The Modeling Toolkit: Making Student Thinking Visible with Public Representations.

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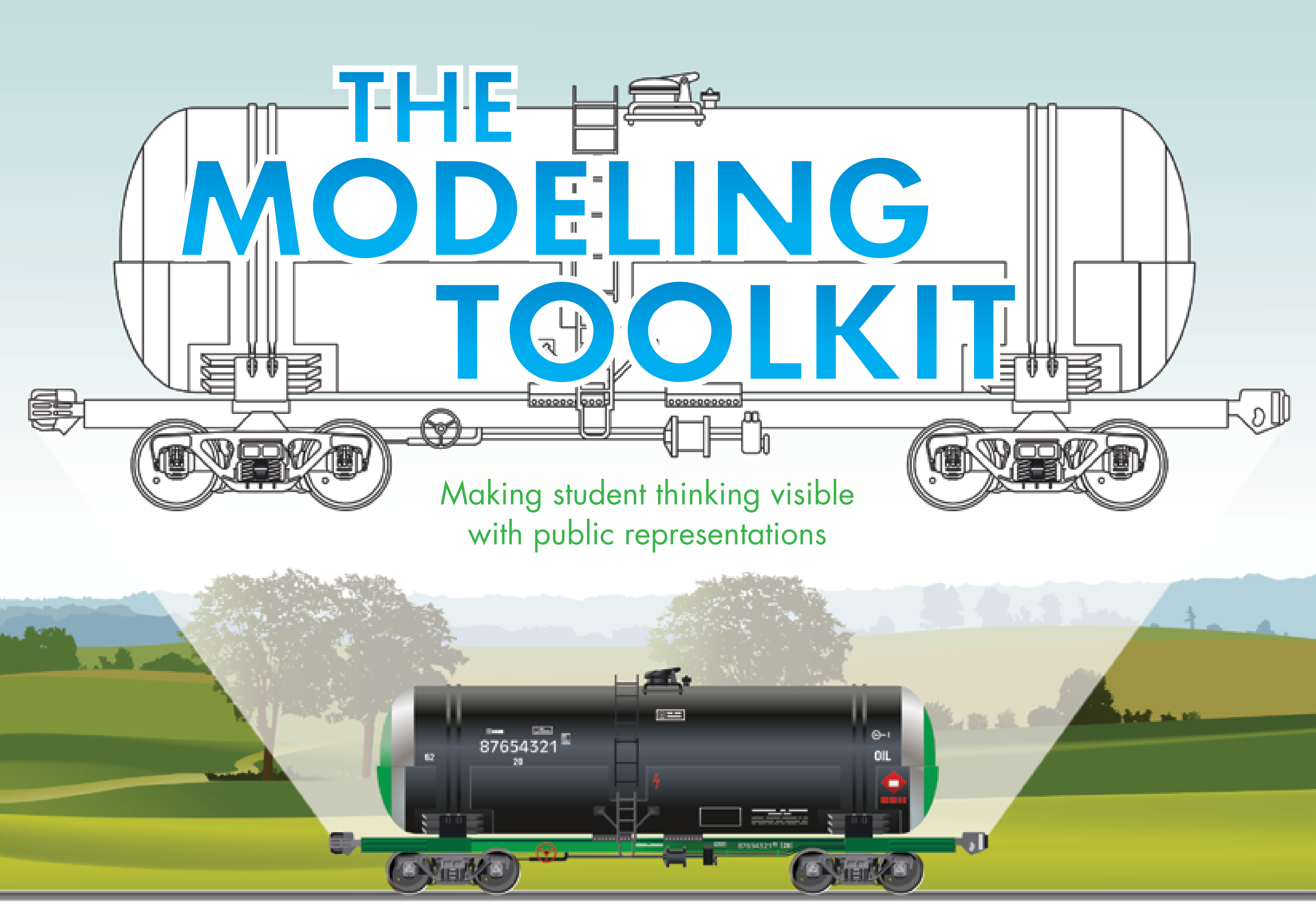


Mark Windschitl and Jessica J. Thompson

Modeling is one of the scientific practices featured in the *Next Generation Science Standards (NGSS)* (Achieve Inc. 2013). This practice is central to the work of science because modeling activities can prompt new questions for investigation, which, in turn, can lead to evidence and information that can be incorporated into a revised model. Models can also support explanations of natural events and processes.

