ABSTRACT

Scientists use models to represent their imagination and conceptualization of a particular phenomenon. They then use models to develop an argument to debate, defend, and debunk ideas in their peer community. Modeling is an essential practice of authentic science. To foster the pedagogical practice of incorporating models in argumentative contexts, we introduce an approach called “Science Negotiation Pedagogy.” We show how models can support argumentation practices in science classrooms in six phases of action: (1) create a driving question; (2) construct a tentative model in groups; (3) construct a tentative argument in groups; (4) negotiate models and arguments in a whole-class discussion, then revise models and arguments through negotiation; (5) consult the experts; and (6) reflect through writing. A unit on the human respiratory system is used as an example to demonstrate how Science Negotiation Pedagogy can be implemented in biology classrooms.

Key Words: Modeling; argumentation; dialogic teaching; pedagogy; human body system.

MODELING IN THE SCIENCE CLASSROOM

Modeling and the development of models are essential practices of science. Scientists use models to represent and explain their understanding of systems or phenomena, to derive evidence and construct claims, to answer questions, to make predictions, and to debate arguments with others (Lehrer & Schauble, 2006; Schwarz et al., 2009). A Framework for K–12 Science Education underscores the pivotal role that models play in science and engineering: “Both scientists and engineers use their models—including sketches, diagrams, mathematical relationships, simulations, and physical models—to make predictions about the likely behavior of a system, and they then collect data to evaluate the predictions and possibly revise the models as a result” (National Research Council, 2012, p. 46). In this way, models make excellent tools with which to develop science argument, including data collection, deriving evidence, and making claims. Argument can be constructed around the critique, evaluation, and revision of tentative models.

Scientists use models to isolate, simplify, or abstract singular processes (Rosenblueth & Wiener, 1945). They may also use them as thinking tools to develop and express their understanding, which ultimately helps them identify and reformulate their questions and further refine their arguments (Manz, 2012). Scientists then share their models for public critique in an effort to refine their models on the basis of peers’ feedback. Peer critique of a scientific model helps ensure that the knowledge claimed is an acceptable representation of scientific knowledge within a peer community (Ford, 2012).

Recent research has indicated that engaging students in the essential practices of science facilitates student development of disciplinary core concepts (Manz, 2012; Wu et al., 2013), promotes conceptual change (Treagust et al., 2002), constructs science argumentation (Sampson & Schleigh, 2013), and advances students’ representational competence (Stull et al., 2012). Forbes et al. (2015) suggested that models can serve as a thinking tool to shape students’ reasoning about natural phenomena as well as support students in constructing, critiquing, and revising arguments. Chang and Linn (2013) and Liu et al. (2014) contend that models are visualization tools that scaffold students’ understanding of abstract, unobservable, and less comprehensive concepts.

However, modeling practices are rarely incorporated into biology classrooms. Teachers often struggle to understand how models can aid in the learning of core concepts in biology, how progressing through models can advance and refine students’ understanding, and when and how to implement an effective pedagogical approach for modeling practices (Winschell et al., 2008). Here, we introduce an approach called “Science Negotiation Pedagogy” that addresses these issues, demonstrating how modeling and development of models play pivotal roles in students’
knowledge development through debating, debunking, and revising arguments in argumentation contexts. Our example is taken from a fifth-grade classroom that was studying the human respiratory system.

Science Negotiation Pedagogy

Intertwining Models with Argumentation Practices in Science

Incorporating both modeling and argumentation practices into the biology classroom is difficult for some teachers because they lack an understanding of models (Yarker, 2013) as well as effective pedagogical approaches for modeling and/or argumentation practices (Sampson & Schleigh, 2013). Lehrer and Schauble (2006) suggest that an effective approach should be coordinated around three supports: (1) use the model to identify evidence for knowledge claims, (2) develop models using social negotiation process and change/refine them as observations and new information are reinterpreted, and (3) use an array of models to represent ideas. In this sense, we conceptualize a framework that incorporates models within argument practices, which biology teachers can utilize in their classrooms (see Figure 1). Based on the framework, Science Negotiation Pedagogy effectively uses models to support argumentation practices in science classrooms.

