Promoting and supporting scientific argumentation in the classroom: The evaluate-alternatives instructional model

by Victor Sampson and Jonathon Grooms

A major goal of the science curriculum is for students to develop an understanding of the scientific view of the world and to be able to use scientific reasoning when a situation requires it. The attainment of this goal, however, seems to be hindered when teachers require students to remember a great deal of scientific knowledge without expecting them to understand the empirical and theoretical grounding of that knowledge (Norris, Philips, and Osborne 2007). If we expect students to reach this goal, then teachers also need to provide students with numerous opportunities to develop the critical-thinking skills and scientific habits of mind that are needed to assess alternative ideas, weigh evidence, interpret the meaning of texts, and evaluate the validity or acceptability of a scientific explanation. This is one reason why the National Science Education Standards (NSES) explicitly state that inquiry should be viewed as a process of "explanation and argument" as well as a process of "exploration and experiment" and suggest that student engagement in scientific argumentation needs to play a more central role in the teaching and learning of science (NRC 1996, p. 113).

In order to help address these issues, we will describe an instructional model that science teachers can use to promote and support student engagement in scientific argumentation (i.e., an attempt to establish or validate a conclusion or explanation on the basis of reasons). This model is called the evaluate-alternatives instructional model and it is grounded in current research on argumentation in science education (e.g., Berland and Reiser 2009; McNeill and Krajcik 2006; Osborne, Erduran, and Simon 2004; Sampson and Clark 2009; Sandoval and Reiser 2004). It is designed to help students learn to view conjectures, explanations, and other claims with initial skepticism and to help students develop more rigorous standards for assessing the merits of an idea. Perhaps more importantly, this model is designed to work with a wide range of topics and grade levels so science teachers can use it as a template to develop a new lesson or to adapt an existing activity to better fit with the vision of science teaching and learning that is outlined by the National Science Education Standards.

The evaluate-alternatives instructional model

The evaluate-alternatives instructional model is designed to allow students to assess the validity or acceptability of several competing explanations for a discrepant event or other puzzling phenomenon. To do this, students are introduced to a natural phenomenon that needs to be explained that is related to the current topic of study and three or more alternative explanations that provide a causal mechanism or a descriptive account for the phenomenon in question. Students are then organized into small groups of three or four and directed to develop a method they can use to generate the data needed to either support or challenge the validity or acceptability of an explanation. The teacher also provides students with information about relevant scientific theories, laws, or models so they can use this information to rationalize their use of evidence. Once students gather the data they need using a method of their own design, they create a tentative argument for the explanation that they believe is the most valid or acceptable, and one or more counterarguments that challenge the other explanations. These arguments and counterarguments are displayed on a medium that can be easily viewed by their classmates (e.g., a 27" × 34" whiteboard or easel pad). Each group then shares their ideas during an interactive poster session. These poster sessions require students to discuss the validity or acceptability of the various explanations using both empirical (e.g., how well it fits with available data) and theoretical (e.g., how well it fits with accepted theories, models, or laws) criteria. After the critical discussions are finished, students are given a chance to meet with their original groups to refine their arguments in an effort to better support or challenge the various explanations. To conclude the activity, each student is required to write out and submit a final argument in support of one of the explanations and a counterargument that challenges the validity of the other two for the purpose of assessment.

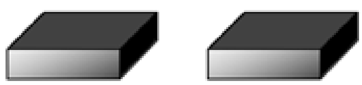
The evaluate-alternatives instructional model is similar to the argument-driven inquiry instructional model (Hall and Sampson 2009; Sampson, Walker, and Grooms Forthcoming) because it requires students to engage in scientific inquiry and argumentation. There are, however, two important differences in these models. First, the evaluate alternatives instructional model does not require students to develop and support their own explanation for a phenomenon under investigation as part of the inquiry process. Students instead are supplied with several potential explanations that are based on common alternative conceptions. Second, the evaluate-alternatives model requires students to craft an argument in support of an explanation and counterarguments that refute other potential explanations at the end of the lesson rather than writing a multipage investigation report. This instructional model therefore provides teachers with a way to design lessons that will give students an opportunity to learn how to design rigorous and informative tests of alternative explanations and how to establish or validate an explanation using empirical and theoretical criteria.

To better illustrate how this model works inside the classroom, we will describe a lesson that we developed for an eighth-grade integrated science course. This lesson was designed to help students understand the transfer of energy (NSES Content Standard B) and develop the abilities necessary to do scientific inquiry (NSES Content Standard A).