Creating and modifying models in response to evidence and the arguments of peers helps students reorganize their understanding of important science ideas (Lehrer and Schauble 2003; Windschitl, Thompson, and Braaten 2008). Students use models as instruments for doing public forms of reasoning, which can be difficult unless you have ways of making student thinking visible.

In this article, we describe a "toolkit" of different representations of student thinking for use in the classroom. Some are types of models, and others are ways for students to make links between the activities or readings they do and the development of the models (for more tools and related strategies, see "On the web").

Five strategies for making thinking visible

1. Small group models

The most versatile way to represent students' thinking is the small group model. Groups of students create their own models at the beginning of a unit and revise them as the unit progresses. These models could be representations of a puzzling phenomenon the teacher introduced on the first day or could be about an event or process similar to the puzzling phenomenon that will be the focus of an entire unit. Examples are how an urban ecosystem responds to a new invasive species or why thermal insulators keep objects from losing heat rapidly.

We have found that *before-during-after* drawings, in particular, help students show their thinking. A three-part drawing (Figure 1, p. 64) done by students at the beginning of a unit on gas laws addresses the unit's anchoring phenomenon—a railroad tanker car that had mysteriously imploded after being steam cleaned on the inside. Figure 2 (p. 64) was drawn later in the unit, after students engaged in activities and readings. Notice how much explanation is elicited from students—in drawing and writing—in this type of model.

FIGURE 1

An initial "before-during-after" model of an imploding tanker car, drawn in a Gas Laws unit.

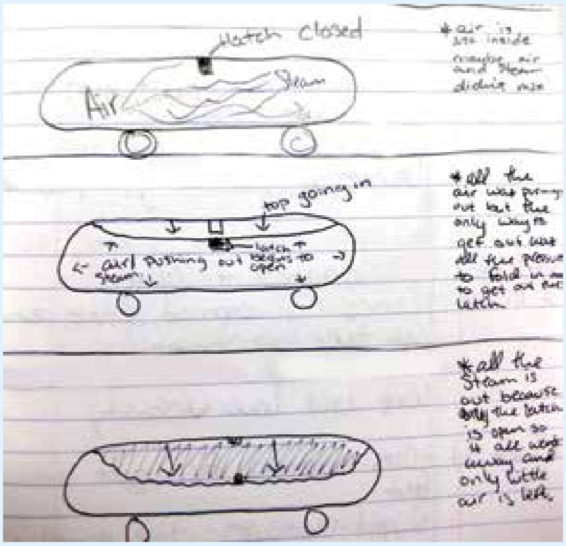
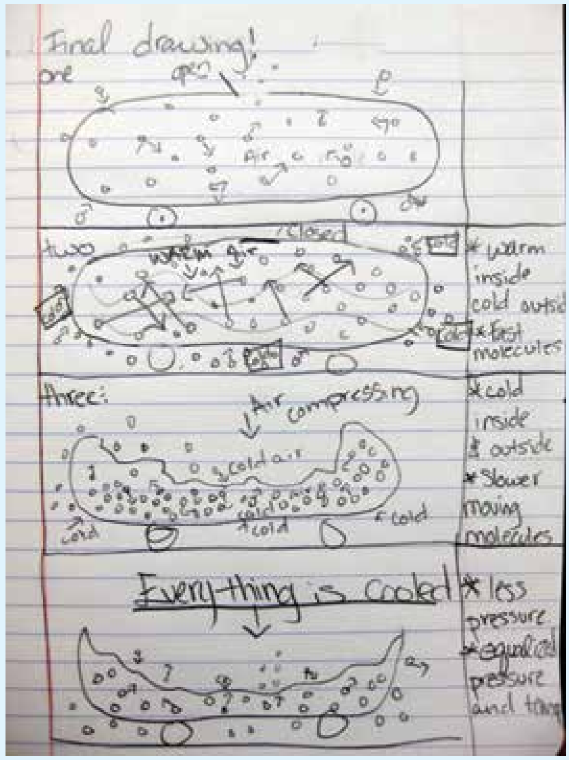


FIGURE 2

Revised model of an imploding tanker car, drawn after several lab activities and readings.



We have also found that for micro-level events, it helps to ask students to "draw what you would see if you had 'microscope' eyes." This works well in chemistry and biology. In Figure 3 students hypothesize what happens as compounds go into solution in a beaker, drawing a "blow-up" view of the solution.

