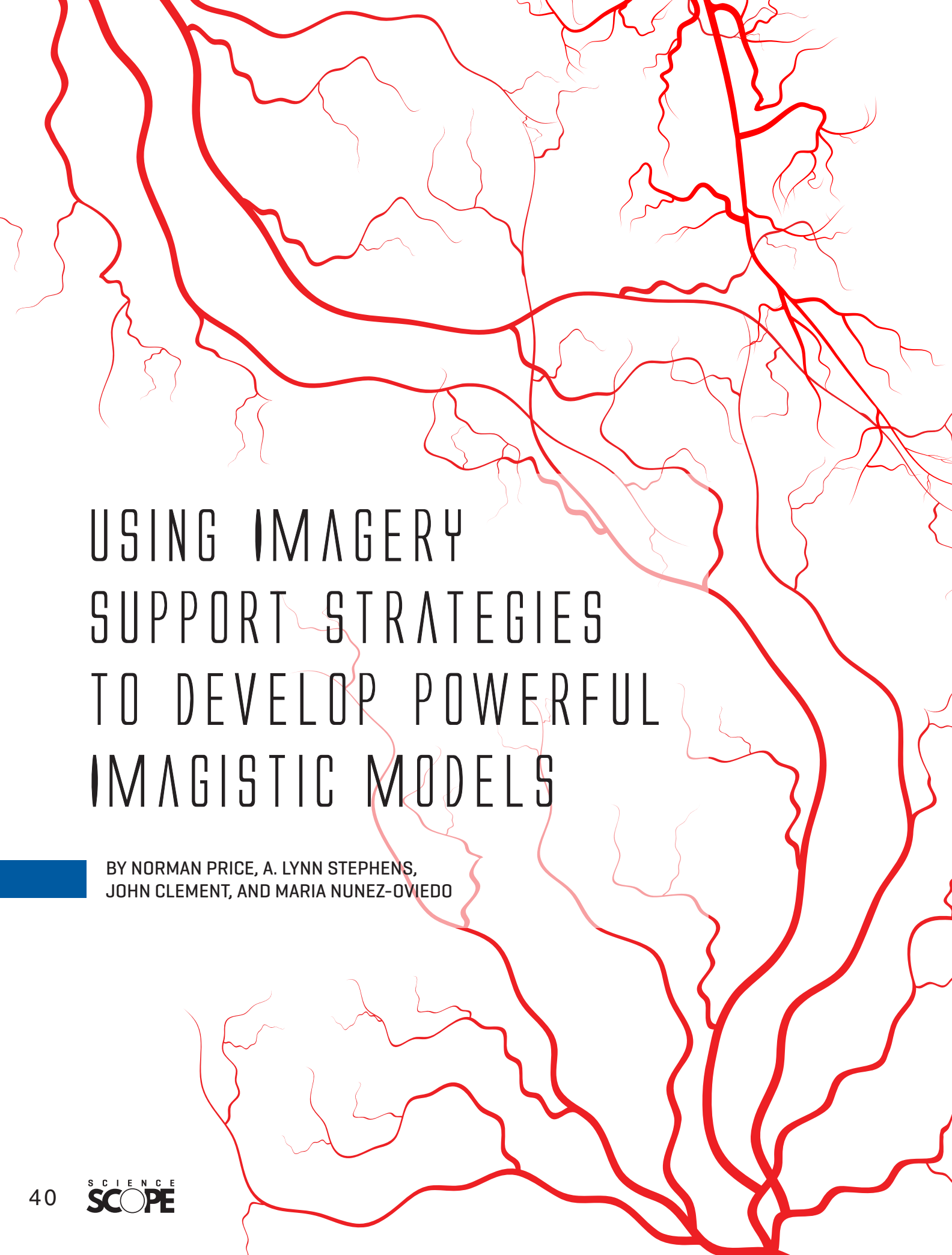


The background of the page is a complex, abstract pattern of red lines of varying thicknesses, resembling a network or a map of connections. The lines are primarily red, with some lighter, almost white, lines interspersed, creating a sense of depth and complexity. The overall effect is that of a stylized, organic network structure.

