RESEARCH ON LEARNING

Two Instructional Models That Teachers Can Use to Promote & Support Scientific Argumentation in the Biology Classroom

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Abstract

We describe two instructional techniques that science teachers can use to promote and support scientific argumentation inside the classroom. These techniques are designed to give students an opportunity to establish or validate a claim on the basis of reasons or to propose, support, evaluate, and refine a claim as part of a group. The description of the techniques includes two example lessons and suggestions for teachers.

Key Words: *Argumentation; argument; instructional model; middle school; high school.*

Students need to know how new knowledge is generated and validated by scientists as well as the important theories, laws, and unifying concepts of the various disciplines in order to understand science as a way of knowing. Students also must develop the abilities and habits of mind needed to construct and support scientific claims through argument and to evaluate or challenge the claims or arguments developed by others. Current research in science education (Duschl, 2008) indicates that a productive way to help students achieve these important educational outcomes is to give them more opportunities to learn *about* scientific argumentation (i.e., the process) and *from* it (i.e., important content) while in school. This task, however, can be difficult for teachers to accomplish within the constraints of a science classroom unless instructional strategies or techniques are available to serve as templates or guides in designing a lesson.

We have therefore used the available literature on argumentation in science education (for an extensive review, see Erduran & Jimenez-Aleixandre, 2007) to develop two instructional models that teachers can use to design a lesson that promotes and supports student engagement in scientific argumentation: the Generate-an-Argument model and the Evaluate Alternatives model. In the sections that follow, we first discuss the nature of argumentation and argument in science in order to clarify our goals for what students should know and be able to do as a result of this type of instruction. We then provide an overview of the two models and an example lesson for each one.

○ Scientific Argumentation & Arguments

Scientific argumentation can be defined as an attempt to establish or validate a claim on the basis of reasons (Norris et al., 2007) or as a process of proposing, supporting, evaluating, and refining a claim as part of a group in a manner that reflects the values of the scientific community (Kuhn, 1993). A claim, in this context, is not simply an idea or an opinion; rather, it is a conjecture, conclusion, explanation, descriptive statement, or an answer to a research question (Norris et al., 2007). We use the term "reasons" to describe the support someone offers for a claim. The term "evidence" is often used to describe the reasons used by scientists, especially when the support is based on data gathered during an investigation. Yet reasons do not have to be based on data to be viewed as scientific. Charles Darwin, for example, used numerous reasons to support his claims that the species found on earth were descended from other species and that the main mechanism for the change in species over time was natural selection. Some of the reasons that Darwin provided in *On the Origin of Species*, such as Malthus's ideas about population growth and Lyell's concept of uniformitarianism, were theoretical in nature. Other reasons, such as the observations he made during his voyage to Central and South America, were much more empirical (see Erduran & Jimenez-Aleixandre, 2007). Yet it is important to note that not all reasons are equally valid in science, and an important component of scientific argumentation is evaluating the acceptability, relevance, and sufficiency of the reasons that are offered in support of a claim.

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It is also important to understand how an argument (i.e., a written or spoken claim and the reasons that are used to support it) in science is different from the arguments that people use in everyday contexts or in other domains (such as history or religion). In order to make these differences explicit to students, we use the framework illustrated in Figure 1. In this framework, a claim is a conjecture, explanation, conclusion, generalizable principle, or answer to a research question. The evidence component of the argument refers to data (i.e., measurements or observations) that have been collected as part of investigation and then analyzed and interpreted by scientists. Researchers then use this information