As the unit progresses, students learn more scientific ideas and have experience with activities that allow them to make changes in these small group models. Students can be asked to redraw their models entirely or add to a sparse model they started with.

Caution: Make sure the model is about an event or process that happens in the context of a particular time or place or under particular conditions and that all these special conditions matter to the explanation. If students model a generic phenomenon (such as the water cycle or how levers work), they will simply reproduce, or "posterize," textbook explanations. The "rock cycle" diagram (Figure 4) is an example of this pitfall.

Tips:

- Have students produce representations that show how the event or process changes over time, for example in before-during-after panels.
- Always ask students to draw both observable and unobservable features.
- Agree on drawing conventions. After students have drawn an initial model, discuss how the class should represent certain ideas, so that everyone understands each other's drawings (e.g., What will arrows mean? How will we draw molecules?).
- For drawings that may be difficult to sketch, provide outlines for students to use as guides. For example, to help students draw what they believe is happening during homeostasis (such as regulating body heat in humans), we provide an outline of a human body.
- Have students change the model only once or twice in the middle of the unit. They will get model fatigue if you go back to the drawings too often.

2. Whole class consensus models

For students needing more help understanding the concept of drawing and revising models, the teacher can start a unit by focusing on a single drawing or set of drawings worked on by the class as a whole.

A whole class consensus model can begin immediately after students have some introductory experience with a puzzling phenomenon. On a piece of poster paper or the whiteboard, the teacher draws a very basic pictorial representation of the phenomenon that students are exploring. Then, with input from students, the teacher adds labels that indicate students' hypotheses about underlying events or processes that influence the phenomenon. Input from students for this initial consensus model is important. And as students proceed to activities and discussions, they should decide how to revise the model.

At first, these drawings should be spare. Students may only be able to contribute very simple idea fragments. These are ideal for noting on the consensus model, because they can be built upon and changed later as students learn more.

In Figure 5 (page 66), students came up with three possible explanatory models for a "solar tube"—a Mylar balloon that expands when exposed to the Sun and can then float away. The teacher captured three hypotheses, one in each drawing. As the unit progressed, the students tested parts of each of these models and began to change and add explanatory detail to the more plausible models.

Tips:

- All of the points to think about from the "small group models" section also apply to the whole class consensus models.
- If students suggest elements for the model that show clear misconceptions, label these to indicate "still in doubt," perhaps with large question marks.
- Have students leave space for "Questions we still have about…" This will reveal what parts of the phenomenon interest them.
- Use small group models more often than whole class models. The small group models reveal more student thinking, generate a sense of ownership, and require more intellectual work.

3. *Sticky notes and sentence frames as tools for changing models*

We have found that sticky notes are the best tool for having the whole class experience how ideas can shift with new information, evidence, or logical argument. These small, color-coded notes are applied directly to the models, their color representing the type of comment being made about some aspect of the model. The comment is written on the note, rather than on the model itself.

FIGURE 3

Use of the "zoom-in" convention to identify unobservable processes in a solubility model.

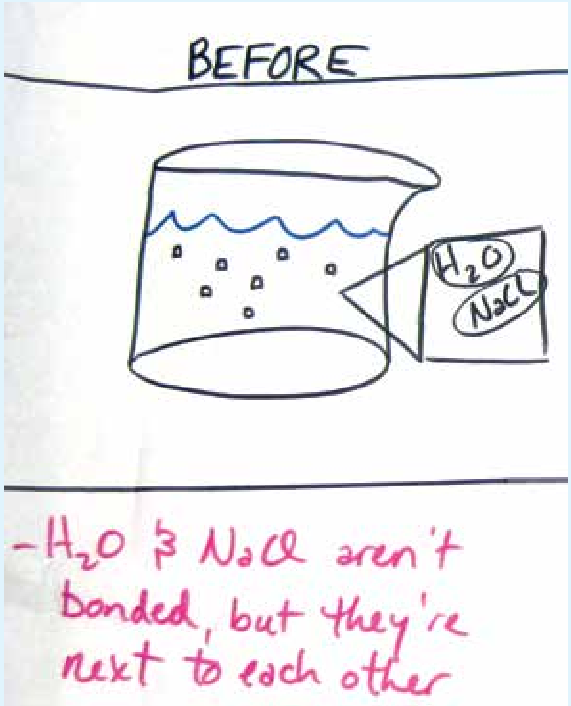


FIGURE 4

Example of "posterizing"—a counter-example to modeling as intellectual work.