USING IMAGERY SUPPORT STRATEGIES TO DEVELOP POWERFUL IMAGISTIC MODELS

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Part 1: Background issues: What is imagery, and how does it contribute to modeling?

Focus on models

A central question for teachers is how to engage students in active reasoning while still aiming for substantial content goals. Asking students to generate and evaluate imagistic models can support both content learning and scientific thinking goals. Recent research indicates that imagery is a central component of scientific modeling (Schwartz and Heiser 2009). When discussing scientific models, teachers and students often lean heavily on words alone and overlook how modeling uses mental pictures and “mental movies.” Metaphorically, modeling processes can be thought of as occurring on a “sketch pad or video screen” of mental imagery in the student’s head. The set of strategies described here are intended to help teachers promote the kind of imagery that is used in scientific models.

What are scientific explanatory models?

The term *model* has many meanings in common usage. Here, when we say *model*, we mean an explanatory mental model, which is a mental representation that includes a hidden causal mechanism that explains a phenomenon. Blood pumping through vessels delivering oxygen via capillaries is an example of an explanatory model, because it is largely hidden for students. Notice how this model is *imagistic*, meaning that it can be imagined internally with the

mind’s eye, and is *runnable*, meaning that it can be animated or set in motion like a *mental movie*.

When a mental movie is used to form a prediction or explanation, we call it a *mental simulation*. Using mental movies to form predictions can help students evaluate their existing models and construct runnable imagistic models that have explanatory power and make sense.

Are there different types of imagery?

The use of imagery, sometimes called *visualization* or *spatial thinking*, is an increasingly valued process in science education. Imagery involves working with internal mental recreations of experience but it also can involve creative mental inventions (Finke 1990). Three types of imagery that have been observed in classrooms are shown in Figure 1 (Stephens and Clement 2010). Each type builds on the previous type. A set of examples illustrates this progression.

What are imagery support strategies?

Teachers can foster their students’ thinking via imagery by using *imagery support strategies*. Figure 2 shows a set of basic imagery support strategies that we have observed teachers use during discussions. The strategies fell into three main categories, which are identified in Figure 2 with the letters A through C. Each category has a name, strategies within it, and short example snippets. The strategies in *italics* will be discussed here, in the context of a model-based lesson (see Figure 2).

CONTENT AREA

Biology

GRADE LEVEL

5–8

BIG IDEA/UNIT

The human body is composed of interacting systems that work together to provide for the needs of the cell.

ESSENTIAL PRE-EXISTING KNOWLEDGE

Animal cells need oxygen and produce carbon dioxide. The heart pumps blood through vessels. Blood carries oxygen to the cells and carbon dioxide away from cells.

TIME REQUIRED

This article describes one class period, but the strategies used can be applied over shorter time periods.

COST

No cost

SAFETY

No safety issues

Part 2: Heart-lung lesson: How were imagery support strategies used in a lesson?

Divergent and convergent phases of the heart-lung lesson

The specific objective of the following lesson, which was in the middle of a unit on circulation, was to have students explain how the respiratory system should be connected to the model of the circulatory system they had developed in previous classes. Before teaching the class, the teacher translated the learning objective of the lesson into a skeletal diagram representing the target model (Figure 3). It shows the lungs, heart, blood vessels, and a representative capillary bed in the big toe at the bottom. This *runnable target model diagram* was not shown to students, but it was kept in mind as the central goal of the lesson as the teacher **led** the discussion.

This lesson followed a two-step, model-based lesson design shown in Figure 4. Diagrams were central to each phase of this lesson.

Elicit ideas phase

In previous lessons, students had developed a partial model of the circulatory system in which the blood flowed from heart to the body capillaries and back to the heart. This is a heart-body-heart (HBH)

flow pattern (Figure 5). They had also learned that the lungs exchange oxygen for carbon dioxide in the blood. This lesson begins with their diagram (Figure 5) or an observation pattern to be explained, either from their life experience or from a previous lab.

