

● YING-CHIH CHEN, JOSHUA STEENHOEK

**ABSTRACT**

Argumentation is now seen as a core practice for helping students engage with the construction and critique of scientific ideas and for making students scientifically literate. This article demonstrates a negotiation model to show how argumentation can be a vehicle to drive students to learn science's big ideas. The model has six phases: creating a testable question, conducting an investigation cooperatively, constructing an argument in groups, negotiating arguments publicly, consulting the experts, and writing and reflecting individually. A fifth-grade classroom example from a unit on the human body serves as an example to portray how argumentation can be integrated into science classrooms.

**Key Words:** Argumentation; argument-based inquiry; negotiation model; human body system; nature of science; scientific practice.

Cumulative understanding of the nature of science has led to an emphasis on argumentation as a means to help students learn science through negotiating their arguments publicly. *A Framework for K–12 Science Education* unprecedentedly addresses the role of argumentation in science and inquiry: “What engages all scientists, however, is a process of critique and argumentation” (p. 78), and argumentation is central in the scientific inquiry (National Research Council, 2012). The importance of this practice of constructing and critiquing evidence-based arguments is echoed throughout the Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010).

However, many science teachers struggle to use the core practices of science and the unique language (e.g., claim and evidence) in their classrooms. To address this challenge, we will demonstrate a negotiation model to show how argumentation can be a vehicle to drive students to learn science's big ideas by explicating how a fifth-grade teacher scaffolds argumentation through a lesson on the human body.

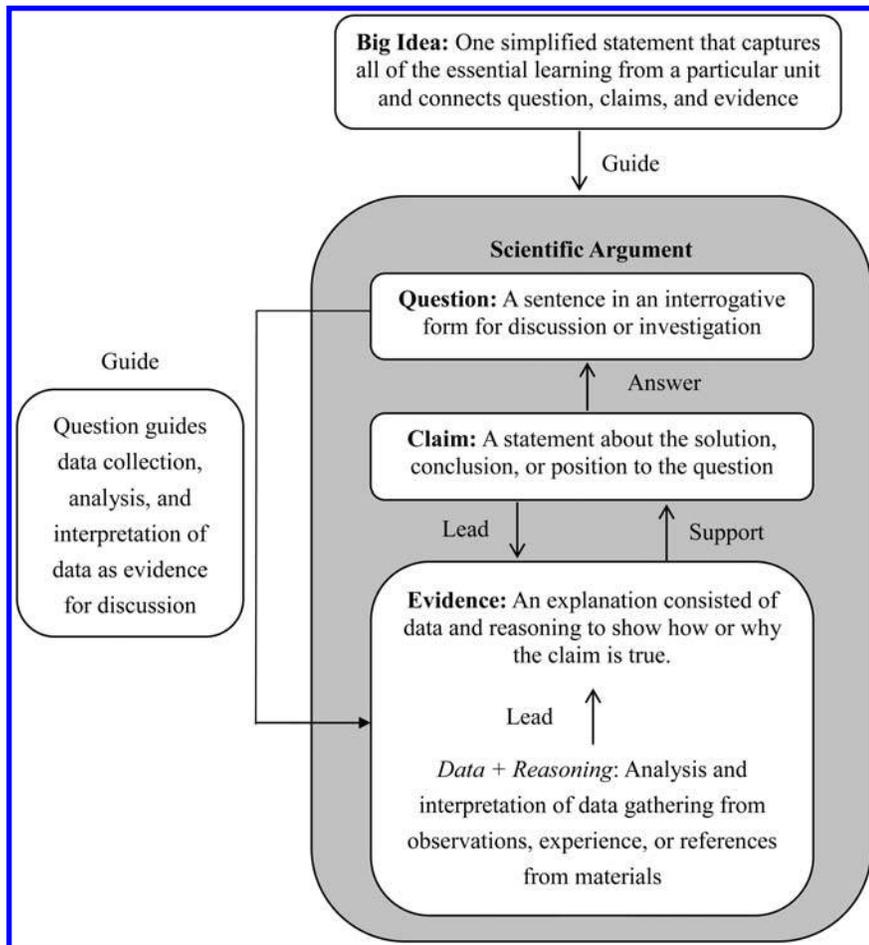
## ○ Negotiating Ideas Using the Argument Structure

Scientists develop acceptable knowledge in communities by searching data patterns, generating claims with the support of evidence, and debating their arguments publicly to strengthen those arguments. To generate a persuasive argument, scientists must convince their peers with high-quality evidence to support claims that can answer the research questions (Sampson & Gleim, 2009; Chen et al., 2013). They use specific structure and practices to construct, critique, defend, and evaluate arguments (Norton-Meier et al., 2008; Garcia-Mila et al., 2013).