The framework consists of utilizing science models and science argument. Models can play a role in the crafting of a scientific argument by providing a topic of conversation around the evidence and claims that students make by building their models, while scientific argument simultaneously influences the revision of a model. A science model can be perceived as a simplified, concrete, visualized, and hypothetical representation of phenomena that can explain and make predictions about phenomena (Schwartz et al., 2009; Manz, 2012; Liu et al., 2014). Science argument consists of two components, claim and evidence. A claim is an assertion that responds to the observations, analyses, and/or phenomena in question. A scientific claim must be supported by evidence. Evidence is a judgment consisting of data and reasoning to show how or why the claim should be supported (Chen et al., 2013). Data are not the same as evidence (Chen et al., 2014; Schultheis & Kjelvik, 2015). Data are factual information collected from investigations and experiments. Evidence is how you interpret data into meaningful explanation. When scientists with different standpoints analyze the same dataset, they may find different patterns and interpretations that generate variations in reasoning. Another important component in this framework is that a response to the question demands information and explanation. Questions normally lead to responses and are critical in determining whether the models and arguments are appropriate and sufficient to make a conclusion (Walton, 2007). A Framework for K–12 Science Education states: “K–12 science and engineering education should focus on a limited number of disciplinary core ideas” (p. 2). Thus, we included big idea as the leading component in this framework to guide the development and revision of models and arguments in science classrooms.

In general, it is not uncommon for people to think of models as nothing more than simple physical representations, such as globes, model airplanes, and plastic representations of body parts (Gilbert et al., 2000). However, they can actually range in complexity from very simple, such as scale and physical models, to very complex, such as computer simulations (Gilbert et al., 2000; Wu et al., 2013). Harrison and Treagust (2000) suggested that in classrooms, novice model users should start by using simple models, in order to make the process of constructing and evaluating models as conceptually achievable as possible.

To address the way in which the framework is employed in biology classrooms, we introduce a Science Negotiation Pedagogy that is derived from the science writing heuristic (Hand et al., 2009), the argument-driven inquiry (Sampson & Schleigh, 2013), and the negotiation cycle (Chen & Steenhoek, 2013). Science Negotiation Pedagogy consists of six phases: (1) create a driving question; (2) construct a tentative model in groups; (3) construct a tentative argument in groups; (4) negotiate models and arguments in a whole-class discussion, then revise models and arguments through negotiation; (5) consult the experts; and (6) reflect through writing. We will explicate the way in which the Science Negotiation Pedagogy might function in a biology classroom by utilizing a fifth-grade classroom’s unit on the respiratory system. In our real classroom example, the students were expected to understand the big idea of the way in which “human body systems work together” by the end of the unit. The following sections delineate each phase of the model in this classroom.

Phase I: Develop a driving question.

In understanding natural phenomena, identifying a question is the first step of the process of inquiry. As Dewey (1938) said, without a question there is only blind groping in the dark. The purpose of a question in a biology classroom is to guide students’ investigation, data analyses, interpretation, and discussion. Typical science classes use multiple investigation questions, which can make it difficult for students to determine what they should focus on while conducting an investigation. We suggest that teachers use a single, concrete, and clear driving question to serve as the central linchpin of activities throughout the unit (Forbes & Davis, 2010, Chen & Steenhoek, 2014). The driving question can be identified as a “thick” or a “thin” question (Hand et al., 2009). Thin questions are yes/no questions that seek to affirm or deny existing knowledge. Thick questions can start from “Why . . . ,” “How . . . ,” or “What factors determine . . . ,” to encourage students to think and dig deeper into concepts. Thick questions have the capacity to highly engage students in investigations, data analyses, and discussion.

Once students understand how to develop high-quality questions, the teacher can work with them to decide whether the questions are testable or researchable. Testable questions are those that can be tested in classrooms, directly connect to the big idea, and enable students to meaningfully conduct engaging investigations. Researchable questions are those that involve complex relationships among variables and/or cannot be tested in classrooms because of the length of time required, lack of appropriate testing environment, and so on.