FIGURE 1 Part of the handout provided to students at the beginning of the example lesson

The Ice Melting Blocks Problem

The figure below shows two black blocks, A and B. These blocks look the same but block A is made of metal and block B is made of plastic. If you put a piece of ice on both blocks at the same time the ice on block A melts much faster. Try it and see!



A B

This observation raises an interesting question: ***Why does ice melt faster on block A?*** Here are three possible answers...

Explanation #1: The ice melts faster on block A because metal absorbs cold. Block A absorbs cold from the ice, which causes the ice to get warmer and melt. This is why block A feels colder than block B; it absorbs and holds more cold energy.

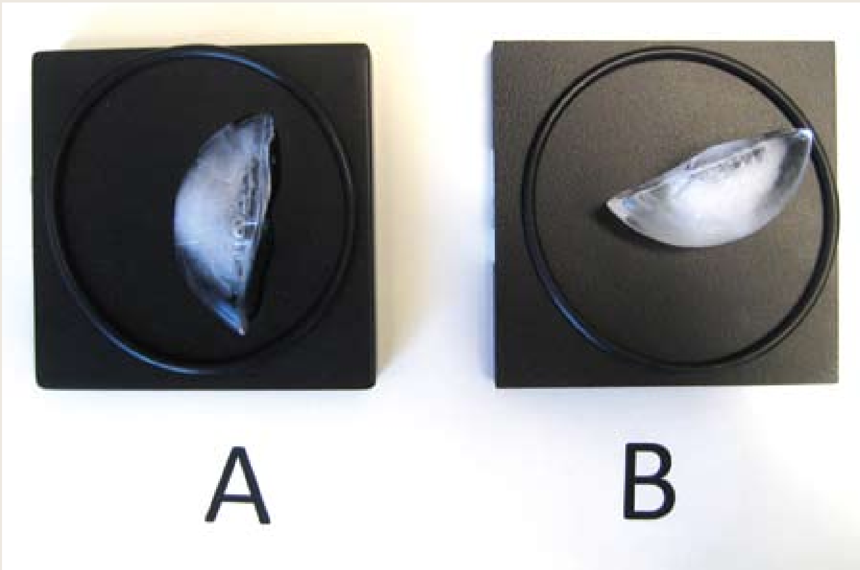
Explanation #2: The ice melts faster on block A because block A is a good conductor of heat. Although both blocks are the same temperature, heat energy transfers into the ice from block A faster then it does from block B. As a result, the ice on block A melts faster.

Explanation #3: The ice melts faster on block A because block A is a good conductor. Although block A is colder than block B it is still warmer than the ice. As cold moves into block A the ice warms up and melts. The ice on block A melts faster because the cold moves from the ice into this block faster.

With your group, determine which explanation provides the best answer to the research question. You can use any of the supplies available to you to test your ideas. Make sure that you generate the evidence you will need to support your explanation as you work. You can record any observation you make in the space below.

Abilities necessary to do scientific inquiry that were targeted in this lesson include the following: (a) formulate and revise scientific explanations and models using logic and evidence, (b) recognize and analyze alternative explanations and models, and (c) communicate and defend a scientific argument. The lesson was also designed to give students an opportunity to improve their verbal-communication and writing skills, their understanding of argumentation in science, and their critical-thinking skills or scientific habits of mind. In this overview we will describe the purpose of each step of the model, the nature of classroom activity and students' interactions during each step, and how teachers can support and guide students as they work.