Translating the argument structure and argumentative practices into science classrooms is challenging for both teachers and students (Sampson et al., 2013). Several researchers have lamented the fact that science instruction in schools currently inhibits this type of negotiated discourse, which is drastically different from the goal of inquiry in school science (Duschl, 2008; Varelas et al., 2008). In supporting this orientation, Nam et al. (2011) pointed out that, through engaging in argumentative practice, students should be aware of the process of producing, testing, and revising knowledge claims and the criteria of evaluating evidence shaped by data. That is, students need to use the argument structure to learn science concepts, just as scientists do.

Here, we develop a framework that enables biology teachers to integrate argument structure in biology classrooms (see Figure 1). The framework consists of four interrelated components: question, claim, evidence, and big idea. A *question* functions as an epistemic probe and a heuristic tool for initiating argumentation to pursue an answer or solution to understand natural phenomena. A *claim* must answer the question and be supported by the evidence. *Evidence* is data that are written together to make a “story” and explanation of how you know your idea is true (Cavagnetto & Hand, 2012). Therefore,

*Translating the argument structure and argumentative practices into science classrooms is challenging for both teachers and students.*



**Figure 1.** The components of an argument and the relationship between them.

evidence, including data and reasoning, is the important piece that supports the claim. Data can be presented in many forms of language, such as graphs, diagrams, and pictures, to extract regular patterns by individual students. Reasoning is the logical explanation for why the data extracted by students support the claim (Chen et al., 2013). We add one more component – *big idea* – to guide the development of arguments in science classrooms. The big idea is one simplified statement that captures all of the essential learning from the unit to help students engage in scientific argumentation and to achieve a depth of understanding of the concepts presented. The big idea of the unit plays a critical role in the relationship among the three argument components, especially the connections between claims and question and between claims and evidence.

This article presents a negotiation model, modified from the science writing heuristic (Norton-Meier et al., 2008), to address how to use the argument structure in classrooms. The model has six phases: creating a testable question, conducting an investigation cooperatively, constructing an argument in groups, negotiating arguments publicly, consulting the experts, and writing and reflecting individually. To explicate how the model may look in action, a fifth-grade classroom example from a unit on the human body is used to show how the negotiation model can work with students. The lesson was designed to help students understand the big idea – that human body systems work together – using the topic of the human digestive system as the avenue to understand the big idea. The following sections describe each phase of the model as we use it in our classroom.

## Phase 1: Creating a Testable Question

A good question can be a powerful motivating factor to lead students to engage in investigation (Windschitl & Buttemer, 2000). “Science begins with a question about a phenomenon, such as ‘Why is the sky blue?’ or ‘What causes cancer?’ and seeks to develop theories that can provide explanatory answers to such questions” (National Research Council, 2012, p. 50). Many science lessons include multiple investigation questions for students. This makes it difficult to determine what students should focus on while conducting an investigation. We suggest that teachers focus on only one driving question to scaffold students’ engagement in the argument-based inquiry. (Teachers have differing views of what a driving question is. *A Framework for K–12 Science Education* is a common thread to help find driving questions associated with curriculum topics.)

Before generating a testable question, teachers can ask students to share what they already know about the given topic. In this case, the teacher had the students draw a picture of the human body, sketch their current understanding of the body’s systems, and write about the role of the digestive system. This activity allows students to activate their prior knowledge and thereafter generate a more specific and usable list of testable questions (Figure 2). Teachers can then discuss the individual organs of the digestive system that the students have drawn