To help students generate a thick and testable question for the biology classroom, we asked them to express and discuss their prior knowledge of the human respiratory system by using a physical model of the human body. Students brainstormed what they already knew and discussed what they would want to know as it related to the big idea: “Human body systems work together.” Students used the criteria of thin–thick and testable–researchable to discuss what driving question they wanted to explore. For this particular activity, the students were asked to choose one question to
focus on as a whole class. After some whole-class dialogue, the majority of students agreed that their question would be “How does our respiratory system work?”

**Phase II: Construct a tentative model in groups.**

The main purpose of this phase is to construct a model that can represent a phenomenon, a respiratory system in this case, and use the model to answer the driving question. Because science is a cooperative enterprise (Johnson et al., 1989), students should be divided into groups of three or four. Each group receives a packet that includes a handout with the driving question negotiated by the class, the description of the activity, and materials the students may need for constructing a model (see Figure 2).

Students are asked to use the materials (bottles, straws, balloons, etc.) to construct a model that simulates how their respiratory system works. Students test their tentative ideas (i.e., predictions) as they negotiate within their group on the best model to simulate the process. To scaffold students’ thinking, the teacher moves from

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**Figure 1.** Framework for science argument and model in science classrooms.
group to group, asking students to explain and justify why their model was constructed in that fashion. For instance, the teacher asks scaffolding questions such as

- What does the balloon represent in your system?
- Can you explain how your model works?
- What is the greatest strength of your model at this time?

It is perfectly acceptable, and expected, that the students’ first attempt at a model will not match current scientific explanations and understandings (Krajcik & Merritt, 2012). At all phases of development, students’ models should be celebrated for the aspects that are most clearly presented in them. Rather than say that something is right or wrong, the teacher can state how well something is represented. For example, the teacher might say, “I noticed that all your models suggest that the balloon is representing our lungs,” or “Some of us really like how several groups today used a variety of words and pictures to explain their system.” These and related comments and encouragements by teacher and classmates during the process will encourage students to take advantage of opportunities to revise their model on the basis of experience, critiques, negotiations, and emerging possibilities. In this way the classroom community’s practice also simulates how scientists engage in their work. Figure 3 is a typical example of students’ first model to represent their understanding of the respiratory system.

**Phase III: Construct a tentative argument in groups**

This phase is designed to engage students in using the model as a vehicle to craft a scientific argument that consists of claims and evidence. Importance is placed on the way in which students establish valid evidence that consists of data and reasoning from the model. Data include not only quantitative information, but also qualitative description (Villanueva & Hand, 2011). In this unit on the human respiratory system, evidence is mainly qualitative. Students are encouraged to use their model to generate their qualitative description and make a justified reasoning. Figure 4 shows the guidelines we provided to students for constructing a scientific argument.
Teachers can monitor students’ progression by asking probing questions, such as “What evidence from your model explains the relationship between the lungs and chest?” or “Can your evidence support your claim?” During this phase, the teacher tries to understand the relative strengths and weaknesses in each group’s model, claim, and evidence so that they can more effectively scaffold whole-class dialogue. The teacher does not affirm or correct the group’s work. The teacher might even ask groups, “What aspects of your model or explanation might your classmates find confusing or questionable when we discuss your model?” In this phase the teacher’s principal role is to ensure that students can express the relationship between their model, claim, and evidence and that those aspects have congruency. Figure 6 is an example of students’ written arguments based on their first model.

Phase IV: Negotiate models and arguments in a whole-class discussion. Revise models and arguments through negotiation.

This phase attempts to build a negotiation environment in which students can share, debate, persuade, and cooperatively construct their understanding of the big idea. Students are required to present their models and arguments in a whole-class discussion setting and receive feedback from other groups. This practice helps students recognize the strengths and weaknesses of their own models and arguments, and fosters subsequent rounds of revision. Teachers are also a part of the community and play a critical role in facilitating students’ negotiations (Benus, 2011; Chen et al., 2016a, b, c). Table 1 provides three dimensions, or levels, in which teachers

**Figure 6.** Students’ sketch and final model to represent their understanding of the human respiratory system.
Table 1. Levels of negotiation in whole-class discussion.

