific practices to emphasize to counteract limitations of System 1 thinking
WYSIATI (what you see is all there is)	Constantly seek new data, especially data that could falsify our current models.
Substituting an easier question	Insist on specific questions and arguments from evidence that respond to them.
Stories, not statistics	Favor rigorous sampling and synthesis of repeated studies over anecdotal evidence.
Confirmation bias	Require a rigorous search for evidence that could disprove hypotheses.
False certainty	Encourage skepticism and a peer-review system that promotes skeptical evaluation.
Source amnesia	Require those making arguments to establish where their knowledge claims come from and why the source is reliable.

universities in six states, we have been studying how students evaluate scientific arguments about issues in various media (e.g., magazine and journal articles, government and industry reports, websites). We have seen that students frequently engage in System 1 practices. To provide a resource for teachers to support students in using science to inform real-world thinking and decision making, we have developed and piloted a unit designed to introduce students to System 2 scientific practices for evaluating arguments about socio-scientific issues. The unit uses a claims, evidence, and reasoning (CER) framework (McNeill and Krajcik 2012), which focuses on aspects of System 2 thinking including identifying key scientific questions, claims, and evidence that underlie arguments about issues. An abbreviated version of the unit is described here (the full unit is available for free online, see Resource). The curriculum materials available online include background information for the teacher, complete lesson plans, handouts for students, and resources (i.e., articles and instructional guidelines) for multiple environmental topics. Teachers can use some of the main unit activities multiple times, substituting different socio-scientific topics as appropriate for their classes.

Activity 1: Introduction to scientific arguments and socio-scientific issues

The unit begins with a whole-class discussion in which the teacher asks students their ideas about what a scientific argument is and how scientific arguments are similar to and different from arguments that people have in their everyday lives. Students' ideas can be written on the board in two columns as they share—one column shows characteristics of scientific arguments and the other characteristics of everyday arguments.

Next, the What Is a Scientific Argument? handout (see Figure 5) is provided to help students consider what kinds of questions can be addressed by science and how science can help us think about issues facing society. The activity closes with students sharing brainstormed examples of scientific and nonscientific questions and of societal issues that involve science. In the full unit provided online, there is also an extension to this activity, which involves students watching a short video (available online) about a socio-scientific issue and identifying the scientific question, scientific argument, and socio-scientific issue addressed. This extension supports students in deepening their understanding of these terms through applying them in the context of a real-world example. Activity 1 requires between 30 and 45 minutes of class time.

Activity 2: Students develop and use criteria to evaluate arguments

This activity begins with the teacher posing the following question for whole-class discussion: "How can you tell the difference between a good scientific argument and a not-so-good scientific argument?" The teacher leads students in generating ideas about what factors are associated with strong and weak scientific

FIGURE 5 What is a scientific argument?

After reading this page, can you think of other examples of scientific questions, nonscientific questions, and socio-scientific issues?

Scientific question: A *scientific question* is a question that can be addressed through scientific investigation. In order for a question to be scientific, it is not necessary for science to be able to answer it with precision (uncertainty can often be managed, but not eliminated, in scientific investigations), but it must be possible to use scientific methods to study the question. Consider a few examples:

Example scientific question: How much carbon from fossil fuel combustion did the United States emit into the atmosphere in 2011?

Example nonscientific question: Should the United States pass a law requiring all passenger cars to average at least 40 miles per gallon of gas consumption?

Scientific argument: In science, we use scientific arguments to answer scientific questions. Scientific arguments include the following:

A claim: A statement that answers a scientific question.

Evidence: Scientific data that support a claim.

Reasoning: An explanation that supports a claim by providing the underlying scientific concept that connects the evidence to the claim.