The lesson examined here began with students being asked to modify or revise the HBH model so it would connect to the lungs. In small groups, students used a think-pair-share strategy and a small portable whiteboard to draw and explain how they would modify their model. Then each small group worked on developing a consensus model, which combined the thinking of the group into one diagram. Using this whiteboard method to collect and share initial student drawings and explanations is an effective way to initiate imagistic thinking and detect the current state of student thinking for many scientific models. The imagery and diagrams serve as concrete entry points when students were writing, talking, and listening to each other to explain science phenomena. Pairing language with visuals helps students, particularly English language learners, practice and develop scientific literacy (Elliott 2007) and vocabulary (Sadoski 2005).

A pair of students in the group then shared their group's model with the whole class. The big challenge of a whole class, idea-eliciting discussion is for the teacher to stay neutral while attempting to comprehend, not evaluate, student models. Developing the

FIGURE 1: Three types of imagery

Name	Description	Example
Mental pictures	These static images can be snapshots remembered from some experience, but they can also be invented pictures or pictures that have been modified.	Imagine a heart connected to the big toe by a loop of blood vessels.
Mental movies	Animated imagery involves some movement, force, or change. It can be generated, as in daydreams, and can be modified.	Imagine the heart pumping so that blood flows through the loop and back to the heart.
Mental simulation	Mental simulations use mental movies to generate a prediction or explanation, akin to a computer simulation run in the mind.	Imagine the blood flowing and predict what will happen to its speed if an organ is put in the loop and filled with millions of little tubes that the blood must pass through.

FIGURE 2: Imagery support strategies

Encourages here means requests, models, or scaffolds.

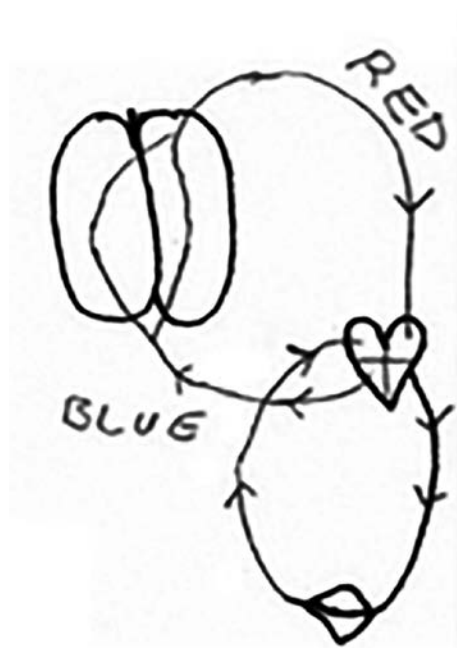
A. Teacher encourages students to think via imagery by using the following: A1. Imagery talk: describing picturing something in one's mind. A2. Conjuring: describing a scene as though it were present nearby. A3. Gesturing: using depictive gestures for shapes or events. A4. Entering the scene: describing by placing one's self in a scene.	Example "If you imagine looking at just the circulatory system. .." "Imagine holding the heart in your hand." "If the heart chamber compresses [moves hands together] ..." "What would you see if you were inside an artery?, a capillary? ... a vein?"
B. Teacher encourages students to use scientific drawings to support imagery by using the following: B1. Skeletal scientific drawing: making or modifying a skeletal drawing or diagram. B2. Drawing gestures: making gestures either above a drawing or pointing to a drawing. B3. Highlighting unobvious features; asking about or describing a nonobvious relationship or imaginable feature in the drawing.	Example Drawing a student's model, small group's model, or collective student model of the circulatory system and modifying it during discussion. Teacher moves fingers over heart-lung drawings to show direction of blood flow. "What would happen to the speed of the blood when it got to the capillaries?"
C. Teacher encourages students to think via mental simulation by encouraging the following: C1. Prediction [or explanation] by mental simulation: making or asking for a prediction or explanation from a mental simulation. C2. Human action metaphor: describing the forces or movements of entities in a nonhuman system as though they were conducted by a person [students need to understand that such anthropomorphisms are metaphors].	Example "And if the blood is coming back here [through vein from the toe], is it going to go back to the lungs?" "The heart tries to push the blood up the leg, but it is quite difficult."

class norms that encourage students to risk publicly sharing their ideas is critical to this task. Various ideas that diverge from the target model are of high value, because they can generate interesting debates and motivate later discussions that focus on converging on the target and seeing it is a better model. In this lesson, a common student model that emerged from this idea-eliciting discussion is shown in Figure 6, creating a heart-body-lung—heart (HBLH) flow pattern.