<table>
<thead>
<tr>
<th></th>
<th>Level 1 Limited</th>
<th>Level 2 Developing</th>
<th>Level 3 Refined</th>
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</thead>
<tbody>
<tr>
<td><strong>Negotiation Based</strong></td>
<td>Teacher does not use the structure and relationship</td>
<td>Teacher attempts to use the model and argument structure to drive students’ conversation. Discussions of models are often isolated from argument structure because they are seen as separate pathways of understanding. Students engage in using models and using arguments as means to drive understanding. Teacher constantly engages students in the use of arguments and models to debate, discuss, debunk, and refine their ideas and purposefully help to link students’ models and arguments to driving question and big idea. Students constantly share, use, and discuss all classroom models and arguments to construct and refine their conceptual understanding of the system.</td>
<td></td>
</tr>
<tr>
<td><strong>on Model &amp;</strong></td>
<td>structure between models and arguments to drive the discussion; teacher focuses on delivering the correct answer to students. Students share and/or present their models and arguments.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Arguments</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Dialogic Interactions</strong></td>
<td>Teacher uses IRE (Initiates, Responds, Evaluates) patterns of questioning to seek single correct answer. Students have little or no opportunity to ask questions and contribute their ideas to the discussion.</td>
<td>Teacher attempts to encourage students to ask questions and use students’ ideas as a basis of the discussion. Students have opportunities to ask, engage with, and elaborate on questions and ideas posed by teacher and classmates. Teacher models an array of questioning topologies and scaffolding techniques to help students create refined exchanges that include questioning, listening, and responding to ideas. Students are careful listeners and respond to ideas with questions and statements that work to construct scientific consensus.</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple</strong></td>
<td>Teacher focuses mostly on either model-making, verbal discussions, OR individual writing. Students share their ideas with a model, discussion, OR summary writing piece without any integration of these aspects.</td>
<td>Teacher attempts to include in the verbal discussions the students’ emerging models and/or written ideas. Students engage in verbal discussion aided by visual or written representations. Teacher fluently and consistently utilizes multiple representations (e.g., pictures, diagrams, and tables, etc.) when discussing the big idea. Students include spoken and written text, models, and other media as needed to represent coherently an understanding of the big idea.</td>
<td></td>
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<tr>
<td><strong>Representations</strong></td>
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</table>

can scaffold students’ capacity to provide constructive feedback and reach a consensus. Level 1 focuses on the use of models and arguments to support negotiation. Level 2 focuses on how teachers use questioning to engage students’ dialogic interaction. Level 3 focuses on the ways in which teachers engage students in representing their ideas through multiple modes (e.g., talk, texts, diagrams, pictures, tables, concrete materials, animation).

At this phase, students usually can explain each part of the respiratory system, but their model may not be able to explain how the respiratory system works. They usually do not pay attention to the function and role of the diaphragm in the respiratory system. To stimulate students’ thinking about the function of the diaphragm, the teacher can ask: “How does the diaphragm help our lungs expand and contract?” or “We do not blow to make the lungs swell up! How do our lungs work?”

As the rounds of revision progress, the teacher will need to ensure that students not only can see and express the parts within the system but also can model and articulate how the system collectively works. This classroom effort typically requires several rounds of re-envisioning, revising, and negotiating with and among small groups and whole-class discussions. In the example unit, our learning community engaged in three rounds of negotiations in an effort to craft their final model (see Figure 6) and argument (see Figure 7).

**Phase V: Consult the experts.**

This phase is designed to provide an opportunity for students to compare their current models and arguments with those of experts. Students should strive to obtain “experts” from both internal and external sources. “Internal experts” are any resources (student-generated data, evidence,
models, writing samples, and/or videos) that can be collected from the classroom. “External experts” are any resources generated outside the classroom, such as textbooks, trade books, nonfiction books, Internet sources, newspapers, invited speakers, and so on.