Socio-scientific issue: A *socio-scientific issue* is an issue that confronts society that involves both scientific questions and nonscientific questions. For example, to deal with the issue of climate change, people will need to answer both scientific questions about how and why climate change occurs and nonscientific questions concerning what we should do about climate change. To decide what to do about a socio-scientific issue, people can consider science, but they can also consider other things, such as the economy, laws, justice, liberty, and cultural values.

arguments. Students develop and discuss a class list of factors for evaluating scientific arguments, which is posted on the board. If students have trouble coming up with ideas, the teacher can provide an example to get them started (e.g., scientific arguments should be based on evidence that is carefully collected). During this activity, it is not important that students identify an accurate or complete list of factors that scientists might use to judge the quality of a scientific argument. Rather, this activity is intended to serve as a formative assessment in which students share their own ideas and begin to grapple with the practice of evaluating scientific arguments.

Next, students can be divided into small groups of three or four. The teacher should provide students with the What's the Argument Here? handout (see Figure 6) and with several articles that briefly provide different arguments about a socio-scientific issue. Articles addressing several environmental issues are provided on our website, or the teacher can choose another topic and identify articles to use with students. Depending on factors such as time availability and students' reading skills, the teacher can also decide whether to give all students all of the articles or to use a jigsaw format, with different groups each reading and reporting about just one article. In their small groups, students should read the article(s) and, using a CER framework, identify the scientific argument(s) being made. In the CER framework, students are supported in identifying and analyzing the components of a scientific argument: a claim (a statement that answers a scientific question), evidence (scientific data that support a claim), and reasoning (an explanation that supports a claim by providing a logical connection between the evidence and the claim) (McNeill and Krajcik 2012).

Next, in their groups, students should apply the class list of factors for evaluating scientific arguments to the argument made in the article they read. Students use the Evaluating the Argument table in Figure 6 to record their judgments. After the small groups complete their evaluations, the teacher should lead a whole-class discussion in which students share their evaluations with the class. Students should share whether they found the scientific argument they read about to be strong or weak and which factors from the list they used to judge the argument. At this time, students are likely to use some System 1 reasoning as they evaluate the arguments in the articles. For example, we found that students sometimes answer easier questions such as "Who conducted the study?" when asked to identify the scientific reasoning that connects evidence to a claim. As this activity is intended as a formative assessment, it is OK if students do not evaluate the scientific arguments using sophisticated scientific reasoning and criteria at this time. Activity 2 requires about 60 minutes of class time.

Activity 3: Introduction to evaluation criteria common to scientific communities

In this activity, students working in small groups read about some criteria that scientists use to evaluate arguments (see Figure 7, How Do Scientists Evaluate Arguments?). The groups then reevaluate the arguments they read in light of the criteria presented in Figure 7. The scientists' criteria list is intended to support students in developing awareness of System 2–type approaches to evaluating scientific arguments. For example, we want to encourage students to carefully examine the quality of evidence and whether the evidence supports the scientific claim, and pay attention to the reliability of sources of arguments. This step is crucial for scaffolding students' experience with scientific reasoning using System 2 thinking, and for helping them contrast System 2 and System 1 thinking. Activity 3 requires about 30 minutes of class time.

FIGURE 6 **What's the argument here?**

Read the article and answer the questions below to consider the scientific argument that is made. Then discuss your ideas with your group. Be prepared to share ideas with the class.

Title of article:

1. What socio-scientific issue is addressed in this article?
2. What scientific question does this article address?

Answer the questions below to identify the scientific argument made by the article.

1. What is the scientific claim? (Hint: A scientific claim is an answer to the scientific question.)
2. What scientific evidence is provided? (Hint: Scientific evidence is data and observations that support the claim.)
3. What reasoning supports the claim? (Hint: Reasoning describes how an underlying scientific concept connects the evidence to the claim. The reasoning could be in the article, or you may have to use your background knowledge about science to develop the reasoning.)

In your group, consider the scientific argument in the article and complete the table below. Which criteria (factors) can you comment about for the argument? For each criterion that is relevant, indicate whether the scientific argument is strong or weak for that criterion and explain why.