Converge on the target model phase

The teacher's goal now shifted to helping students converge on the target model. The teacher drew the selected small-group model (Figure 6) on the board (without identifying its source), but a few students wanted the teacher just to provide the correct model. The teacher reminded them that this was not a test of their ability to memorize, but rather a challenge

FIGURE 3: Target model generated by the teacher before the lesson



to apply scientific thinking to determine whether the student model worked (by running the model), identify what was wrong with it (evaluate the model), and then fix it (modify the model). These are crucial processes for *doing* modeling.

In order to move toward the target model, students need to be willing to step away from their initial models. The teacher did not simply tell students the model in Figure 6 was wrong, but encouraged

FIGURE 4: Summary of the two-step process for teaching modeling

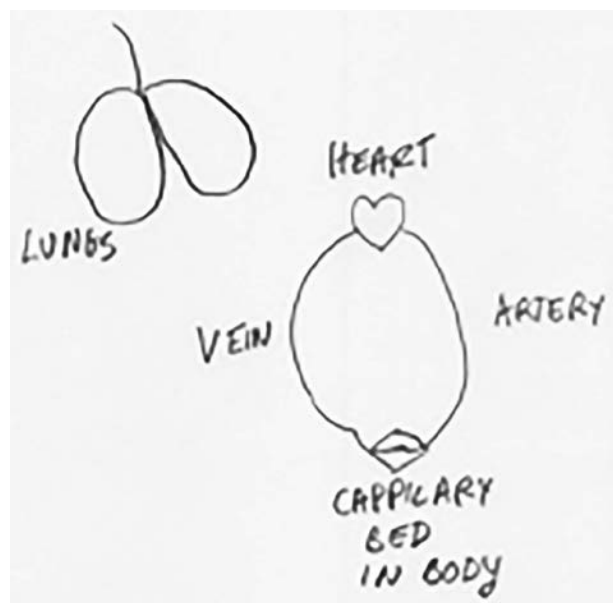
Elicit ideas from students

In class, first elicit student ideas and identify some partially correct student models. This may take 10–20 minutes.

Converge on the target

Discuss partial models and converge on the target. This may take 10–20 minutes. [This will vary, depending on the size of the model, or piece of the model, being attempted.]

FIGURE 5: Model [HBH] was developed in previous lessons; it was used to initiate eliciting phase in the lesson described here.



them to create a mental simulation of how the blood would flow in this model and to reason about how well it would work. In the transcript excerpt (Figure 7), the teacher was attempting to support the imagery needed to “run” this mental simulation of variable blood flow speeds and to help students realize that the heart would have difficulty pushing the blood through the body and the lungs, as it would need to do in the HBLH Model. From previous work, students understood that the speed of blood flow is slowest in the capillaries, as the blood and the cells surrounding the capillaries exchange gases and nutrients.

Highlighting unobvious relationships [B3]

In lines 1b, 1c, and 5f of Figure 7, the teacher is highlighting unobvious relationships in the drawing to support the mental movie of how blood slows down when it travels through the capillaries. This is unobvious because blood speed changes are complex and not represented by features in the diagram.

Drawing-based gestures [B2]

The imagery of blood flow is also supported by the many drawing gestures in which he points and motions over the diagram to depict rates of blood flow (lines 1a, 1d, 1f, 3b, 5b, 5d, and 5e).