We have found that often students are able to read more thoughtfully and to more critically analyze expert resources after several rounds of negotiating their models and arguments. This consultation with expert ideas enhances student authorship in the learning process. In this process, students are able to develop a more comprehensive understanding of the scientific vocabulary of their big idea and use that vocabulary in their modeling, presentations, discussions, and individual writing.

### Phase VI: Reflect through individual writing.

Reflective writing at the end of a unit of instruction has been recognized as a promising tool that works to capture the ways in which student understanding developed and solidified (McDermott & Hand, 2010; Chen et al., 2013; Sampson et al., 2013). Writing has also been shown to play an important role in student learning, which has been emphasized by the Common Core State Standards (National Governors Association, 2010). We use writing in this phase to help individual students reflect on which ideas changed for them over time, what experiences fostered those changes, and what summary understandings they claim to have learned. In this phase, students have the opportunity to review all of their models, artifacts, and arguments over the unit, similar to the ways in which scientists express how knowledge is advanced in the discussion section of a research paper. It is important to note that students are not expected to make advances in the scientific community with new and noteworthy scientific knowledge; rather, this phase is an individual proxy for the ways in which individual students express their own personal understanding of the big idea with respect to their models, negotiations, and how the community of science understands the same big idea.

Leading into, during, and after this phase, students should be encouraged in their writing to consider which aspects of the nature of science they were attending to or were challenged by. In our example, making a model and negotiating meaning by using evidence-based findings of this living system is a very tenuous and creative process that demands that one understand how a lung takes in and expels air through consistent action that is biological, mechanical, and naturally occurring. In this way, students have implicitly experienced many aspects of the nature of science without the need to explicitly teach the nature of science separately from science (Sampson et al., 2009).

In an effort to help students attend to reflective writing practices in science classrooms, we provide expectations for their summary writing activities (see Table 2). This guidance can help students understand (1) what counts as a well-constructed claim with appropriate supporting evidence; and (2) what constitutes a strong, well-supported relationship between the question, claim, evidence, and model when constructing a scientific argument. Teachers can use this writing activity to evaluate students’ breadth and depth of understanding of the big idea, and what additional experiences they might need to advance their understanding.

### Science Negotiation Pedagogy in the Words of Students

Our research in classrooms (Benus, 2011; Benus et al., 2013; Yarker, 2013; Chen et al., 2016a, b, c) indicates that Science Negotiation Pedagogy contributes to student learning. When students reflect...
Table 2. Writing Expectation Guidance.

<table>
<thead>
<tr>
<th></th>
<th>Level 1 Limited</th>
<th>Level 2 Developing</th>
<th>Level 3 Professional</th>
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<tbody>
<tr>
<td>Appropriateness of the Claim &amp; Model</td>
<td>Makes a somewhat scientifically appropriate claim or model.</td>
<td>Makes a scientifically appropriate claim that somewhat aligns to the constructed model.</td>
<td>Makes a scientifically appropriate claim that is closely aligned to the constructed model.</td>
</tr>
<tr>
<td>Quality of Evidence</td>
<td>Explanation consists of data with very limited reasoning, and little interpretation of data.</td>
<td>Explanation consists of data with some identifiable patterns of reasoning and interpretation.</td>
<td>Analysis and interpretation is strongly aligned and carefully reasoned from the data, model, and expertise from internal and external sources.</td>
</tr>
<tr>
<td>Alignment of Question, Claim, Model &amp; Evidence</td>
<td>Makes a limited connection between question, claim, model, and evidence.</td>
<td>Makes identifiable connections between question, claim, model, and evidence.</td>
<td>The evidence provided precisely informs the question and is closely connected to the claim and model.</td>
</tr>
</tbody>
</table>

Table 3. Excerpt of students’ reflections on engagement after experiencing “Science Negotiation Pedagogy.”