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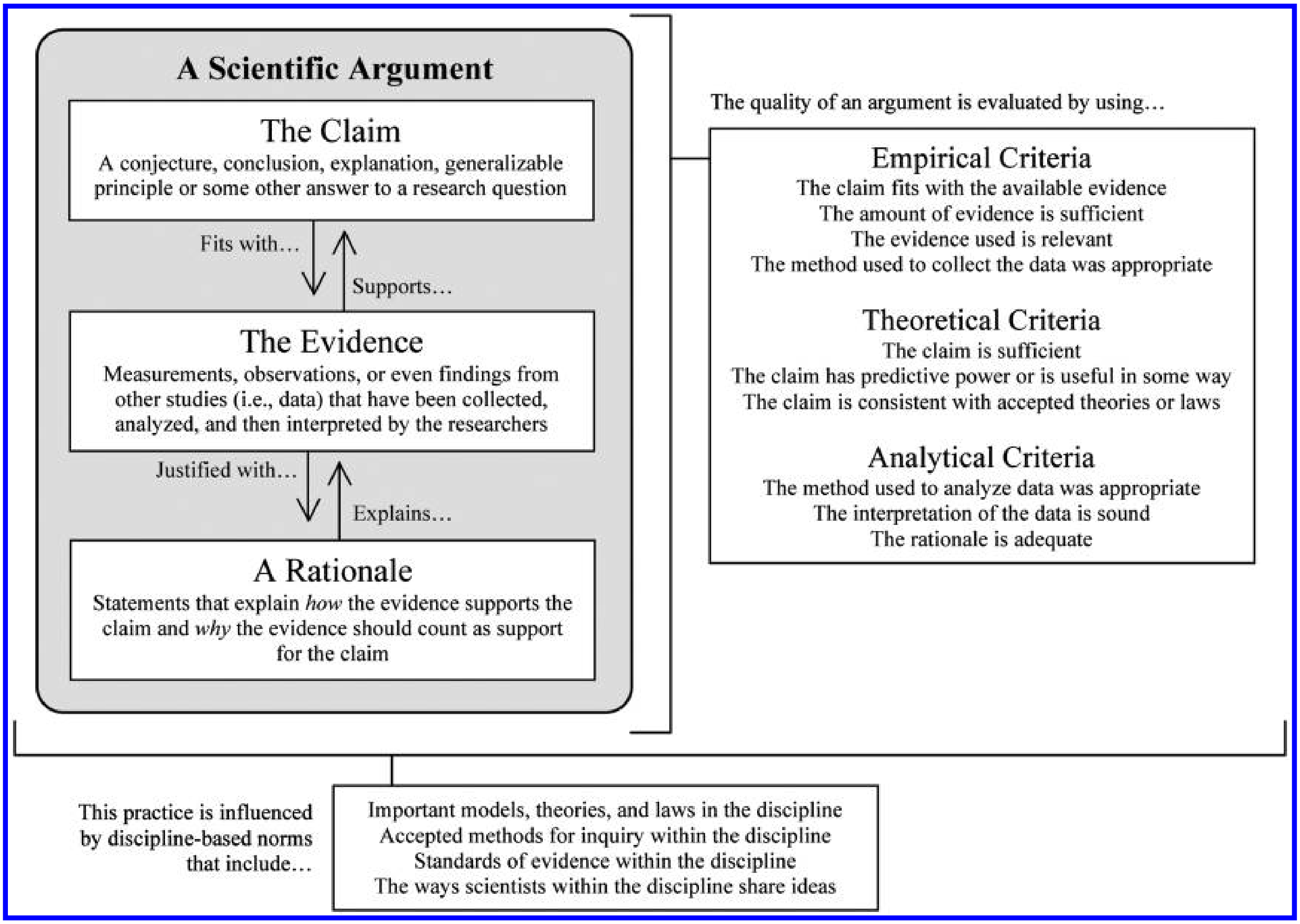

Figure 1. A framework that can be used to illustrate the components of a scientific argument, and some criteria that can and should be used to evaluate the merits of a scientific argument.

to support the validity or the legitimacy of the claim. Other reasons, such as a reference to an accepted theory, law, or model in science or the conclusion or findings from another investigation can also be used as evidence in a scientific argument. The "rationale" component of an argument refers to statements that explain why the evidence should count as evidence and how the evidence supports the claim.

In addition to these important structural components of an argument, this framework also highlights several types of criteria that students can and should use to evaluate the merits of an argument in science. Criteria that are empirical in nature include how well the claim fits with all the available evidence, the adequacy of the evidence included in the argument, and the quality of the evidence. Theoretical criteria, by contrast, refer to standards that are important in science but are not empirical in nature. These include evaluations about the adequacy of the claim (i.e., it includes everything it needs to), its usefulness (e.g., it stimulates new inquiries), and how consistent it is with accepted theories, laws, or models. Finally, analytical criteria focus on the overall quality of the line of reasoning (e.g., hypothetical-deductive, correlational, analogical, etc.) and whether or not the argument provides a sound rationale for how the reasons support the conclusion and why the reasons were included in the argument. What counts as quality within these different categories, however, varies from discipline to discipline, depending on the types of phenomena investigated, what counts as an accepted mode of inquiry (e.g., experimentation, field work, etc.), and the theory-laden nature of scientific work. It is therefore important to keep in mind that the nature of scientific arguments and what counts as quality in science depends on the discipline (e.g., biology or physics), field (e.g., cellular biology or evolutionary biology), and research area (e.g., biophysical and structural cellular biology or developmental cellular biology).