Fostering simple mental simulations [C1]

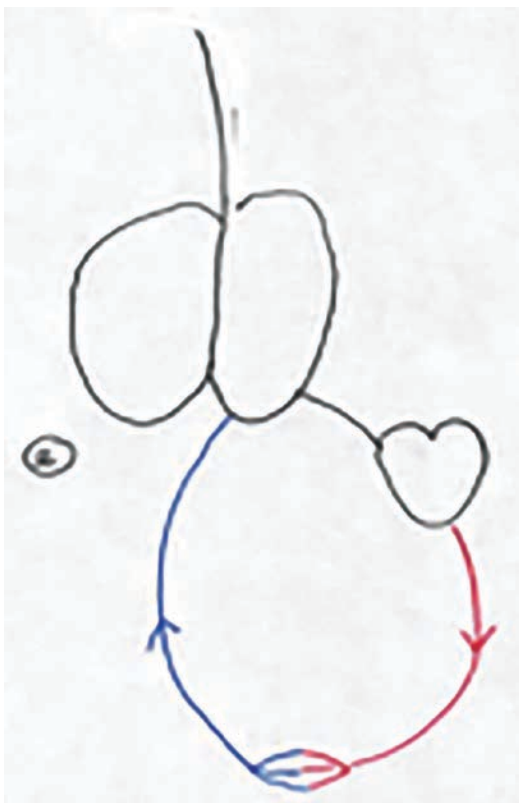
In lines 3a, 5a, and 5c, the teacher asks questions about the blood flow. These questions encourage students to run simulations because they request students to make a prediction (or explanation) from a mental movie. We consider line 3a “How would it get back up?,” line 5a “How does it get there?,” and line 5c “Is it going to go back to the heart?” to be forms of the prediction question, “If you imagine the blood flowing in this picture, does it look to you as though it will be difficult for the blood to make it

back to the heart?” The latter would have been an even clearer request for a simulation.

Subsequent model evaluation and modification at the end of convergent phase

The teacher student interactions shown above took only three minutes of class time but they reveal the density of imagery supports used by the teacher to encourage students to run the model and to consider prediction questions. The time spent running the student model was followed by the removal of a number of vessels from the drawing to arrive at the modified model seen in Figure 8a. Then, during whole-class discussion, students and the teacher worked together to connect the lung to the circulatory system as shown in Figures 8b–f. This joint teacher-student process of model evaluation and modification resulted in the convergence on the target model shown in Figure 8f.

FIGURE 6: Model [HBLH] produced by a small group in eliciting phase; this was used to initiate the class discussion for convergent phase



Assessment

At the end of the lesson, as a check for understanding, the teacher asked students for the types of blood (oxygen-rich or oxygen-poor) inside each of the chambers of the heart, and students responded correctly. However, a small but important detail of the model was still missing in the heart structure—and a student noticed. He realized that in the drawing there were no connections between the upper and lower chambers of the heart. Unprompted, he volunteered to go to the board and used his finger to erase a part of the line between each pair of chambers, at the location where there are, in fact, valves that allow the blood to move between the chambers. We take this as evidence that the student was using imagistic thinking. His actions suggested that he attempted to run the model and realized that blood flow would be blocked unless blood could flow between the chambers. An important feature of having a runnable model is that running it allows you to spot and fix problems with the model.

While students are working in small groups, a useful formative assessment is to ask all students to take turns practicing using their finger to trace and

FIGURE 7: Transcript segment from the heart and lung lesson showing teacher and student interactions. In the figure below, T = Teacher and S = Student.