Evaluating the argument

Restate the claim for the argument made in this article:		
Criterion (factor)	Strength (strong [S] or weak [W])	Explain why the scientific argument is strong or weak for each criterion you list.

Activity 4: Why should we care about scientific arguments?

In this activity, students and teacher as a whole group consider why scientific arguments are important beyond science class (using the Figure 8 handout, Socio-Scientific Arguments: Do They Only Matter in Science Class?). Activity 4 is intended to encourage students to consider and discuss some parameters for what scientific (System 2 type) thinking can and cannot help us do. Students should take from this discussion that science cannot tell us what to do about divisive socio-scientific issues and that many scientific questions cannot be answered with 100% certainty. However, science is a careful and systematic way of understanding and the best tool we have for addressing many questions about how the material world works. Thus, scientific (System 2 type) thinking can help us to make better-informed decisions about environmental and other socio-scientific issues that are confronting our society today. Activity 4 requires about 60 minutes of class time.

Classroom implementation

We implemented this unit in classrooms ranging from middle school through college. The main goal was to use the CER framework to introduce students to some System 2 practices that science provides us with for evaluating scientific arguments about environmental issues facing our society. For many teachers, using a CER framework with students was a new instructional practice. Even so, we found teachers to be very open to teaching this unit with their students. One teacher commented, "I will definitely use the CER model with my new class in the spring semester, as well as with other classes I teach. I think students need to learn how to evaluate information that is presented to them; they shouldn't automatically believe everything they hear."

One of the most difficult parts of the unit was helping students identify and explain the reasoning that connects the evidence and the claim, especially if the topic was a new content area for them. For example, in a class exploring the topic of carbon storage, one article discusses a study that found differences in the amount of carbon stored in different types of forests. Some students struggled to separate the evidence presented in the article from the reasoning, while others simply resorted to telling us more about the study instead of the scientific reasoning that would explain the evidence. Many students need supportive scaffolding and multiple opportunities for practice with CER before they are able to confidently identify the reasoning in scientific arguments they encounter.

FIGURE 7 **How do scientists evaluate arguments?**

Some criteria (factors) scientists use to evaluate scientific arguments are as follows:

- Is there scientific evidence to support the claim?
- Is the sample size for collecting data sufficient? (In other words, is the sample big enough?)
- Were appropriate measures used in collecting data? (In other words, did scientists measure the right variables to answer the scientific question?)
- Was the data-collection procedure for gathering evidence rigorous and careful?
- Have the results been replicated? (In other words, has similar evidence been found in multiple separate instances)?
- Have multiple scientists found similar results? Have some scientists found different results?
- Is there an underlying scientific concept that links the evidence to the claim?
- Is there consensus (agreement) among scientists about the argument?
- Have the results been published in a peer-reviewed, reputable publication?
- Did someone who might have a bias fund or carry out this work? For example, was the work paid for by a company that has an interest in getting certain results?

Discuss with your group and write down your ideas about the following questions:

1. Why do you think the criteria on the list above are important to scientists?
2. Are there some factors on the list we developed as a class that are the same as or similar to criteria on the scientists' list? If yes, which factors from the class list are similar to those on the scientists' list?
3. Considering the scientists' list, are there any changes you would make to your evaluation of the strengths and weaknesses of the arguments provided by the stakeholders in the articles? Using different-color ink, make any additions or changes to your original list of strengths and weaknesses for the arguments.

Another challenging aspect of this unit is the process of identifying whether arguments are strong or weak based on specific criteria. Activities 2 and 3 encourage students to slow down, use System 2 thinking, and really focus on why one argument might be more credible than another. Some examples of criteria for strong arguments identified by students in activity 2 above include the following:

- "lots of data"
- "multiple tests"
- "representations like graphs"
- "relevancy of the question"
- "testability"

FIGURE 8 Socio-scientific arguments: Do they only matter in science class?

