A NEGOTIATION CYCLE TO PROMOTE ARGUMENTATION IN SCIENCE CLASSROOMS

by Ying-Chih Chen and Joshua Steenhoek

A *Framework for K–12 Science Education* (NRC 2012) identifies three dimensions of K–12 science and engineering curricula and classrooms are addressed in the *Next Generation Science Standards*: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. The concept of argumentation is emphasized in practice #7 of the *Framework*: Engaging students "in argumentation from evidence about an explanation supports students' understanding of the reason and empirical evidence from that explanation" (NRC 2012, p. 44).

But have you wondered what argumentation practices look like in the classroom? Have you been searching for ways to help students understand and appreciate science core ideas through argumentation? This article introduces a negotiation cycle to help teachers incorporate argumentation into the science classroom. The negotiation cycle, which is modified from the Science Writing Heuristic approach (Hand et al. 2009), emphasizes using argument as a vehicle to learn about scientific core ideas and practices. It also connects to the Common Core language-arts standards (NGA and CCSSO 2010), because writing and reading pedagogies are embedded in the cycle.

Teachers can use multiple rounds of the cycle to deepend students' understanding of science core ideas. The numbers of rounds of the negotiation cycle will depend on how students progress, the depth of learning that is required, and students' ability to shift toward a consensus that is scientifically acceptable. The negotiation cycle can be repeated until students are satisfied with their arguments and do not receive any critique from their peers or teacher.

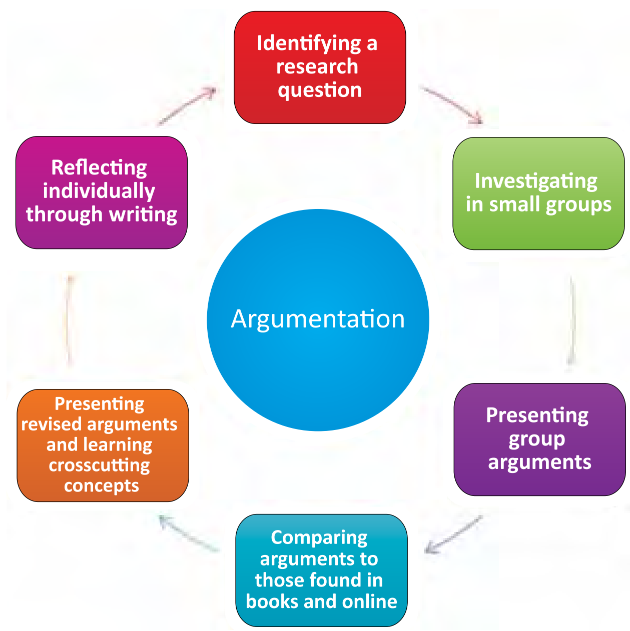
Learning science by engaging in argument from evidence

Science is not about discovering or memorizing facts; rather it is about constructing and critiquing arguments and considering multiple explanations for phenomena (McNeill 2009). Scientists construct their arguments and share them publicly to gain critique. The public critiquing process helps scientists to evaluate weaknesses in their work so they can strengthen their argument (NRC 2012). However, argumentation has "too often been underemphasized in the context of science education" (NRC 2012, p. 44). In order to engage students in constructing and critiquing arguments like scientists, the nature of typical classroom activities and discourse patterns needs to change. In other words, teachers must to do more than tell students about science content or provide recipes to conduct fun, hand-on activities (Zembal-Saul 2009). Teachers also need to create learning environments where students can negotiate core ideas with peers by using claims and evidence to develop their understanding about the natural world (Hand et al. 2009). This is the idea of the first and third dimensions of the new Framework, which emphasize learning a limited number of core ideas through argumentation practices.

To accomplish this, students should be provided with opportunities to develop a tentative argument to answer a research question by connecting empirical data to their knowledge framework. Students are then asked to present their argument to others and negotiate its weaknesses, including inconsistencies, insufficient evidence, and relationships of the argument to the question and core idea. Once their argument is negotiated, students evaluate and revise it to develop a better argument and understanding to answer the research question (Sampson, Grooms, and Walker 2011).