○ The Generate-an-Argument Instructional Model

The Generate-an-Argument model, which is based on the work of Osborne et al. (2004) and Garratt et al. (1999), is designed to engage students in scientific argumentation without requiring them to gather data in the lab or the field first. The intent is to provide students with an opportunity to develop a claim that answers a research question based on a corpus of data and current or historical scientific knowledge, craft a reasoned argument, and respond appropriately to critical comments from others. Teachers can use this model in a variety of contexts, such as in the lab or in large lecture halls or classrooms that lack the materials (lab benches, glassware, etc.) and safety equipment needed to gather data.

To illustrate how this instructional model works, we will describe a lesson that we designed to help students understand the concept of species (*National Science Education Standards* [*NSES*] Content Standard D, grades 9–12) and develop the abilities necessary to do scientific inquiry (*NSES* Content Standard A, grades 9–12) (National Research Council [NRC], 1996). The model consists of four steps. In the following overview we describe the purpose of each step, the nature of classroom activity during each step, and how to support and guide the students as they work.

Step 1: Identification of the Problem, Question, & Task

To begin, students are placed into groups of three and given an instructional handout. The handout provides a research question for the students to answer, information about how they will share their arguments, what criteria they will use to evaluate each other's arguments, and a corpus of data that they can use to develop their claim and argument. In the example lesson, the handout we provided included a brief introduction to biological classification and some difficulties associated with the classification of new species (to help provide a context for the upcoming activity). The handout also included pictures of seven frogs (in this case we provided pictures of both males and females of three species that exhibit sexual dimorphism) and a problem for the students to solve (i.e., seven different-looking frogs were captured by a biologist working in Central America that need to be classified). The handout then provided the students with a guiding question to answer (i.e., How should we classify these seven different frogs?) and directions about what they need to accomplish over the course of the lesson. The handout also contained information about all seven frogs that was both relevant (e.g., mating habits and range) and irrelevant (e.g., appearance, diet, etc.) to the task. The overall goal of the handout was to make the problem, question, and task explicit and then create a need for students to engage in scientific argumentation.

Step 2: Generation of a Tentative Argument

Once the students are familiar with the goal of the activity, they are given time to develop their tentative arguments. At this stage, it is important that their thinking is visible both to the teacher and to other students. This can be accomplished by requiring the students to craft their arguments in a medium that can easily be seen by others, such as a 24 × 36 inch whiteboard (or easel paper). The whiteboard should include the group's tentative claim, with the evidence and reasoning they are using to support it (i.e., their argument) as well as the research question or goal of the investigation (see Figure 2).

In this example, the students made their claims explicit (e.g., these frogs represent five different species) with evidence generated from the supplied data (A mates with other A's and E's, etc.) and then linked the evidence and claim together with their rationale (we make these claims based on sexual behavior and other similar characteristics). Having a concrete display of their thinking on a whiteboard makes it easier for the students to follow their own train of thought and to evaluate the claims, evidence, and rationale of the other groups. The visual representation of the argument also enables the teacher to direct the students' thinking in a more productive manner because the teacher can see the multiple pieces of each argument. At this point, it is important for the teacher to help the students identify inconsistencies in their claims and begin to draw their attention to how the components of their arguments (e.g., evidence and rationale) are linked together, but the teacher should not provide the students the correct claim.

Step 3: The Argumentation Session

Once each group has created a visual representation of its argument, the students should be directed to share their findings using a round-robin presentation structure. In a round robin, each group has one person stay with their poster to share their argument while the remainder of the group rotates around to each of the other groups one at a time to learn about the other arguments (see Figure 3). Throughout this stage students must communicate their ideas, evaluate information, and articulate any questions they may have. The ability to question or critique an argument is a valuable skill for students to develop and helps to foster important habits of mind (e.g., skepticism, valuing evidence). This stage also helps students understand that the goal of scientific argumentation is not to win at all costs but to develop a better understanding of the phenomenon under investigation (Erduran & Jimenez-Aleixandre, 2007).