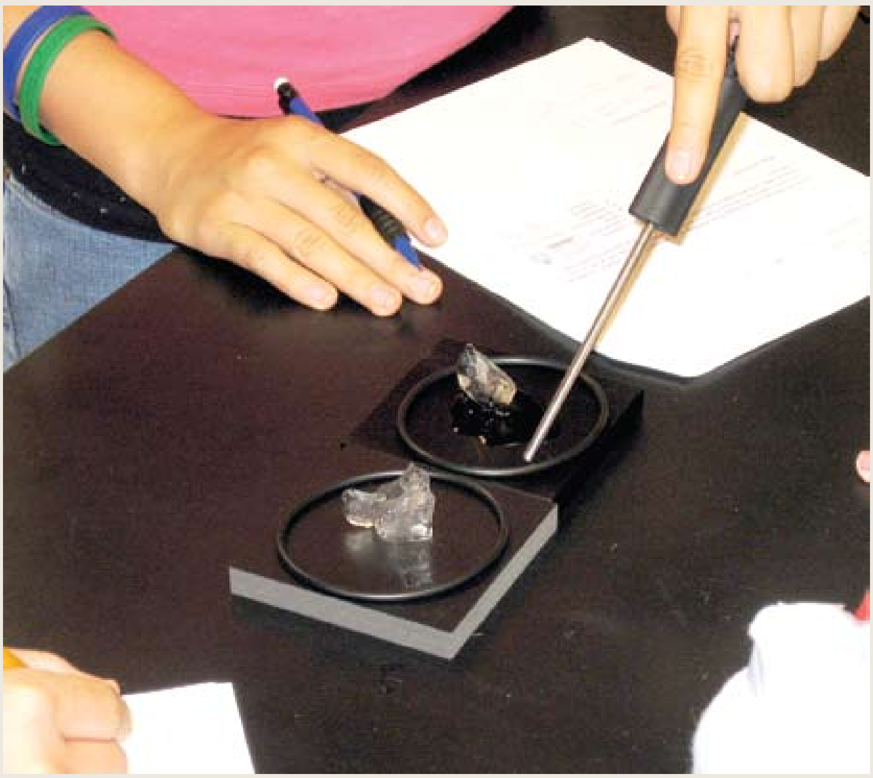
FIGURE 2 The ice melting blocks



Step 1: Introduction of the phenomenon to investigate

The teacher initiates the lesson by introducing a puzzling phenomenon to investigate that is aligned with the content of the curriculum. The puzzling phenomenon we used for this lesson is called the Ice Melting Blocks (see Figure 1). Science teachers often use Ice Melting Blocks to demonstrate the concept of thermal conductivity, but in this case we used the blocks as a discrepant event. We first divide the class into groups of three or four and supply each group with a set of Ice Melting Blocks (which can be purchased through most science education supply companies for about $20 a pair). We then ask each student to examine the blocks. The blocks look similar but one is made of aluminum (block A) and one is made of plastic (block B). The aluminum block, however, feels cold to the touch, while the plastic block feels slightly warm; this is because

FIGURE 3 Students use temperature probes to gather data to support or challenge the alternative explanations



the aluminum block is a better conductor of thermal energy than the plastic block. After students have a chance to hold both blocks, we direct them to place an ice cube on each one (see Figure 2). The ice on the aluminum block melts within two minutes, while the ice cube on the plastic block seems to remain unchanged. This observation confuses most students, because the aluminum block feels much colder than the plastic block at room temperature.

This confusion sparks students' curiosity and "creates a need" (Kuhn and Reiser 2006) for them to figure out an underlying cause. At this point, the teacher should supply students with a handout (see Figure 1, p. 67) that provides them with an overview of the phenomenon to explain (i.e., differences in melting rates), a research question to answer (i.e., Why does the ice melt faster on block A), and three or more alternative explanations to evaluate. The handout includes one explanation that is valid from a scientific perspective (in this case #2), and two that are based on common student alternative conceptions (#1 and #3). Teachers can find information about common alternative conceptions that can be used to develop the alternative explanations by doing an internet search or by simply asking a few students to explain the phenomenon in their own words a few days before the lesson. The teacher can then wrap up this step of the lesson by encouraging each group of students to gather the data they need in order to determine which alternative explanation provided on the handout is the most valid or acceptable.

FIGURE 4 Additional information provided to students

Some potentially relevant information about this problem

The ***molecular-kinetic theory of matter*** indicates that all matter is made up of submicroscopic particles called atoms. This theory states:

- Atoms are constantly in motion so they have ***kinetic energy***.
- The more kinetic energy an atom has the faster it vibrates or moves.
- ***Temperature*** is a measurement of the ***average kinetic energy*** of all the particles in an object.
- The motion of the particles that make up an object increases when the temperature of the object goes up.
- The motion of the particles that make up an object decreases when the temperature of an object goes down.
- **Heat** is the ***total kinetic energy*** of all the particles in an object *or* the ***transfer of kinetic energy*** from the particles in one object to another.

Heat conduction or ***thermal conduction*** is the transfer of thermal energy through matter from a region of higher temperature to a region of lower temperature. This process acts to equalize temperature differences.