The negotiation cycle introduced here demonstrates how to incorporate those ideas emphasized by the Framework into science classrooms (Figure 1). The negotiation cycle comprises six phases, each of which has a unique purpose in engaging students in argumentation practice (Figure 2). Engaging students in argumentation practice is challenging and won't happen overnight (Cavagnetto 2011). It usually takes more than five months to move students from focusing on memorizing facts to constructing and critiquing knowledge through arguments. When students engage in the negotiation cycle over time, they develop the skills to look for patterns of data in generating convincing evidence, use evidence to frame an argument and then persuade peers of the validity of their points, and identify flaws in their own arguments (Chen 2011).

FIGURE 1 Negotiation cycle



The negotiation cycle

A multiple-day lesson that takes place over two weeks is described here to illustrate how this negotiation cycle works. This lesson was designed to help students understand how the respiratory system works with other systems. Students were introduced to one core idea (human body systems work together) with one question (how does our respiratory system work with other systems?) designed to show the function of respiration. To blend this core idea with argumentation practice, students were asked to build a model to demonstrate and explain how the respiratory system works (see Figure 3).

Phase I: Identifying a research question

In the initial phase, the class develops a research question to guide investigation. To generate the re-

FIGURE 2 Six phases of the negotiation cycle

Phase	Task	Purpose
I	Identifying a research question	Elicit prior knowledge and gain understanding of the scientific context in which the research question is explored.
II	Investigating in small groups	Learn how to collect data from an investigation, generate evidence with an appropriate explanation supported by data, and craft an argument that can be shared with others.
III	Presenting group arguments	Share arguments to gain critique and understand the weakness of arguments. Know how to critique other groups' arguments and give feedback.
IV	Comparing arguments to those found in books and online	Refine and improve on initial arguments through thinking about peers' critique, and information from textbooks and the internet.
V	Presenting revised arguments and learning crosscutting concepts	Share the revised argument to gain critique. Learn crosscutting concepts to deepen understanding of a given core idea.
VI	Reflecting individually through writing	Reflect on what was learned, the challenges faced, and if arguments answered the research question.

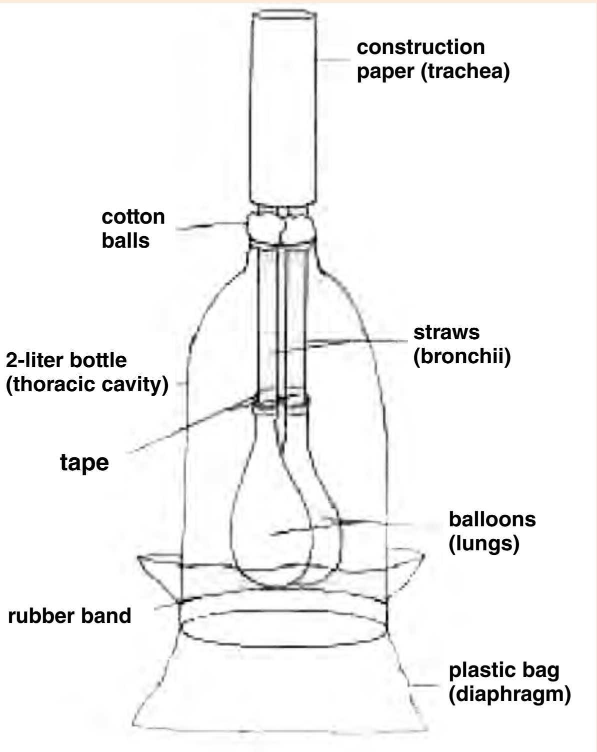
FIGURE 3 Student handout for the respiratory system

Core idea: Human body systems work together.

Research question: How does our respiratory system work with other systems?

Goal: Your group must design a model that can represent our real respiratory system to answer the research question. To be successful, you will need to develop your group's claim and evidence that answer the research question by using the model you build.
You may use the following materials during your investigation: plastic bottles, straws, clay, rubber bands, balloons, tape, scissors, blades.

* The diagram to the right is an example of a model that students may be able to develop to represent the system (students can develop other models that represent the system, as well). We suggest that teachers not provide this model for students in the beginning of the lesson. However, teachers should guide students to think about models that can really represent our respiratory system so they can eventually use the model at right to explain how it works with other systems.