Line	T or S	Speech and [gesture]	Imagery support strategies
1a	T	[points to the capillary bed drawn on the blackboard]	B2: Gesture over drawing
1b		So let's say it slows down.	B3: Highlighting
1c		Now we got this blood that is pretty slowed down, right—	B3: Highlighting
1d		[points to the vein side of the capillary bed]	B2: Gesture over drawing
1e		—coming out of here. Alright?	
1f		[moves the ruler from the capillary bed upward]	B2: Gesture over drawing
2	S:	Oh, but before [referring to previous model without the lung] it [blood] can get back up to the heart.	
3a	T:	Well, yeah. How does it get back to up [to the heart] from here [after exiting the capillary bed]?	C1: Requests mental simulation
3b		[traces the vessel connecting the toe capillary bed to the lungs and heart]	B2: Gesture over drawing
4	S:	Uh ...	
5a	T:	That's the question. How does it get here [after exiting the capillary bed]?	C1: Requests mental simulation
5b		[moves the ruler along the blood vessel twice from the toe to the heart]	B2: Gesture over drawing
5c		And if it is coming back here, is it going to go back to the heart?	C1: Requests mental simulation
5d		[points to the heart]	B2: Gesture over drawing
5f		Because if it is inching its way back up, slowly slowly slowly—	B3: Highlighting
5e		[moves the ruler slowly over the vessel that connects the toe capillary bed to the heart]	B2: Gesture over drawing

describe blood flow. Group members can ask the presenting student to pause in different locations in the system and describe the kind of blood (for example, oxygen-rich or -poor) found in particular vessels. The teacher, by circulating among the groups, can watch and listen to this practice and assess the understanding of all group members by asking them if they agree or disagree with the student presenting to the small group. Asking students to explain how the blood came to be oxygen-rich or -poor can also reveal how well they understand the model.

The teacher can also do a quick check of the dia-

gram using this informal checklist: (1) Heart with chambers, (2) Blood vessels labeled with names and arrows, (3) Proper connection and flow of blood to lung, heart, and toe, and (4) Colors used to indicate the kind of blood present, with a key to describe the meaning of the colors used. (It is important to note here that we remind students that blood is never quite blue, and that the use of colors, such as blue or purple, to indicate oxygen-poor blood is a limitation of the model representation. It is always important to reinforce the idea that there are no perfect models; all have limitations.)

One step toward a summative assessment is to ask students to compare their initial model diagram to their final model diagram and to locate a model modification that is present in the final one, but missing in their initial model. A summative assessment of modeling should not only measure student understanding of new terms, but also assess their skill at imaging and running the model dynamically. This can be done by asking for drawings on students' assessment with instructions to include representations of the dynamics of the model. For example, in each of the following questions, one can encourage running of the model and request an explanatory diagram using this prompt: Explain your answer by drawing and labeling a simple diagram, including arrows to indicate blood flow, colors to indicate the kind of blood present, and names of key organs.

1. When O_2 goes into blood from the lung, does the blood have to pass through the heart before it gets to the big toe?
2. When blood returns from the toe does it first go to the heart or first go to the lung?
3. If there is a clot in the ... what happens? On your drawing, indicate where the most dangerous location to have a blood clot that slows blood flow would be.