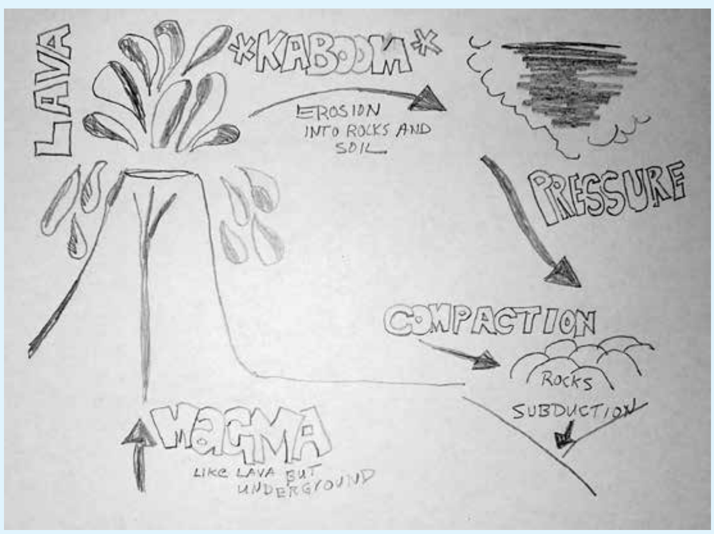
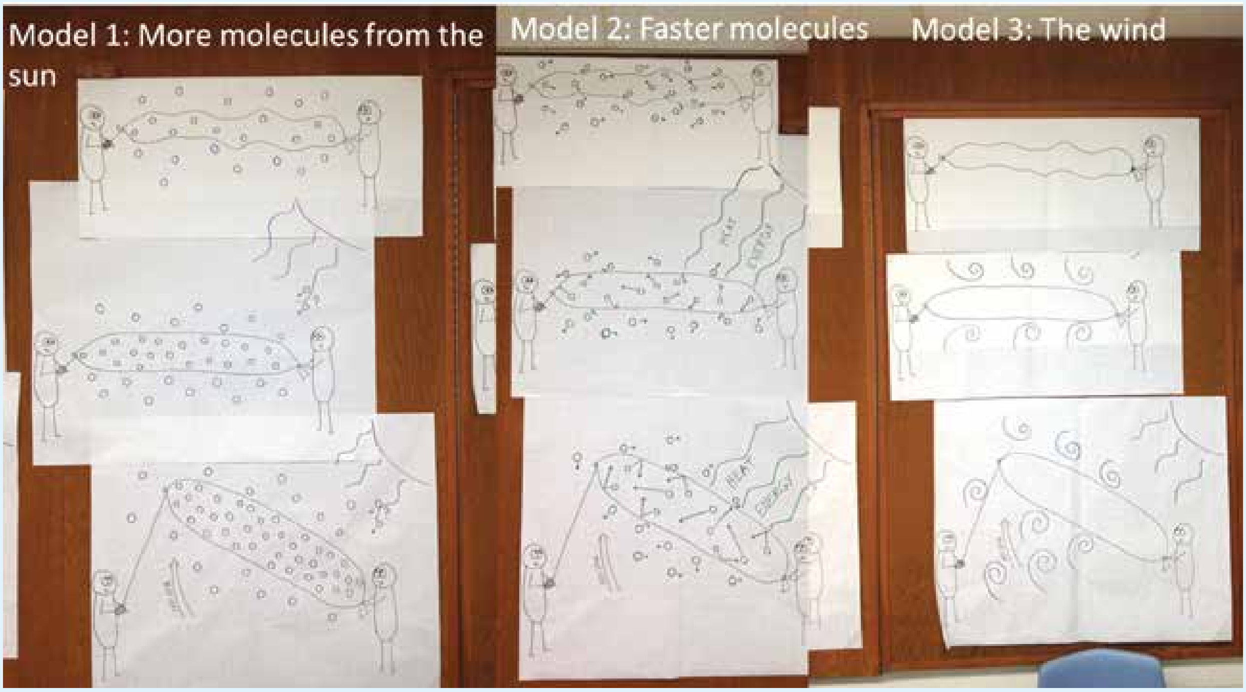


FIGURE 5

Initial whole class consensus models (showing three different proposed explanations) were drawn by the teacher with guidance from students.