It is important that the teacher allow the students enough time to discuss their arguments in a thorough manner but also to maintain their focus on the topic. The teacher can accomplish this by providing a time limit on

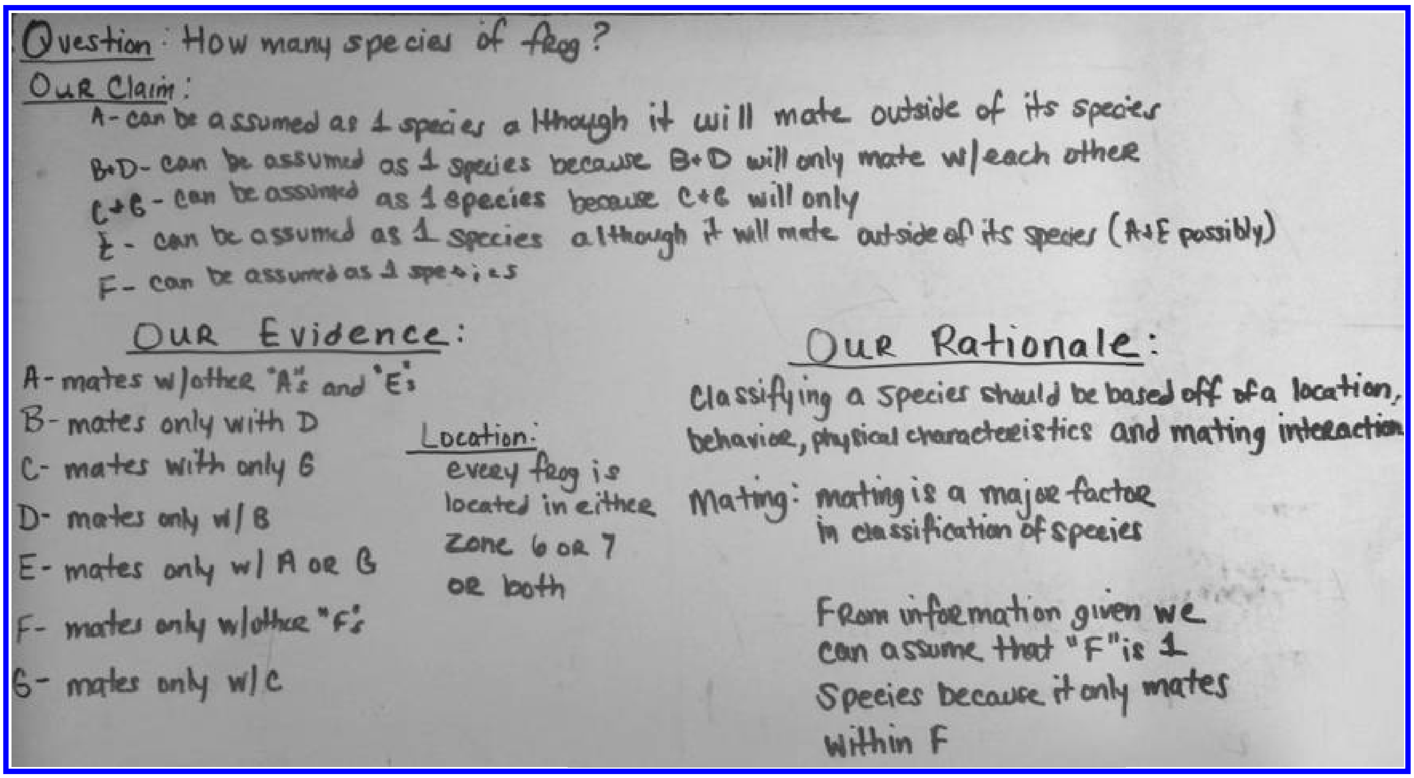

Figure 2. Students use whiteboards to construct a tentative argument. This type of medium helps make their thinking and reasoning visible.