(KILBURN 1997)

FIGURE 4 A physical model of a human body system

search question, teachers can provide a physical model or pictures to elicit and pique students' diverse thinking about the role of the respiratory system in the whole human body system (Figure 4). As a class, students brainstormed what they already knew about the respiratory system and the human body system in general. Students were familiar with the purpose of the respiratory system in the human body system but unaware of how our respiratory system works with other systems. Through the discussion, students came up with an agreed-upon investigation question: How does our respiratory system work with other systems? This initial phase takes approximately 20 minutes.

Phase II: Investigating in small groups

After the class generated the research question, students were divided into small groups of three or four. Each group was given a packet that included materials and a handout with the goal and research question for the investigation (see Figure 3). Students were asked to use the materials to build a model to simulate how the respiratory system works based on their prior knowledge. This phase provides students with the opportunity to think about how to use the simulation model as evidence to explain how the respiratory system works and to test their ideas through peers' critique in a group. In science, evidence not only includes qualitative information (e.g., data, observations), it also uses explanatory information that is related to the drawing or model (Villanueva and Hand 2011). A framework consisting of a core idea, a question, a claim, and evidence (Figure 5) can be introduced in the beginning of phase II and used to guide student argumentation practice. Based on their models and the framework, the groups generated a tentative claim and supporting evidence in response to the research question. Figure 6 is an example of one group's tentative claim and evidence.

This framework in Figure 5 is used to drive argumentation practice when students engage in small-group investigation. For example, students in this investigation were required to answer questions such as the following: What is my claim? How does my claim answer the question? What evidence do I have for my claim? (Cavagnetto 2011). If students had difficulty building an argument, we used sentence stems

FIGURE 5 A framework for argument structure

Core Idea: One simplified statement that captures all of the essential learning from the unit

↓ Guides

Scientific Argument

Question: A sentence in an interrogative form for discussion or investigation

↑ Answers

Claim: A statement about the solution, conclusion, or position to the question

Leads ↓ ↑ Supports

Evidence: An explanation consisting of data and reasoning to show how or why the claim is true

—***Data:*** Citation from observation, experience, or books

—***Reasoning:*** Interpretation and explanation of the data showing how the data supports the claim

FIGURE 6 A sample of claim and evidence

Claim: What inferences can I make?	**Evidence: How do I know? (Justify your claim by providing evidence for it.)**
The respiratory system helps to move the air entering the mouth to the lungs.	That process for breathing is in your mouth, through the windpipe, and into your lungs. We use the straw to represent the windpipe and the balloons to represent the lungs. The bottle can be our rib cage. We can blow to make the lungs swell up.

such as the following to provide guidance in the use of claim and evidence: "My claim is _____ because_____ [evidence]." Prior to students going public with their ideas, we asked penetrating questions (Bass, Contant, and Carin 2009) to help them self-critique their own models. This private negotiation encourages students to use their empirical knowledge while writing their evidence to support their claim. Teachers can move from group to group and monitor student progress by asking questions such as the following:

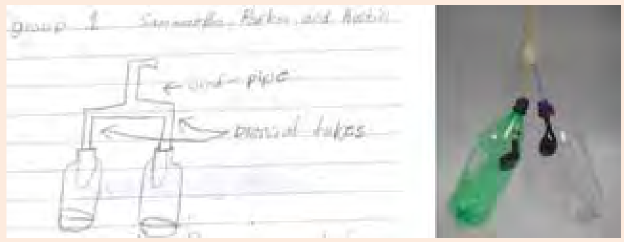
- Could you explain how your model works?
- Show me the evidence from your model that supports the claim.
- Could you explain why you connect straws to the balloon?
- What evidence did you use from your model to explain the relationship between the lungs and chest?

It is important for the teacher to challenge and clarify students' thinking without providing the "right answer." In this phase, students' models typically do not match the scientific model. This is perfectly acceptable as long as the student model is reasonable and feasible based on their current evidence. There will be multiple opportunities for students to revise their scientifically incorrect thinking. This phase of the negotiation cycle takes one or two 50-minute class periods depending on students' previous experiences with argumentation. Figure 7 shows an example of a student's first sketch and model of the respiratory system.