We generally group comments under three categories: "Adding an idea" (orange sticky), "Revising an idea" (green) or "Posing a question" (purple). In one case (Figure 6), physics students studying force, motion, and friction initially drew a representation of a man who, on a video, ran up to a wall, planted his foot on it, and completed a back flip. After several readings and lab activities, students were then asked to comment on each other's explanatory models. The orange sticky note on the lower left references a lab and suggests an idea: "We think according to Activity 4 with the different surfaces, the type of surface matters because friction matters. The type of surface you kick off of (wall) determines how hard or easy it is to overcome static friction." This caused the group that received the comment to change their model to make it more accurate and to reflect what they had learned about friction.

To help students not familiar with talking or writing this way, we use sentence frames (Figure 7, p. 68) as a guide. We have noticed that after a few weeks, students begin to take up the "grammar" of science talk in their own speech with peers and with the teacher.

Tips:

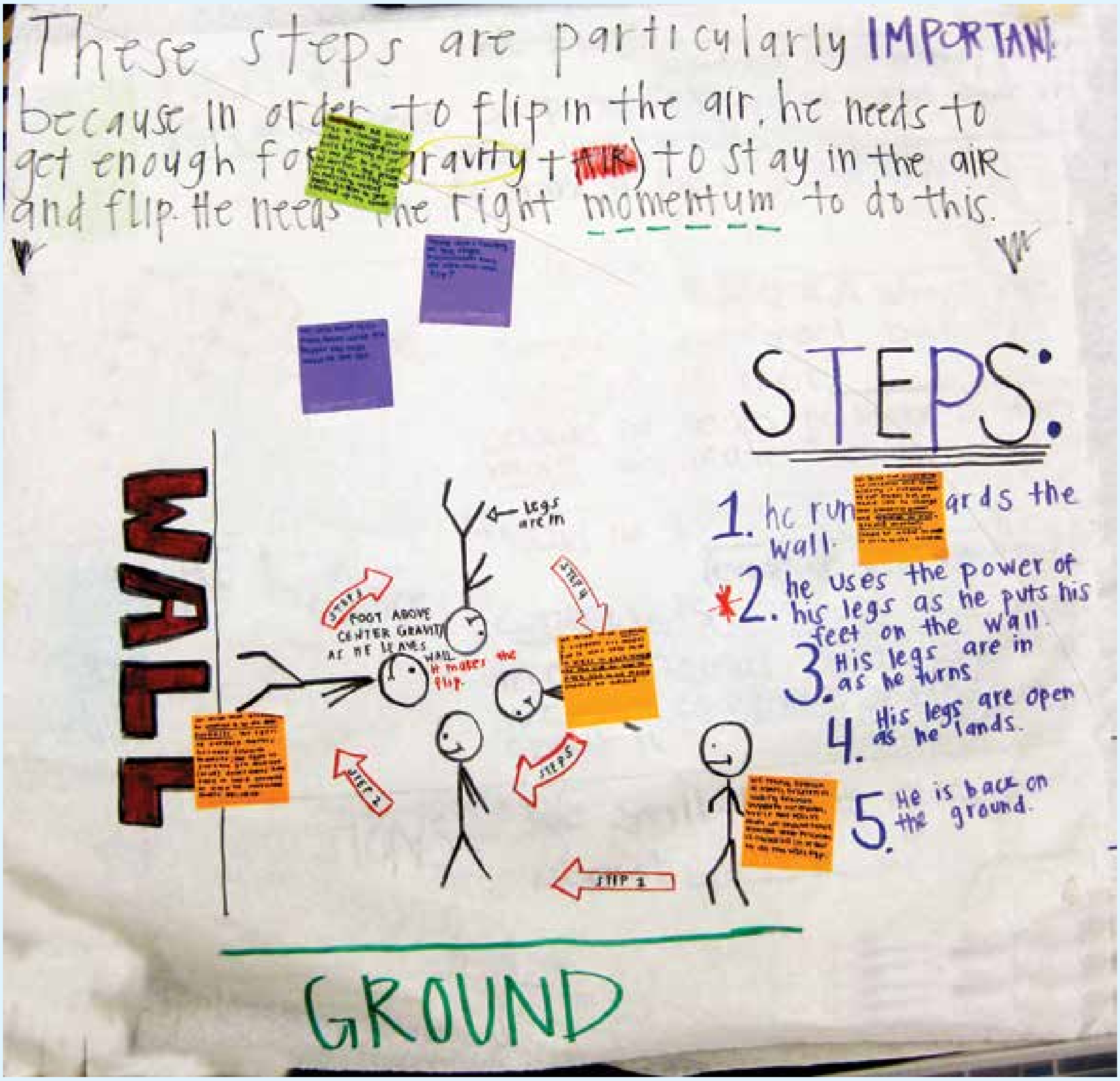
- Students are often reluctant to comment on others' drawings, so we have them practice by placing notes on their own models. They learn how to write notes in full sentences that provide reasons for requesting possible changes.
- We always provide students with sentence frames.
- One sentence frame should be about a puzzle or a question that a group has. This opens the door to really new ideas or to gaps in the potential explanation that could not be expressed in any other way.
- Allow time after the commentary for the creators of the model to read the notes and decide if they should act upon the suggestions.