<table>
<thead>
<tr>
<th>Writing /interview quotes from students</th>
<th>Phases of Science Negotiation Pedagogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI. Reflect through individual writing</td>
<td>I. Create a driving question</td>
</tr>
<tr>
<td>&quot;To explain our idea, we draw a picture or used a model to show our thought in negotiation&quot;</td>
<td>✓</td>
</tr>
<tr>
<td>&quot;The model helps me to construct my claim and evidence&quot;</td>
<td>✓</td>
</tr>
<tr>
<td>&quot;After I have more experience [modeling and argumentative practice], I know how to write good claim and evidence&quot;</td>
<td>✓</td>
</tr>
<tr>
<td>&quot;Now I understand that only providing one data wouldn’t be that good of evidence because it wouldn’t really get much stuff to know. You actually have to have reasoning, I think, to actually explain how it happened. That explains everything in the claim&quot;</td>
<td>✓</td>
</tr>
<tr>
<td>&quot;Communication is kind of like a form of arguing and negotiating&quot;</td>
<td>✓</td>
</tr>
<tr>
<td>&quot;If you agree or disagree, you can’t just say, ‘I agree’ and expect them to just believe you. You have to say&quot;</td>
<td>✓</td>
</tr>
</tbody>
</table>
Table 3. Continued

<table>
<thead>
<tr>
<th>Writing /interview quotes from students</th>
<th>Phases of Science Negotiation Pedagogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI. Reflect through individual writing</td>
<td>I. Create a driving question</td>
</tr>
<tr>
<td></td>
<td>II. Construct a tentative model in groups</td>
</tr>
<tr>
<td></td>
<td>III. Construct a tentative argument in groups</td>
</tr>
<tr>
<td></td>
<td>IV. Negotiate models and arguments in a whole-class discussion.</td>
</tr>
<tr>
<td></td>
<td>V. Consult the experts</td>
</tr>
<tr>
<td>why you disagree or why you agree…</td>
<td>√</td>
</tr>
<tr>
<td>drawing a picture [model] is a good way to explain my idea”</td>
<td>√</td>
</tr>
<tr>
<td>“We have our own question, and we have to test by ourselves. The interesting part is to write up our claim and evidence and use our model to negotiate it in class. We decide whether our evidence supports the claim”</td>
<td>√</td>
</tr>
</tbody>
</table>

Table 4. Purposes of each phase and alignment with NGSS’s practices.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Purpose</th>
<th>Alignment with NGSS</th>
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<tbody>
<tr>
<td>I. Create a driving question.</td>
<td>By creating their own question about the big ideas, students are motivated and interested in learning the target concepts. This need to know defines, drives, and guides the whole process.</td>
<td>Practice 1: asking questions (for science) and defining problems (for engineering)</td>
</tr>
<tr>
<td>II. Construct a tentative model in groups.</td>
<td>Students learn how to build a model that can be used to explain, rethink, and revise how the phenomena can be understood.</td>
<td>Practice 2: developing and using models &lt;br&gt;Practice 3: planning and carrying out investigations</td>
</tr>
<tr>
<td>III. Construct a tentative argument in groups.</td>
<td>Students learn how to make a claim that is aligned to a model that can be used to generate data. Analysis and interpretation of data used in the argument is strengthened over time with expertise from internal and external sources.</td>
<td>Practice 4: analyzing and interpreting data &lt;br&gt;Practice 5: engaging in argument from evidence</td>
</tr>
<tr>
<td>IV. Negotiate models and arguments in a whole-class discussion.</td>
<td>Students share models and arguments with peers; give feedback to other groups; realize the strengths and weaknesses of models and arguments in order to revise.</td>
<td>Practice 6: constructing explanations (for science) and designing solutions (for engineering) &lt;br&gt;Practice 8: obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td>V. Consult the experts.</td>
<td>Students evaluate their own models and arguments through comparisons to the expertise of internal and external sources.</td>
<td>Practice 8: obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td>VI. Reflect through individual writing.</td>
<td>Captures the way in which student understanding of their own and the learning community’s arguments and models developed and solidified as the unit of instruction progressed.</td>
<td>Practice 8: obtaining, evaluating, and communicating information</td>
</tr>
</tbody>
</table>
through individual writing and interviews (an aspect of phase VI), we have found that they discuss one or more phases as an integral part of their learning experience. Table 3 shows examples from students’ interviews of what they learned from engaging in Science Negotiation Pedagogy. Collectively, the excerpts indicate that students’ reflections often deal with their growth from the construction process (phases II and III) and the negotiation process (phase IV). We also recognize that phases I and V are not often a focus of reflection because they work to anchor the overarching negotiation pedagogy. Certainly, students spend time developing their question (phase I) and consulting with experts (phase V), but learning that is anchored by phases I and V gives students something to write and talk about because of their own personal and social investments in the construction and negotiation of ideas.