Phase III: Presenting group arguments

This phase provides an environment in which students construct and critique their claim and evidence in a whole-class negotiation. Students should be prompted to focus on the negotiation about claims

FIGURE 7 A student's sketch and model of the respiratory system



and evidence rather than making a personal attack. The following guidelines are particularly important in this phase. Developing these guidelines with the class will create a sense of ownership, and therefore students will be more inclined to abide by the rules. These guidelines emphasize what students need to do and how to negotiate.

What do I do when I negotiate?

- Make others' arguments better: Focus on the idea/claim/evidence, not the person.
- Encourage other students: If someone is not talking or has not had an opportunity to talk, involve that person by asking questions.
- Provide evidence for what you say: When you make a claim, you must support it with evidence. Challenge others' thinking by using evidence.
- Be respectful: Use an appropriate volume and tone; listen to other ideas and make connections.

How do I negotiate?

- Take a side: Agree with what someone says or disagree with what someone says and explain why you disagree.

- Use conversation to find the most accurate conclusion. Try to let others see why you are thinking accurately.

The teacher needs to encourage students to provide feedback to other groups' arguments and identify the weakness of their own arguments through the public negotiation process. It is most important that students ascertain if their claims are supported by evidence and explain the real situation. For example, after student groups presented their model of the respiratory system (shown in Figure 7), their peers critiqued the model with comments and questions such as "We don't have people blowing air down your windpipe," or "How do the muscles and the bones help to get air in and out of your body?" Peers' critiques helped student groups to understand the limitations of their model, and they used the feedback they received when reconstructing their model in phase IV. We suggest that teachers give students one 50-minute class period to complete this phase of the cycle.

Phase IV: Comparing arguments to those found in books and online

At this point, when students are well aware of the weaknesses of their models, they conduct research online and using nonfiction texts to gather more information to revise their model. For example, students quickly did a general search for the "respiratory system" and found there is a muscle below the lungs called the *diaphragm*. This new idea sparked a flurry of questions and additional searches. Students were encouraged to find multiple sources that all support the same idea. This process allows numerous opportunities to make additional connections through the text, diagrams, and their own models. After using these resources to find out what others had said about ideas similar to theirs, students decided whether they wanted to make changes to their models based on what they'd learned through their research.

Using reading strategies can also help students make meaning from text and compare their ideas with texts. Figure 8 provides some suggestions for students when comparing their models with experts' models from books or the internet.

Because the muscular system (diaphragm) is the key point to make the respiratory system work, teachers can scaffold students to focus on the exploration of what the muscles are while students search for information from books or online. Students usually encounter difficulties in understanding how the diaphragm interacts with the respiratory system. The teacher may interject questions such as the following: "What gives lungs their movement?"; "What is the diaphragm and where is it located?"; and "Put your hands on your chest while you breathe. Can you feel how changing the size of your chest makes the air go in and out?" These questions should be pinpointed to the relationship between the diaphragm and the lungs. Teachers' questioning can scaffold students' thinking toward the core idea. The research activity should take approximately one 50-minute class period to complete.

After comparing their ideas with other sources, students were provided opportunities to revise their

FIGURE 8 Recommendations for comparing models with experts' work

Recommended	Not recommended
Articulate similarities and differences with text/expert.	Simply restate information heard from peers or taken from experts or continually repeat your own ideas with no regard for new learning.
Make connection between text/expert and your own argument.	Rarely or never listen to other ideas and connections.
Construct an improved version of the argument.	Make comments that solely attack peer ideas or only focus on yourself.

first models. Initially, many of the groups neglected to mention the relationship between the respiratory and muscular systems. Even when groups mentioned the muscular system in the previous model, they usually had difficulty explicitly explaining how these two systems work together. As Figure 9 shows, this time, students considered how the diaphragm, rib cage, windpipe, and lungs work together based on their group discussion and evidence from the internet and books. Although this model (and others) was still not completely consistent with a current scientific model, it did have sophisticated features. Specifically, the diaphragm worked in unison with the lungs and rib cage. The revision activity should take approximately one 50-minute class period to complete.