Some objects are able to conduct heat better than others. This is called the thermal conductivity of a material. A table of the conductivity values of some different materials is provided below:

Material	Thermal conductivity (W/m·K)
Cement	0.29
Air	0.025
Water (liquid)	0.6
Glass	1.1
Aluminum	200
Gold	318
Copper	380
Plastic	0.16

Step 2: Generation of data

The next stage of the instructional model provides students with an opportunity to design and implement a method that can be used to generate data or to test the explanations. During this lesson, we supplied each group of students with ice, electronic timers, electronic balances, and temperature probes. Students used these materials to determine how long ice takes to melt on each block, the initial temperature of each block, and how the temperature of the blocks changed over time (see Figure 3). This type of work, however, can be challenging for students, because the strategies they use to evaluate an explanation are often guided by a confirmation bias (the tendency to seek out data that support an existing belief while ignoring or distorting everything else). This type of thinking will often prevent students from discussing, critiquing, and testing the merits of each potential explanation in a systematic manner. It is therefore important for the teacher to circulate from group to group and act as a resource for students. Teachers will also need to make sure that all students understand and follow established laboratory safety procedures during this step of the model.

We also provided students with an additional handout that included information about the molecular-kinetic theory of matter, thermal conductivity, and the thermal conductivities of various materials (see Figure 4) during this step of the model. Students were supplied with this information because it is needed in order to refute some of the ideas found within the explanations. For example, the idea of cold energy transferring to the blocks as the ice melts (see explanations 1 and 3 in Figure 1) cannot be refuted on the basis of empirical data alone; a change in temperature in the blocks can be explained equally well using a model of heat transfer or a model of cold transfer. The idea of cold energy, however, is inconsistent with the molecular-kinetic theory of matter. Therefore, it is important to encourage students to use theoretical criteria as well as empirical criteria to evaluate the validity or acceptability of these explanations (and all explanations in science).

Teachers also need to ensure that students think about what they are doing and why they are doing it during this step of the model. For example, teachers should ask students probing questions to help them remember the goal of the activity (e.g., "What are you trying to do?"), to encourage them to think about whether or not the data are relevant (e.g., "Why is that important to know?"), or to help them to remember to use rigorous criteria to evaluate the merits of an idea (e.g., "Does that fit with all the data or the theories and laws on your handout?"). It is important for teachers to remember that students will often struggle with this step of the model when it is first implemented, but over time students will get better at designing informative tests, gathering data, and critiquing ideas using both empirical and theoretical criteria.

FIGURE 5 **A tentative argument**

Students use whiteboards to present their tentative arguments and counterarguments during the interactive poster session. This type of medium helps make their thinking and reasoning visible.

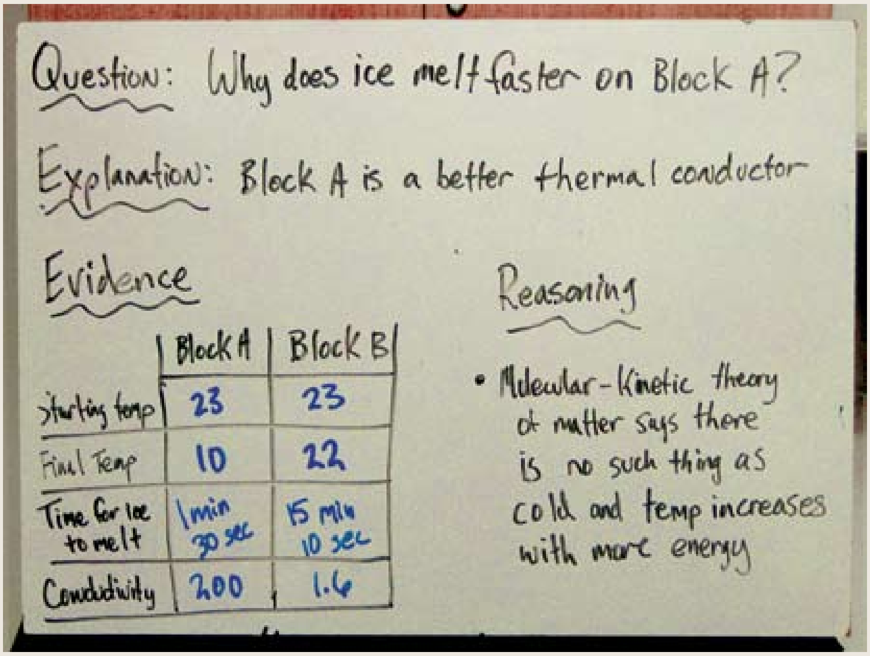


FIGURE 6 **The argument and counterargument writing prompt**

1. *What is your argument?* In the space below, use appropriate evidence and reasoning to support the explanation that you think is the most valid or acceptable.
2. *What is your counterargument?* In the space below, generate a scientific argument that includes appropriate evidence and reasoning to challenge the validity of the other two explanations