4. "Gotta-have" explanation checklists

The "gotta-have" checklist is a set of ideas students think must be included in the final explanatory model. This may start with very simple statements or even just terms, but students should add to the list over time as they engage in cycles

FIGURE 6

Sticky notes affixed to a model of force, motion, and friction recommend additions and revisions to the drawn relationships.



of reading, activity, and connecting with their everyday experiences. If students miss key elements of the final causal explanation, the teacher should modify instruction to address these missing pieces.

The gotta-have explanation checklist is not a list of vocabulary words. As the checklist is developed, lesson by lesson, it needs to be composed of ideas or relationships that students believe are important to a final explanation. Figure 8 (p. 68) is an example developed by students during a unit on gas laws with the imploding railroad car as anchoring phenomenon.

Tips:

- An explanation list can be started at the beginning of the unit but should be added to or subtracted from every few days as the students learn more.
- Students should codevelop the list with you—it is a representation of their thinking.
- Avoid making it a vocabulary checklist. Including the word *how* (see gas laws checklist) can help express the items as ideas rather than terms.

- As students create their final explanatory models, make sure they access the checklist. It works very well as a common set of ideas to refer to as the teacher circulates around the room and observes the construction of the final models and written text.

5. Summary tables

Because a model is supposed to change over time in response to new evidence or arguments, students need to record what they have done. We have found it useful to create a table with four columns:

1. Activities we did.
2. Patterns or observations; what happened?
3. What do you think caused these patterns or observations?
4. How do these patterns help us think about the essential question or puzzling phenomenon?

Figure 9 is a variation of a summary table. It is placed on a classroom wall for the duration of a unit focusing on the question, "Why are there no seasons near the equator?" After each round of reading and activity, students discuss how to think about the phenomenon and must fill in one complete row. As more and more rows are filled, ideally, students start to piece together a more coherent and complete explanation.

Tips:

- Don't have too many columns in your summary table, and don't have more than five rows.
- Students should be in charge of negotiating what goes in each column after a reading or activity.
- Don't wait until the end of a unit to fill in all the rows, which confuses students. Fill in each row immediately after each activity.
- When students draw and write their final explanatory model, have them refer to just one or two rows on the summary table to help them support part of that explanation. Especially early in the year, you don't want students to try to use the whole summary table and all the evidence expressed within it to support their explanations.

Conclusion

The toolkit discussed here is not static: Experiment with different combinations of support and what shape the tools take. The purpose for all of these tools is to support more students in participating in thinking and talking about science ideas in your classroom. ■

FIGURE 7

Sentence frames that support students' use of scientific language around revising models.

Add to model

- We added [*describe what you added*] because [*evidence from activity, reading, discussions, or other groups' hypotheses*].
- We think ______________ supports our model, but it also tells us that ___________ should be added to make it even more accurate.

Revise model

- We changed [*description of what you changed*] because [*evidence from activity, reading, discussion with other groups*].
- We used to think __________________, but now we think __________________, because ____________________________.
- We think __________________________ contradicts ___________________ in our original model because ___________________________.

Questions

- We are wondering about [*part of model*] because _____________________.
- We think that if we knew ____________, it would help us explain _________________________.

FIGURE 8

"Gotta-have" checklist for explaining the imploding tanker car (Gas Laws unit).

Include in your explanation:

- How molecules cause pressure.
- How conditions inside and outside the tanker change in each phase.
- How heat energy affects different parts of the system.
- How changes in the pressure of a container affect volume.

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This article was adapted with permission from an article at Tools for Ambitious Science Teaching: *http://tools4teaching science.org*.

On the web

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FIGURE 9

Summary table for organizing how lab activities and readings inform students' explanatory models for the seasons.