1. What are some socio-scientific issues that you know about or that are important to you?
2. For one issue you have identified, what are some scientific questions to investigate to help people understand the issue better?
3. Can answers to scientific questions provide us with all the information we need to make a good decision about what to do about a socio-scientific issue? Why or why not?
4. If not, what other information would be needed?
5. Is there generally a right and wrong answer to what should be done about a socio-scientific issue? Why or why not?
6. If two people had the same exact information available to them about a socio-scientific issue, could they make different decisions with both being considered informed decisions? Why or why not?
7. Can all scientific questions be answered with 100% certainty? If not, can investigating these questions still help us to understand issues better, or is science only useful if it provides definite answers?
8. Has this set of activities changed the way you will consider scientific arguments in the future? If yes, how will what you do be different from what you have done before?

We recognize that each of these (as well as each of the criteria identified in Figure 8) could be a jumping-off point for more in-depth exploration of how scientists evaluate scientific arguments. However, as it is currently structured, this unit is only designed to introduce students to scientific criteria for evaluating arguments. Further structured and scaffolded experiences would be required to help students develop facility with applying the criteria to evaluate scientific arguments. We predict that engaging in this unit just once or twice in a school year may help students develop awareness of how using scientific thinking to evaluate an argument is different from using everyday thinking.

We do believe, though, that integrating multiple opportunities to evaluate scientific arguments throughout a course will support students in becoming "critical consumers of scientific information" (NRC 2012, p. 9). Figure 9 provides examples of indicators that teachers might look for in their students' work (e.g., responses to Figure 6) to judge how students are evaluating scientific arguments (i.e., whether they may be using less scientific, System 1–type approaches versus more scientific, System 2–type approaches). Through repeated experiences evaluating (and discussing evaluations of) scientific arguments about different socio-scientific issues, students may develop greater proficiency with using more sophisticated approaches to this important scientific practice.

We have noticed that as students repeatedly use the CER framework, they become more confident in identifying evidence and reasoning and are better able to have conversations that focus on evaluating scientific evidence. In the words of one teacher, "I think that what students got out of this was an improved ability to judge socio-scientific issues more on scientific merit than emotion." This, we feel, is an important and worthwhile goal for any classroom. To that end, the full unit available on our website includes multiple cases with articles that teachers can use with their students. Many of the case topics relate to life sciences core disciplinary ideas in the *Next Generation Science Standards* (e.g., carbon cycling and population dynamics) (Achieve Inc. 2013). ■

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FIGURE 9 Indicators of less and more sophisticated evaluations of arguments

Argument evaluation element	Less sophisticated evaluation indicators	More sophisticated evaluation indicators
Claim	Student's identified claim does not match the claim made by article author(s) or only matches part of the claim made in the article.	Student's identified claim is the answer to the scientific question posed in the article.
Evidence	Student may provide a different claim rather than evidence comprising data and observations. Student may provide vague reference to evidence without specifics or identify who collected the evidence rather than the evidence itself.	Student identifies specific data and observations provided in article that support the claim (or student may note that the article lacks sufficient evidence in the form of data and observations).
Reasoning	Student may have difficulty separating evidence from reasoning. Student may refer to personal belief rather than scientific principles to connect evidence to claim. Student may answer a different question (i.e., not explain how the evidence supports the claim).	Student uses scientific knowledge and principles to explain how the evidence supports the claim (or doesn't support the claim). Student may draw on scientific understanding not articulated in the article to explain how the evidence supports the claim.
Criteria for evaluating arguments	Firsthand experience is good evidence. Personal inference (e.g., makes sense to me, good arguments are ones that confirm personal beliefs) Appeal to authority (evaluating a person rather than a scientific argument) A right explanation does not require evidence.	See Figure 7.

the Evaluating Arguments unit. Also, thanks to the teachers and students who piloted the unit for us.

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Resource

The complete unit, including article resources for multiple socio-ecological issues—*http://bit.ly/GzRjGT*

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