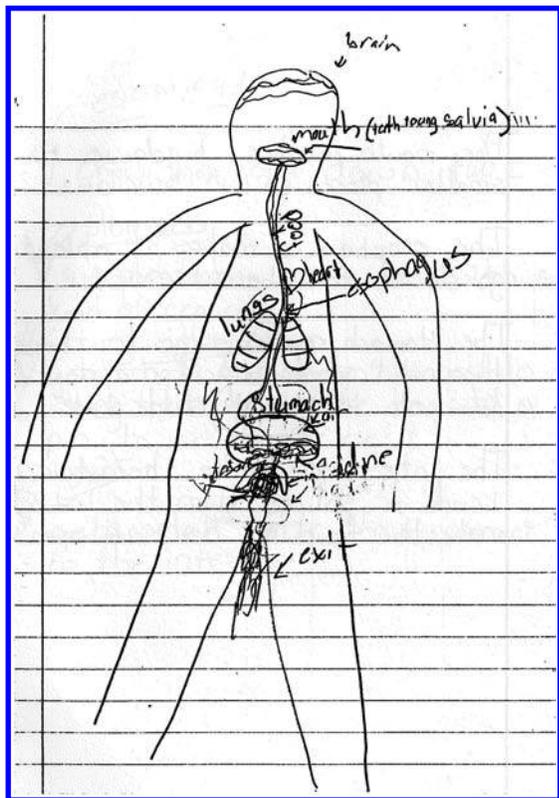
in general. For example, the mouth is the beginning of the digestive tract, where the first bite of food is taken, while the stomach is a muscular organ between the esophagus and small intestine. The students’ motivation is greatly enhanced when they are able to share their prior knowledge with each other. This allows them to encounter many differing ideas. These ideas cause the students to reanalyze their supporting evidence and to challenge the solidarity of others’. Once the teacher shifts the students’ activity to writing down any questions they are curious about and that can be tested, the students’ curiosity is much more cohesive.

A high-quality testable question can start, for example, from “Why...” or “What affects...” (instead of a yes/no question). Students usually can generate several questions that are researchable but difficult to test in the classroom. Therefore, questions can be divided into two categories: testable or researchable (Norton-Meier et al., 2008). Testable questions can be characterized by the following features:

- Inclusion of concepts needed in order to understand the big idea
- Identification of a variable to control, manipulate, and measure
- Capability of being tested in a classroom (including equipment and resources)

Researchable questions can be characterized by the following features:

- Inclusion of interesting concepts that extend the expected learning for the grade level



**Figure 2.** Example of a student’s writing for the human-body unit.

- Reference to complex relationships that lead to expert resources
- Incapability of being tested in a classroom (because equipment or resources are lacking)

Through discussing multiple questions based on the criteria, this class developed a testable question as a class: Why does the digestive system work? This is not a situation of the teacher telling the students what they need to explore; rather, students take their ownership of learning and decide the driving question they want to test through the teacher’s scaffolding.

### Phase 2: Conducting an Investigation Cooperatively

In the beginning of this phase, students are asked to design a method to address the question as a whole class. Once they have developed the basic tests, students are organized into small groups of three or four and further develop a detailed investigation that they can conduct to collect the data needed to craft a claim and evidence to answer the question.

Each group was given a packet that included a handout with the goal, the testable question developed as a class, and the materials for the investigation (see Figure 3). Each team was asked to discuss a detailed plan to use materials to simulate a process of the human digestive system. To help students complete the task, teachers should help them think about the function of the digestive system. For example, the mouth functions as chewing breaks the food into pieces that are more easily digested, while saliva mixes with food to begin the process of breaking it down into a form your body can absorb

and use. In doing so, students can capture the function of each organ of the digestive system and simulate the authentic process of the digestive system. Figure 4 is an example of a test procedure designed by a student group.

When students conduct the tests, it may be helpful for teachers to move from group to group and ask them to record what they see from each step of the tests. For example, teachers can ask focused questions such as “What data do you record?” and “Why do you think those data are important?” Figure 5 is an example of observation summarized by another student group.

### Phase 3: Constructing an Argument in Groups

The purpose of this phase is to make a claim and marshal evidence to develop a convincing argument about a question through searching the patterns of data as a group. To help students construct a scientific argument, the teacher can help them think about the components of an argument, the relationship between components, and the difference between data and evidence (see Figure 1). In science, data cannot become evidence without reasoning. The teacher can ask penetrating questions to help students craft their arguments, such as “What is your claim for the question?” or “What evidence can support your claim?” Figure 6 is an example of an argument developed by another student group.