Students discuss aspects of constructing and arguing about their models both explicitly and implicitly. Students explicitly talk about constructing the model for the purpose of explaining their argument to peers (phase II), but generally they only allude to the negotiation that develops from the model itself (phase IV). While it is not necessary for students to understand the role that models play in the learning process, it is important that they recognize and identify the role that models play in the scientific process because this develops reasoning skills, understanding of content, and understanding of the nature of science (Treagust et al., 2002; Manz, 2012; Yarker, 2013; Liu et al., 2014). Therefore, explicit discussion of the role that models played in their own construction of the argument (phase III) and negotiation process (phase IV) is the ideal outcome. Future work should address this issue.

Conclusions

The Next Generation Science Standards (NGSS) advocate that argumentation practices should be embedded in school science, and they further suggest that models should play a significant role in how students learn science (NGSS Lead States, 2013). Science Negotiation Pedagogy provides contemporary insight into the ways in which biology teachers might foster students’ modeling practice within an argument-based environment. Science Negotiation Pedagogy positions the exchange and development of conceptual understanding through activities such as listening, reading, talking, writing, performing experiments, and developing and evaluating models. These activities are of paramount importance to traditional classroom practices that are often very focused on learning facts and confirming predetermined lab results.

With certainty, we interpret the NGSS message as a demand that science classrooms place argumentation and model making at the center of intellectual activity. Table 3 summarizes the purposes of each phase and the ways in which Science Negotiation Pedagogy aligns with the practices suggested by NGSS. When classroom culture moves away from teacher-centered and predetermined inquiry to more argumentative practices that embed modeling-based inquiry, students can have more ownership of learning and generate better learning outcomes (Chen, 2011).

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YING-CHIH CHEN is an Assistant Professor in the Mary Lou Fulton Teachers College, Arizona State University, Tempe, AZ 85287; e-mail: ychen995@asu.edu. MATHEW J. BENUS is an Assistant Professor in the School of Education, Indiana University Northwest, Gary, IN 46408; e-mail: mbenus@indiana.edu. MORGAN B. YARKER is a Certified Consulting Meteorologist and Science Educator in Cedar Rapids, IA 52402; e-mail: morge.brown@gmail.com

Biology Teachers Association of New Jersey (BTANJ)

Colorado Biology Teachers Association (CBTA)

Cleveland Regional Association of Biologists (CRABS)

Connecticut Association of Biology Teachers (CTABT)

Delaware Association of Biology Teachers (DABT)

Empire State Association of Two-Year College Biologists (ESATYCB)

Hong Kong Association of Biology Teachers (HKABT)

Illinois Association of Biology Teachers (IABT)

Illinois Association of Community College Biologists (IACCB)

Indiana Association of Biology Teachers (IABT)

Kansas Association of Biology Teachers (KABT)

Louisiana Association of Biology Teachers (LABT)

Massachusetts Association of Biology Teachers (MABT)

Michigan Association of Biology Teachers (MABT)

Mississippi Association of Biology Educators (MSABE)

Missouri Association of Biology Teachers (MOBioTA)

New York Biology Teachers Association (NYBTA)

South Carolina Association of Biology Teachers (SCABT)

Texas Association of Biology Teachers (TABT)

Virginia Association of Biology Teachers (VABT)

The National Association of Biology Teachers supports these affiliate organizations in their efforts to further biology & life science education.