Figure 3. Students engage in an argumentation session in which they propose, support, evaluate, and refine their ideas.

each discussion and by setting up the classroom so that the students can easily move from group to group. We recommend the round-robin format because it allows for the greatest number of interactions between students. A small group of students is also easier to keep engaged, and the teacher can circulate between the groups and question the students' thinking.

Step 4: Group Sense-Making & Individual Arguments

After each student has had the opportunity to view and discuss the claims and arguments that his or her peers have developed, the students should reconvene in their original groups to discuss their own argument again. At this point they should be directed to evaluate their claim in light of all the evidence, rationales, and other claims that they have seen. The teacher should direct the students' attention to the various aspects needed in a sufficient claim to evaluate how well the evidence and other reasons are connected to the claim. The students should be prompted to fully evaluate the persuasive nature of their own argument as well as those of the other groups. The teacher should then wrap up this discussion by making explicit connections between the activity and the main concept that the lesson was designed to help the students understand (in this case the biological species concept and what counts as an argument in science).

Individuals are then given an opportunity to articulate what they know and how they know it by crafting their own written argument. This component is included in the model because writing is an important aspect of science. Scientists must be able to share the conclusions of their research through writing. In addition, current research indicates that writing tasks like this one tend to encourage metacognition and can improve students' retention of the content (Wallace et al., 2004). Finally, and perhaps most importantly, writing makes each student's thinking visible to the teacher and provides an authentic assessment of each student's understanding of the content and their ability to craft a scientific argument. We use the prompt in Figure 4 to make the requirements of the writing task explicit to the students.

○ The Evaluate Alternatives Instructional Model

The Evaluate Alternatives model, which is based on the work of Osborne et al. (2004) and Solomon et al. (1992), is similar in many ways to the Generate-an-Argument model. However, this model places more emphasis on the evaluation of alternative claims and the importance of designing an informative investigation that can be used to test the merits of a claim. The students also need access to laboratory materials (lab benches, glassware, etc.) and safety equipment so that they can gather the empirical data they need to support or refute the alternative explanations. A lesson designed using this model tends to require a longer period to complete than a lesson designed using the Generate-an-Argument model.

To illustrate how this instructional model works, we will describe a lesson that we designed to help students understand that all new cells are formed from existing cells and to introduce them to the idea that the cell is the fundamental unit of structure, function, and organization in all living organisms (*NSES* Content Standard C, grades 9–12). It also helps students learn more about the history of science (*NSES* Content Standard G, grades 9–12) and enables them to develop the abilities necessary to do scientific inquiry (*NSES* Content Standard A, grades 9–12). In the following overview we describe the purpose of each step of the model, the nature of classroom activity during each step, and how to support and guide the students as they work.

Step 1: Introduce the Phenomenon to Investigate & the Alternative Explanations

In the first step of this model, students are introduced to a phenomenon that needs to be explained and two or more alternative claims that provide a causal mechanism or a descriptive account for the phenomenon under investigation. The students are then directed to develop a method that they can use to generate the data needed to either support or challenge the validity or acceptability of the alternative claims. The students can also be provided with information about relevant scientific theories, laws, or models so that they can use these ideas to help design their tests and rationalize their choice and use of data.

In this lesson, students were provided with a historical overview of the idea of spontaneous generation and how people attempted to test this idea before the work of Pasteur. They were also provided with two alternative claims to evaluate. (1) Life can arise from inanimate objects, but the conditions conducive to the formation of life must be present. These conditions include the availability of fresh air, water, and a source of food. (2) All living things come from a preexisting living thing. Living things appear to come from decaying organic substances because eggs are laid on, or spores land on, a food source and then begin to grow. The intent of this step is to capture the students' attention or to spark their curiosity, to give them a reason to engage in scientific argumentation, and to make the goals of the task explicit.

Name: Date:

What is your argument? **In the space below, write a multi-paragraph argument to persuade another scientist that your claim is valid and acceptable.**

As you write your argument, remember to do the following:

- **State the claim you are trying to support**
- **Include appropriate evidence and a sufficient rationale**
- **Organize your paper in a way that enhances readability**
- **Use a broad range of words including vocabulary that we have learned**
- **Make sure your writing has an easy flow and rhythm**
- **Correct grammar, punctuation, and spelling errors**

Figure 4. The writing prompt given to the students during the last step of the Generate-an-Argument instructional model. A second prompt that requires the students to provide a counterargument can be added to this one for the Evaluate Alternatives model.