### Phase 4: Negotiating Arguments Publicly

This phase attempts to provide students a negotiable environment in which to present their arguments and

<b>Big Idea:</b>	<b>Human body systems work together.</b>
<b>Research question:</b>	Why does the digestive system work?
<b>Activities:</b>	You and your group will need to simulate the process of how food (saltine crackers) is digested after you eat it. You may use the following materials during your investigation. You will need to observe and record what happens to the food at each phase of the digestive process. To be successful, you will need to develop an argument consisting of a claim and evidence to answer the research question. Your group will present your argument in the class to convince your classmates that your ideas are acceptable and valid to answer the question.
<b>Materials:</b>	Saltine crackers, popsicle sticks, spoons, saliva, vinegar, beakers, plastic bags, rock polisher, paper towel, gauze mask, and goggles.
<b>Suggested tests:</b>	(You can develop your group test based on the suggestion.)
<b>Test 1 (Teeth):</b>	Use popsicle sticks to simulate teeth and chew up saltine crackers.
<b>Test 2 (Tongue):</b>	Use a spoon to simulate the tongue and stir the saltine crackers.
<b>Test 3 (Saliva):</b>	Put saliva into the beaker.
<b>Test 4 (Stomach Acid):</b>	Pour all things into a plastic bag and put vinegar into the beaker to simulate stomach acid.
<b>Test 5 (Intestines):</b>	Seal the plastic bag and shake it. Put the bag in rock polisher and turn on the rock polisher for 24 hours.
<b>Safety Issue:</b>	Because this simulation activity will produce strong smell and food debris, you should wear gauze masks and goggles to protect your faces and eyes from being splashed.

**Figure 3.** Handout provided to students at the beginning of the unit.

### Test (teeth)

- 1) gather materials
- 2) tape popstical sticks together
- 3) put one bite size piece of food on table.
- 4) bite the piece of food 10-15 times with p.s.
- 5) observe and record

don't move teeth to food don't move ~~food~~ to teeth

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### Test #2 (teeth/tongue)

Repeat test #1 1-5 but move food under teeth

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### Test #3 (teeth/tongue/saliva)

\*Use test #2 and food results

- 1) Put food result in cup
- 2) Collect 10 mL of saliva in beaker
- 3) pour saliva into food cup
- 4) mix food and saliva using p.s. for 1 minute
- 5) observe and record

### Test #4 (stomach acid)

- 1) take vinegar and pour in beaker to measure 25 mL
- 2) take result from test 3 and pour into cup or baggie.
- 3) pour the 25 mL of vinegar into cup or baggie that has the food.
- 4) mix food and vinegar together using p.s. or seal and shake
- 5) observe and record

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### Test #5 (intestines)

- 1) take result of test 4 and
- 2) put baggie in rock polisher
- 3) turn on rock polisher for 23 hours
- 4) observe and record

Figure 4. Example of a test procedure designed by students.

## Analysis

In our group with the chip we observed that first the "teeth" smashed up the chip with physical contact. The "tongue" moved the food back under the teeth so it could be smashed up into even smaller pieces. Next we put the food results into a bag with 10 mL of saliva and mixed it up for 1 min. After that we added vinegar (acid) and put into rock tumbler for 24 hours or so. after we took out and observed.

Spit  
chip + vinegar  
looked like  
Smashed goo  
being reaped  
by vinegar or  
water

looked like watered down chips

Figure 5. Example of a student group's summary of observations.

receive critiques from their peers and their teacher (Kuhn & McDermott, 2013). Students are required to give constructive feedback to other groups, and this practice can help them understand and address the strengths and weaknesses of their own arguments. It is important to note that the teacher plays a critical role in scaffolding the students' ability to provide constructive feedback. Table 1 explicates three dimensions of how teachers can increase their effectiveness in scaffolding the students' ability to provide the constructive feedback by shifting from level 1 toward level 3. The first dimension focuses on the conversation among the teacher and students. The second one focuses on the way in which students represent their ideas during the conversation. The third one emphasizes how students use argument structure to debate, discuss, and critique their arguments.

At this point, students usually can explain the process of the human body's digestive system, but they may not be aware that its main function is to get energy from food. Questions such as the following can help them understand this: "Why do we need to eat food?" "Is the purpose of our digestive system only to break down food to smaller pieces?" "Why does the digestive system need to break down food into very small pieces?" Those questions can scaffold students' thinking toward the main function of the digestive system to answer the driving question.

We encourage teachers to provide students with multiple rounds of public negotiation to revise their arguments (Chen & Steenhoek, 2013). In our class, students did one more round of public negotiation.