Step 3: Generation of tentative arguments and counterarguments

Next, students should be directed to create a tentative argument on a medium that can be easily seen by others (such as the whiteboard illustrated in Figure 5). This argument should include the explanation that the group thinks is the most valid or acceptable, collected data that document differences or similarities in the blocks (such as initial and final temperature) as evidence, and the group's reasoning. The reasoning component is a ratio-

FIGURE 7 Rubric that is used to evaluate students' final arguments

Criteria	Level 1	Level 2	Level 3	Score
The argument				
Quality of the evidence	Reasons are given to support the conclusion or explanation but no data or observations are included.	Data or observations are included but this information is not used to show differences between groups, a trend over time, or a relationship between variables.	Data or observations are included that show differences between groups, a trend over time, or a relationship between variables.	
Sufficiency of the evidence	Includes only a single observation or piece of data in support of the conclusion.	Includes multiple pieces of evidence but not enough to support each component of the conclusion or explanation.	Includes multiple pieces of evidence and each component of the conclusion or explanation is supported.	
Adequacy of the reasoning	Makes a simple assertion that the evidence "proves it" or it simply refers to the evidence without explaining it.	Explains why the evidence was included or how the evidence supports the explanation or conclusion but not both.	Explains why the evidence was included and how the evidence supports the explanation or conclusion.	
The counterargument				
Quality of the evidence	Reasons are given to support the conclusion or explanation but no data or observations are included.	Data or observations are included but this information is not used to show differences between groups, a trend over time, or a relationship between variables.	Data or observations are included that show differences between groups, a trend over time, or a relationship between variables.	
Sufficiency of the evidence	Includes only a single observation or piece of data in support of the conclusion.	Includes multiple pieces of evidence but not enough to support each component of the conclusion or explanation.	Includes multiple pieces of evidence and each component of the conclusion or explanation is supported.	
Adequacy of the reasoning	Makes a simple assertion that the evidence "proves it wrong" or it simply refers to the evidence without explaining it.	Explains why the evidence was included or how the evidence supports the explanation or conclusion but not both.	Explains why the evidence was included and how the evidence supports the explanation or conclusion.	
The writing				
Sentence fluency	The writing is difficult to follow or to read aloud; sentences tend to be incomplete, rambling, or very awkward.	The writing tends to be mechanical rather than fluid; occasional awkward constructions may force the reader to slow down or reread.	The writing has an easy flow and rhythm; sentences are carefully crafted, with strong and varied structure.	
Word choice	The writing shows an extremely limited vocabulary, or is filled with so many misused words that the meaning is obscured.	The author does not employ a variety of words, producing a sort of "generic" argument filled with familiar words and phrases.	The author employs a broad range of words, which have been carefully chosen and thoughtfully placed for impact.	
Conventions	The author made several grammatical, spelling, punctuation, paragraphing, or capitalization errors.	The author made only one or two grammatical, spelling, punctuation, paragraphing, or capitalization errors.	The author used appropriate grammar, spelling, punctuation, paragraphing, and capitalization.	
			Total:	/27
Comments or suggestions for ways to improve:				

nalization for why the evidence was included and why the evidence supports the explanation. Students should also be encouraged to use theories or laws as part of the reasoning component in order to strengthen their argument and to challenge the merits of the other explanations.

The intent of this step of the instructional model is to focus students' attention on the importance of argument in science and provide an opportunity for students to learn how to coordinate theory and evidence. This type of focus will not only help students develop new standards for what counts as warranted knowledge in science, but it will also help students understand the theory-laden nature of science. In other words, students should be expected to understand that scientists use theories, laws, models, and the conclusions of other investigations to design new investigations, to interpret empirical data, and to evaluate the validity or the acceptability of new explanations for puzzling phenomena.