Step 2: Testing the Explanations

This second step is one of the places where this model differs from the Generate-an-Argument model. As opposed to generating an argument from data provided by the teacher, the students are expected to generate their own data set, analyze it, and then use this information to support or refute the provided explanations. The students are therefore responsible for designing and implementing their own test of the alternative claims. This step is designed to give the students an opportunity to learn how to design a rigorous investigation and to better understand the ambiguities associated with empirical work.

During this portion of the investigation it is important for the teacher to circulate throughout the room and guide the students toward a productive investigation by asking questions and helping them to refine their method. For example, the teacher can ask questions such as "How will you be certain that X caused Z when you changed both X and Y?" and "How do you know that there are enough nutrients in your broth to support life?" to help the students remember to include a control, or "What are you trying to test?" and "What would you expect to see if that explanation is incorrect?" to help them differentiate between hypotheses (i.e., tentative explanations) and predictions (the data expected if an explanation is valid). This step, with proper guidance by the teacher, can also help the students understand that a variety of methods can be used to test the same claim. Overall, this step of the model took seven days to complete in the example lesson. One day was devoted to designing and setting up an experiment, 5 days for growth to appear in the flasks, and 1 day to record the results of the tests.

Steps 3–5: Generation of a Tentative Argument, an Argumentation Session, & Generation of Individual Arguments & Counterarguments

Steps 3–5 in the Evaluate Alternatives model are similar to steps 2–4 in the Generate-an-Argument model. In other words, once the students have gathered the data they need, they are directed to create an argument in a medium that can be shared by others. The students can be encouraged to include counterarguments as well as arguments in this model. The students are then directed to share their arguments and counterarguments with other groups using the whiteboards (or other readily available media). This session gives the students an opportunity to view a number of different arguments and to question and evaluate the methods of the other groups.

After the argumentation sessions are complete and the teacher has led a whole-class discussion about the concepts addressed in the lesson (in this case cell theory and experimental design), the students are provided with two writing prompts to complete. The first is the same as the prompt used at the end of the Generate-an-Argument model (see Figure 4). This prompt directs the students to craft a written argument in support of the claim that they think is the most valid or acceptable. This second prompt is similar to the first except that the students are directed to produce a counterargument that refutes the alternative claim. The intent of this step is to help the students gain valuable practice in generating a coherent scientific argument and a counterargument. It is also designed to cultivate essential scientific habits of mind. These written arguments and counterarguments can then be scored with a rubric (to download an example, see http://www.vicsampson.com) and used for summative or diagnostic assessment purposes.

○ Conclusions & Implications for the Teaching & Learning of Science

The two models presented here are based on current research on argumentation in science education and studies that indicate that argumentation plays a central role in scientific inquiry (Erduran & Jimenez-Aleixandre, 2007). Teachers can therefore use these models to better align classroom instruction with the nature of scientific inquiry and to focus on important learning outcomes that are often neglected in the science classroom. Empirical studies, for example, indicate that engaging students in scientific argumentation can help them develop a better understanding of the role of argument and evidence in science, improve their communication and writing skills, and strengthen their critical-thinking skills and their ability to collaborate with others (Erduran & Jimenez-Aleixandre, 2007; Duschl, 2008). These models are also well aligned with how students learn science in classrooms (Donovan & Bransford, 2005). Teachers can therefore use these models to help students reach the goals outlined in the *NSES* (NRC, 1996). Students need to develop these understandings and skills while in school in order to be literate in science (American Association for the Advancement of Science, 1989; NRC, 1996).

These instructional models, we argue, should provide a useful tool for teachers because they can be used as a template or a guide to design a lesson that addresses the content outlined in an existing curriculum. The models will work in a wide range of contexts. For example, we have used them to design lessons that engaged students in scientific argumentation in middle and high school science classrooms, large lecture courses at the undergraduate level, and science-teacher education programs at the graduate level. We therefore believe that these two instructional models have great potential and will provide teachers with a way to transform the nature of classroom instruction so that more students are able to develop a better understanding of both the science concept under study and the process through which scientific concepts are developed, evaluated, and refined.

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