Figure 7 is an example of a final argument consisting of a claim and evidence. Compare Figures 5 and 7; this group revised and strengthened the argument through public negotiation without formal lecture. Students engage in an authentic argumentative process, just as scientists do.

<b>Claim:</b>	<b>Our digestive system works with other systems in our body</b>
<b>Evidence:</b>	Our digestive system works with other systems in our body. For example, our bone system works with our digestive system because our jaw is a bone and it crunches up the food into tiny food remains. The muscle system works with the bone and digestive system because the jaw can't move without the muscles, and if the jaw can't move, the food will not get crunched up, causing us to choke and die because the food is too big and will get caught in your esophagus. We also need saliva because it makes the food mushier and it helps it slide down the esophagus into the stomach. If we didn't have the saliva, food wouldn't slide down the esophagus, especially to the stomach. We need the stomach because if we didn't have the stomach, the food and acid wouldn't have any place to stay. Then the food couldn't get any smaller/ liquid. Then it goes out the body as waste.

Figure 6. Example of an argument written by a student group.

### Phase 5: Consulting the Experts

This phase allows students to compare their own arguments to what experts say. Experts could include speakers, Internet resources, textbooks, trade books, magazines, or newspapers. Students often read much more carefully and are able to think critically about the materials after negotiating their arguments in class. Instead of accepting the information thoroughly without debate, students are required to pick up the information from the materials as their evidence to solidify and validate their arguments. This is often a great time for students to find confidence that their ideas are scientifically accurate and to be able to attach additional meaning and scientific vocabulary. Students are also

Table 1. Levels of public negotiation.

	<b>LEVEL 1 Limited</b>	<b>LEVEL 2 Basic</b>	<b>LEVEL 3 Exemplary</b>
<b>Dialogical Interactions</b>	<ul style="list-style-type: none"> <li>Teacher initiates closed-ended questions to seek single correct answer.</li> <li>Students have few opportunities to discuss their ideas.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher attempts to ask open-ended questions to engage students in the conversation.</li> <li>Students can express, elaborate, and clarify their ideas in the conversation.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher constantly asks different layers of questions (i.e., Bloom's Taxonomy) to elicit, compare, challenge, and synthesize students' ideas to get a consensus.</li> <li>Students listen to other ideas and construct scientific knowledge through conversation.</li> </ul>
<b>Representation</b>	<ul style="list-style-type: none"> <li>Teacher focuses only on a single mode (talk or writing) to engage students in discussion.</li> <li>Students discuss their ideas without using writing as another negotiated tool.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher attempts to use both talk and written representations to help students communicate their ideas.</li> <li>Students use written representations to scaffold their discussion.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher consistently requires students to communicate their ideas through different modes and connect them to the big idea (talk, texts, diagrams, figures, pictures, concrete materials, etc.).</li> <li>Students used a variety of modes to represent and communicate their arguments.</li> </ul>
<b>Science Argument</b>	<ul style="list-style-type: none"> <li>Teacher does not use the argument structure to drive the conversation or focuses on getting the correct answer for claims and evidence.</li> <li>Students are only involved in the presentations of their arguments, rather than in debating their ideas on the basis of their claims and evidence.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher attempts to use the argument structure to establish the dialogical interactions (e.g., How does your evidence support the claim, How does your claim connect to the big idea, etc.).</li> <li>Students engage in argumentative dialogue using the structure of questions, claims, and evidence.</li> </ul>	<ul style="list-style-type: none"> <li>Teacher consistently encourages students to use the three components of argument and to link big ideas, questions, claims, and evidence.</li> <li>Students can engage in justifying their argument, provide feedback to other groups' arguments, are aware their weakness of argument, and are willing to revise.</li> </ul>

<b>Claim:</b>	<b>Our digestive system works with other systems in our body.</b>
<b>Evidence:</b>	Our digestive system works with other systems to break down the food and produce energy. Systems not only help produce the energy, they also receive the energy to help the body work. The process to digest is: First, the food goes through the mouth and gets broken down by the teeth, tongue, and saliva. Next it goes down the esophagus and into the stomach and gets broken down even more by the stomach acid. Then it goes through the intestines and exits the body. Sometime along the line, the energy in the food is drained and transferred to different systems. Our digestive system works with other systems. For example, the skeleton system works with our digestive system because the jaw is a bone. Our jaw helps because the teeth are connected to the jaw, and the jaw moves up and down to move the teeth and crunch up the food. Another example is the muscle system. It helps because the tongue is a muscle. It's important because the tongue moves the food under the teeth to be chomped up, and it also pushes the food into the esophagus so it can drop into the stomach. Also, another muscle is the muscle that moves the jaw. Without that muscle, the jaw wouldn't be able to move, so the teeth wouldn't be able to chomp up the food, so the food wouldn't get caught in our esophagus, and we would choke and die.