Phase V: Presenting revised arguments and learning crosscutting concepts

After student groups finalized their respiratory models, they presented them to the rest of the class. The model shown in Figure 9 received many peer critiques, including the following: "The diaphragm doesn't touch them. You can't move your lungs" and "You do not explain how the diaphragm works with the lungs." These critiques stimulated students to reflect on the relationship between the diaphragm and the lungs. We suggest that teachers give students 30 minutes to complete the whole-class negotiation.

After group presentations, students may perceive the limitation of their knowledge to build a model that explains the system. At this point, we employed activities to help students understand that air is matter and takes up space as well as the relationship between air pressure and the volume of air. See the online version of this article at *www.nsta.org/middleschool* for an activity that demonstrates the relationship between air pressure and the volume of air. In the activity, students observe what happens to a marshmallow in a sealed syringe when the plunger is pushed down and pulled out. Teachers can have students place one finger over the syringe to seal the opening and ask students to describe how it feels when the plunger is pushed down and pulled out.

This activity helped students understand the function of the diaphragm and how the diaphragm works with the respiratory system through the concept of the relationship between pressure and volume of air. The focus was to integrate into this unit students' knowledge from physics about the balance of space and air pressure. This is the idea of the second dimension of the new Framework that emphasizes learning crosscutting concepts across science disciplines. The activity should take approximately one 50-minute class period to complete.

Throughout the unit, students continually explored additional evidence about how the respiratory works with other systems, which targeted the core idea. We suggest that teachers give students at least 30 minutes to reflect on and revise their group arguments after introducing the relationship between pressure and volume of air. As Figure 10 indicates, at the end of the unit, most students developed models more consistent

FIGURE 9 A student's sketch and model of the respiratory system

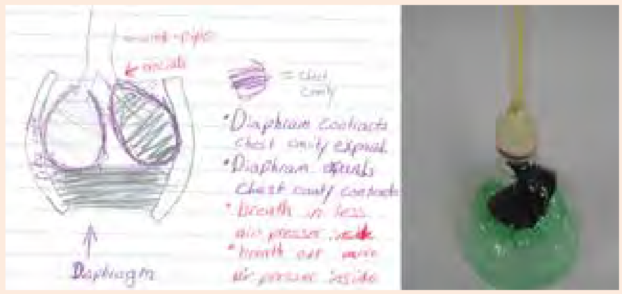
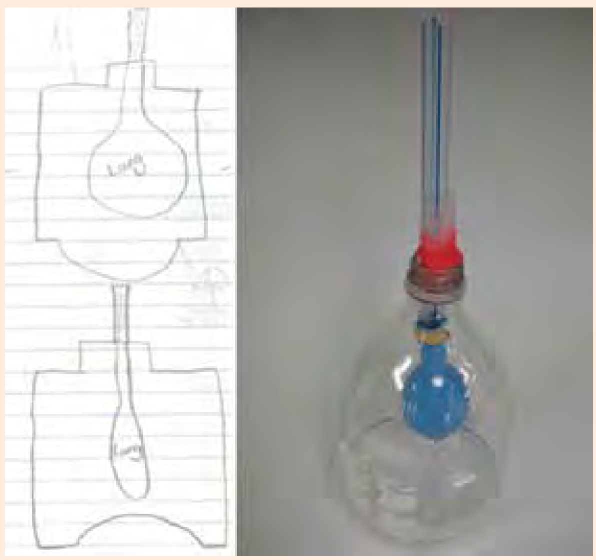


FIGURE 10 A student's sketch and model of the respiratory system



with the current scientific model of the respiratory system. At this point, if there are any remaining students who do not yet understand how to make their model consistent with the scientific model, teachers should engage in Just-in-Time instruction to help these students understand how the diaphragm brings air into the lungs. The sketch and model in Figure 10 show that the diaphragm doesn't have to touch the lung, and the lung still moves.