We recommend that the classroom teacher once again circulate from group to group in order to act as a resource for students during this stage of the lesson, because this process will be unfamiliar to students. The main goal of the teacher at this point of the lesson is to help students understand what makes an argument persuasive or convincing in science (i.e., explanations need to be supported by sufficient and appropriate evidence and reasoning). To do this, teachers can provide students with a template for what needs to be included in an argument and define each aspect of an argument (e.g., explanation, evidence, reasoning) in an explicit manner before students begin. The teacher can then move from group to group as students work and ask them probing questions to help them think about what counts as evidence, to encourage them to provide a rationalization for why they included the evidence they did, and to explain what their evidence means.

Step 4: Interactive poster session

In this step, students are given an opportunity to share and critique the various arguments in a small-group format. We include this step in the model because research indicates that students learn more when they have a chance to respond to the questions and challenges of other students, articulate more substantial warrants for their views, and evaluate the merits of multiple arguments (NRC 2007). This step of the model is also designed to provide students with an opportunity to determine if the available data are relevant, sufficient, and convincing enough to support one explanation over another.

It is important to note, however, that supporting and promoting this type of interaction among students inside the classroom is often difficult, because this type of activity is foreign to most students. This is one reason why students are required to generate their arguments on a medium that can be seen by others. This helps students to focus their attention on evaluating evidence and reasoning rather than attacking the source of the ideas. We also recommend that teachers use a round-robin format rather than a whole-class presentation format. In the round-robin format, one member of the group stays at the work station to share the group's ideas while the other group members go to different groups one at a time in order to listen to and critique the explanations developed by their classmates (see Hall and Sampson 2009). This type of format ensures that all ideas are heard and more students are actively involved in the process.

Step 5: Generation of individual arguments and counterarguments

The last step in this instructional model is for the original groups to reconvene and discuss what they learned by listening to and critiquing the arguments of their classmates. Each student is then required to produce a written argument in support of one of the explanations and a written counterargument that challenges the other two. This writing component is included in the instructional model because writing is an important part of doing science. Scientists must be able to share the results of their own research and be able to critique in writing the conclusions of others. In addition, writing helps students learn how to articulate their thinking in a clear and concise manner, it encourages metacognition, and it improves student understanding of the content (Wallace, Hand, and Prain 2004). Finally, and perhaps most importantly, writing provides teachers with a window into students' thinking, an authentic assessment of student learning, and an opportunity to give students educative feedback.

In order to help students learn how to write scientific arguments and counterarguments, we recommend using the prompts provided in Figure 6. These prompts are designed to encourage students to think about what they know, how they know it, and why one explanation is more valid or acceptable than the alternatives. They are also designed to encourage students to think about sentence fluency, word choice, and their writing conventions. A rubric for scoring these arguments is provided in Figure 7. This rubric includes criteria that target many of the components of a quality argument in science (Sampson and Clark 2008), as well as the overall writing style. We included a general description of the various performance levels in this rubric so teachers can tailor it as needed to fit the topic of a specific lesson. Teachers can use this rubric to determine if students understand the content and are able to craft a scientific argument in an appropriate manner, or to provide students with the educative feedback they need to improve.

Benefits of the evaluate alternatives instructional model

As noted earlier, the National Science Education Standards explicitly state that inquiry should be viewed as a process of "explanation and argument" and indicate that scientific argumentation should play a more central role in the teaching and learning of science (NRC 1996, p. 113). However, before we can expect students to view inquiry in this way or be able to engage in the complex practice of scientific argumentation in a productive manner, the focus and nature of classroom instruction will need to change. This will require teachers to focus on "how we know" in science (i.e., how new knowledge is generated and validated) in addition to "what we know" about the world and how it works (i.e., the theories, laws, and unifying concepts). Science teachers will also need to place greater emphasis on the abilities and habits of mind that students need to have in order to construct and support scientific knowledge claims through argument and to evaluate the claims or arguments developed by others.

To accomplish this goal, science teachers need to design lessons that give students an opportunity to learn how to evaluate alternative explanations from data, identify and judge the relevance or sufficiency of evidence, and support or challenge the validity of an explanation in an argument. Science teachers will also need to find a way to help students learn, adopt, and use the same rigorous criteria that scientists use to determine what counts as warranted scientific knowledge. This can be a difficult task within the constraints of a science classroom, especially when teachers lack an instructional model that promotes and supports student engagement in scientific argumentation. We hope that teachers can use this instructional model to design lessons that will help students develop the knowledge, skills, and habits of mind needed to evaluate the validity or acceptability of scientific knowledge.

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