**Figure 7.** Example of a student group's revision of a written argument.

given a chance to resolve any scientifically incorrect understandings that persist.

### Phase 6: Writing & Reflecting Individually

The final phase is to help individual students reflect on what they learned over the unit, how their ideas changed in the process, and why they want to change their ideas. It is an appropriate time to discuss the critical role of evidence that scientists develop for supporting their claims and constructing acceptable knowledge in the community (Chen et al., 2013).

Table 2 is a rubric for scoring students' arguments and helping both students and teachers understand what counts as a good claim, what counts as good evidence, and what makes a good connection between a question, a claim, and evidence. The rubric can be adopted to fit the learning goals of other units and your district standard. This writing activity also can help teachers monitor what students learn over the unit and what concepts students need to explore more.

### Conclusion

*A Framework for K–12 Science Education* suggests that argumentation should play a central role in school

**Table 2. Writing rubric for the digestive system.**

Dimensions	Score		
	Limited (1)	Basic (2)	Exemplary (3)
<b>Accuracy of a Claim</b>	Claim is incomplete, with less information than necessary, or is scientifically incorrect.	Claim is a complete statement with some good connection to data analysis but is confusing.	Claim is complete, scientifically correct, and comes directly from the data analysis.
	<b>Example:</b> Addresses only the process of the digestive system, but the statement is scientifically incorrect.	<b>Example:</b> Addresses the process of the digestive system but does not explicitly address the purpose of the digestive system.	<b>Example:</b> Addresses the process and the purpose of the digestive system as well as how the digestive system works with other systems (e.g., muscular system, skeleton system).
<b>Quality of Evidence</b>	Evidence is a list of data or just restates "what" happen in the data.	Evidence uses important data points and a few unrelated data points to explain what was learned from the investigation.	Evidence uses only important data points and focuses on the explanation of "why" and "how" the data consolidate the evidence.
	<b>Example:</b> Lists the major organs of the digestive system (e.g., teeth, tongue, esophagus, stomach, intestines); nothing is said about the process and purpose of the digestive system.	<b>Example:</b> Explains the process of the respiratory system (e.g., to break food into smaller pieces), but nothing is said about the purpose of the digestive system (e.g., to produce energy).	<b>Example:</b> Uses the simulation model to explain the process of the digestive system and further extends to the main purpose of the digestive system.
<b>The Relationship between a Question, a Claim, and a Big Idea</b>	Claim does not answer the question.	Claim answers the question but is hard to connect to the big idea.	Claim directly answers the question and connects to the big idea.
<b>The Relationship between a Claim and Evidence</b>	Evidence does not support the claim.	Evidence attempts to support the claim but does not explain very well.	Evidence supports the claim in detail.

science because it is a vehicle to drive students to learn the big ideas presented. The increased focus on argument-based inquiry in school science provides an opportunity for teachers to create a negotiable environment in which students can construct and critique knowledge. We present the negotiation model to demonstrate how to engage students in using the scientific argument structure to learn science's big ideas through argumentative practices. Empirical studies have shown that engaging students in the negotiation model can help them develop deeper conceptual understanding, advance critical thinking skills, and promote literacy in science (Cavagnetto et al., 2011; Chen, 2011; Nam et al., 2011). It is time for all of us to move away from activity-driven inquiry to argument-based inquiry in which students can construct and critique scientific knowledge through authentic and core practices of science.

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YING-CHIH CHEN is a Research Associate at the STEM Education Center at the University of Minnesota in St. Paul, MN 55108; e-mail: chen2719@umn.edu. Ying-Chih Chen will be an Assistant Professor at Arizona State University in Tempe, AZ, 85287 in Fall 2014; e-mail: chenpeter78@gmail.com. JOSHUA STEENHOEK is a fifth-grade math and science teacher at Jefferson Intermediate School in Pella, IA 50219; e-mail: joshua.steenhoek@pella.k12.ia.us.

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