Phase VI: Reflective writing

At the end of the unit, a summative writing activity helps students reflect on what they've learned, the challenges they've faced, and whether their arguments answered the research question. This is also a good time to discuss the various aspects of the nature of science, that scientists revise their argument based on evidence and negotiation, and that scientific knowledge is tentative and changes over time based on evidence. Each student was required to produce a written argument in support of one of the claims and evidence. This writing activity also provided teachers with a window into each student's thinking, a summative assessment of student learning, and an opportunity to give students useful feedback.

Because writing a strong claim and evidence was difficult for students, we provided them with a guideline for doing so (Figure 11). See Figure 12 for a rubric for scoring these arguments; the rubric helped both students and teachers understand what counts as a good claim and what counts as good evidence. Teachers can tailor the rubric as needed to fit a specific unit or situation.

The following example, which clearly demonstrates knowledge of how the diaphragm works with the lungs and rib cage, is excerpted from one student's work: "When the diaphragm goes down, the rib cage gives the lung more space. The diaphragm going down creates a larger space, or area of lower air pressure inside of the body than outside. The air of higher pressure travels to the area of lower air pressure until the pressures are equalized. When the diaphragm moves upward, the chest has a higher air pressure than outside and forces the air out of the body." This phase of the lesson requires one 50-minute class period to complete.

Benefits of the negotiation cycle

This negotiation cycle can help students engage in argumentation practices blended with core ideas. It can also help students develop critical-thinking skills, conceptual understanding, and communication skills through talk and writing activities (Chen 2011). The negotiation cycle proposes a way for students to move away from being passive learners with didactic instruction to becoming independent learners who can take ownership of their learning and engage in argument from evidence (practice #7; NRC 2012). This negotiation cycle also aligns with recommendation 4 of the Framework: "Standards should emphasize all three dimensions articulated in the framework—not only crosscutting concepts and disciplinary core ideas but also scientific and engineering practices" (NRC 2012, p. 300).

Follow-up test results showed that the group of students that used the negotiation cycle to study science over time performed better on critical-thinking tests and the Iowa Test of Basic Skills than students who were taught using lecture-based teaching strategies (Akkus, Gunel, and Hand 2007). For example, the effect-size calculations for critical-thinking tests indicated

FIGURE 11 Guidelines for writing a strong claim and evidence

Claim

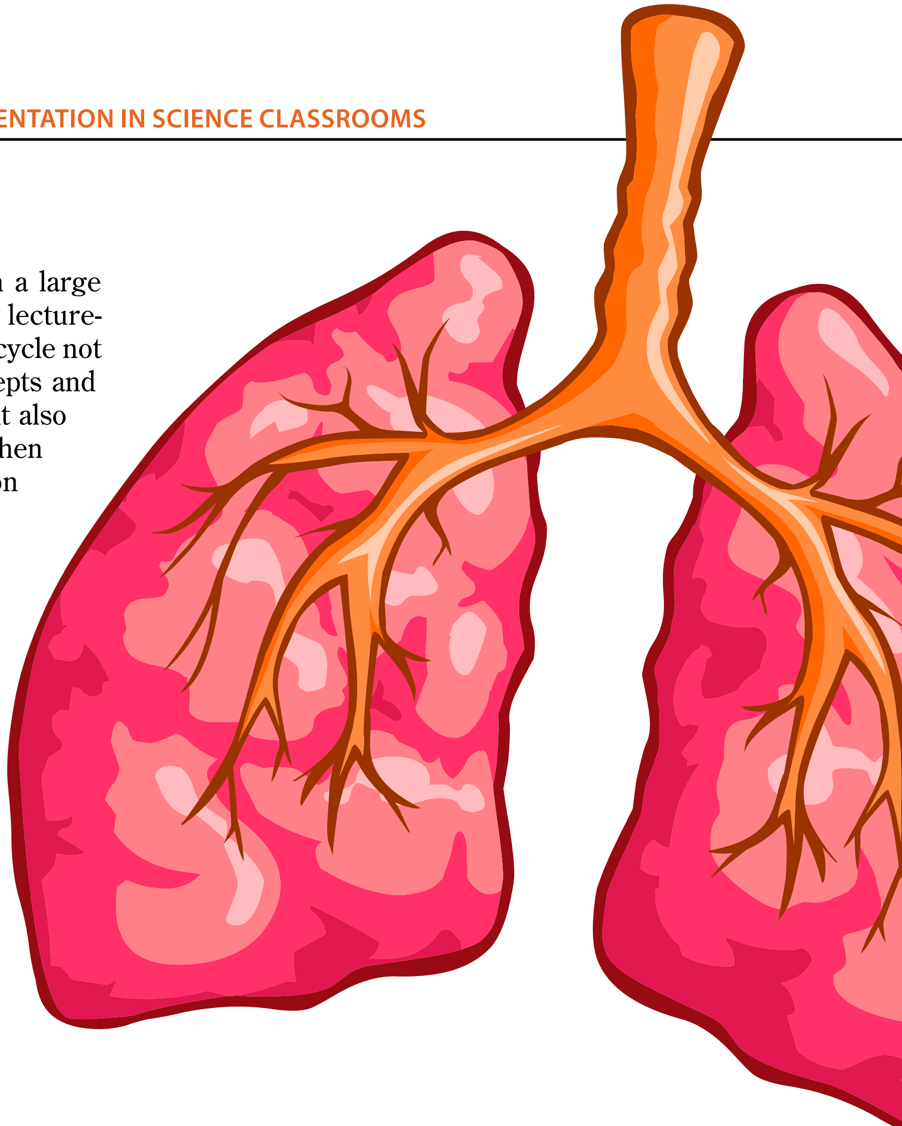
- Make sure your claim relates to the core idea and answers the question.
- State one sentence that can lead to your evidence.