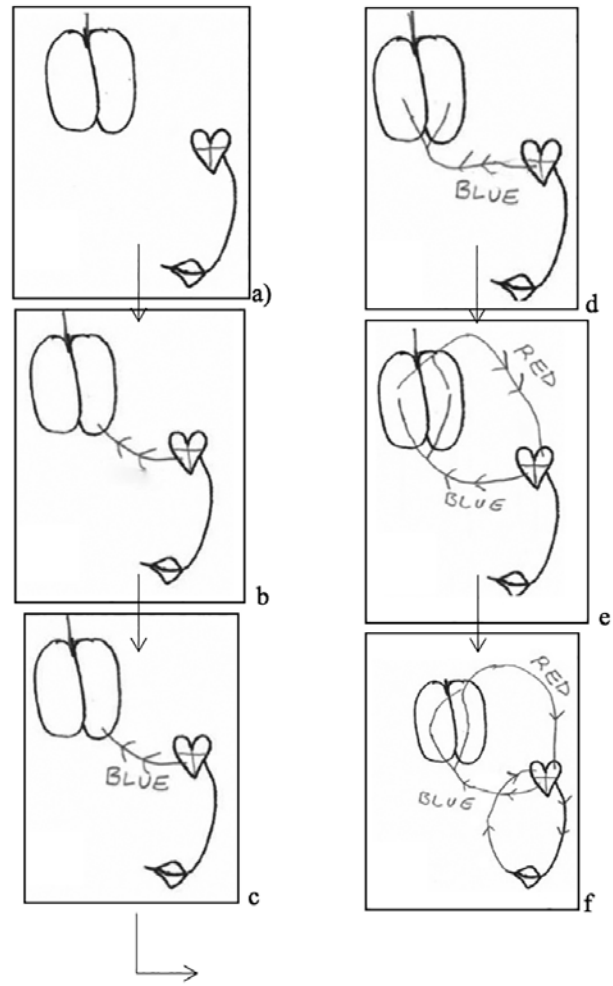
Conclusion

The simple strategy of asking students to contribute to and discuss drawings visible to the whole class offered many supports to the discussion of the models in the heart-lung lesson, as shown in Figure 9. Figure 9 also shows how the imagery support strategies were linked in a productive sequence leading to model modification. Having a diagram supported the use of gestures, and both diagram and gestures supported students' dynamic imagery (mental movies) and simulations, which supported model evaluation and modification, and final understanding.

Link between modeling and imagery

In this lesson, the teacher's imagery support strate-

FIGURE 8A-F: Modifications to the student model



gies helped students make sense of runnable imagistic models and use those models to engage in thinking processes.

Image support strategies have many applications in other content areas. Imagistic models are essential in science and have advantages for memory and for natural spatial reasoning abilities that piggyback on the brain's powerful perceptual processes. The strategies in Figure 2 offer simple and easy-to-apply ways of supporting imagery and improving student modeling in the classroom. For more on discussion and modeling strategies, see Williams and Clement (2015), Krajcik and Merritt (2012), and the American Modeling Teachers Association website. ●

Connecting to the *Next Generation Science Standards* [NGSS Lead States 2013]

- The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standard

MS-LS1: From Molecules to Organisms: Structures and Processes

www.nextgenscience.org/dci-arrangement/ms-ls1-molecules-organisms-structures-and-processes

Performance Expectation

MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.

DIMENSIONS		CLASSROOM CONNECTIONS
Science and Engineering Practice		
Developing and Using Models		Students collect observations during a “fossil dig,” analyzing and comparing their data to discover the processes of biological change over geologic time and the technique of relative dating. Students analyze stratigraphic succession charts to deepen their understanding of geologic time and processes.
Disciplinary Core Idea		
LS1.A: Structure and Function • In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions.		Students evaluate and modify a circulatory model to incorporate details about the structure of the heart that are necessary for blood flow. Students trace and describe blood flow and the kind of blood [oxygen-rich or -poor] found in specific blood vessels, the heart, and the lungs.
Crosscutting Concept		
Systems and System Models		Students construct, evaluate, and modify a model that explains how the respiratory and circulatory systems should be connected to deliver oxygen to the body.

Connections to the *Common Core State Standards* [NGAC and CCSSO 2010]

ELA

RST.6-8.7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually [e.g., in a flowchart, diagram, model, graph, or table]

FIGURE 9: Sequence used in this episode

Number	Strategy	Examples
B1	Skeletal scientific drawing	By starting with a <i>diagram</i> of a student model ...
B2	Drawing gestures	... the teacher was supported in using <i>gestures</i> to <i>animate the diagram</i> .
B3	Highlighting unobvious features	The diagram with gestures encouraged students to develop and <i>run a mental movie</i> of the blood flowing and imagine the blood slowing down in the capillaries, raising the issue of how it could make it through the lungs and back to the heart.
C1	Mental simulation	<i>Prediction questions about the drawing</i> encouraged students to run the model and ...
	Model evaluation	... <i>to evaluate</i> how the reduction of blood speed would affect the functioning of the model.
	Model modification	<i>Model modification</i> was supported by having a simple and easily changed diagram that facilitated the addition of a separate vessel circuit for the lungs, and running the revised model.
	Model evaluation	In the initial drawing of heart chambers, blood was blocked from moving between the chambers.
	Model modification	A student added valves between chambers to the drawing.

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