Evidence

- Always make connections to the core idea, class experience, investigations, and outside resources.
- You are trying to convince your readers. Focus on an explanation as to why and how. Do not just state what you observe during experiments.
- You can use pictures, math, and graphs to explain your ideas. These will help readers understand your ideas.

FIGURE 12 Rubric for the writing assignment

	Score 1	Score 2	Score 3
Core idea	• Difficult to identify the main theme or concept: What is the writer's main point or purpose? • Only addresses organs of respiratory system. • Addresses the function of respiratory system, but the concepts are scientifically incorrect or confusing.	• Conceptual science knowledge and core ideas are evident and correct in much of the writing. • Only addresses the function of respiratory system. • Addresses the respiratory and other systems, but does not clearly describe the relationship between the respiratory system and other systems and how they work together.	• Conceptual science knowledge and core ideas are evident and correct throughout the writing. • Addresses the function of the respiratory system and how the respiratory system works with other systems (e.g., muscular system, skeletal system, circulatory system).
Claim	• Makes a scientifically incorrect claim. Makes a weak connection between the claim and question. • Only states what the respiratory system is.	• Makes a scientifically correct claim, and partially catches the essence of the investigation. Makes a moderate connection between the claim and question. • States what the respiratory system is and how it works.	• Makes a scientifically correct claim and completely captures the essence of the investigation. Makes a strong and sophisticated connection between the claim and evidence. • States what the respiratory system is and how it works with other systems.
Evidence	• Provides an inappropriate and inadequate explanation or just reports data as evidence. Makes a weak connection between the claim and evidence. • Lists the major organs of the respiratory system; nothing is said about the function of the respiratory system and how the respiratory system works with other systems.	• Provides an appropriate and adequate explanation partially based on interpretation of investigation data. Makes a moderate connection between the claim and evidence. • Explains the major function of the respiratory system (e.g., gas exchange) and how the diaphragm affects the lungs' movement. • Distinguishes between internal and external respiration.	• Provides an appropriate and adequate explanation completely based on an interpretation of the investigation data. Makes a strong and sophisticated connection between the claim and evidence. • Explains the function of the respiratory system and how the diaphragm affects the lungs' movement (e.g., uses the concept of the balance of air pressure). • Explains how the respiratory system works and how it affects other systems. • Uses scientific vocabulary correctly (e.g., *exhale*, *inhale*).



that using the negotiation cycle resulted in a large effect when compared to the group using lecture-based teaching. In addition, this negotiation cycle not only works with a variety of scientific concepts and age groups with appropriate modifications, it also serves as a practical approach for teachers when incorporating the Framework's emphasis on argumentation into their classrooms. ■

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