central question for teachers is how to engage active student thinking, be responsive to student ideas, and still aim for substantial learning around specific disciplinary core ideas. These aims are especially significant in light of the Next Generation Science Standards (NGSS), which emphasize the scientific practice of generating and evaluating models (NGSS Lead States 2013). In an era of increased access to powerful computer animations and simulations, freely available on the internet, we have new opportunities to elicit and respond to student ideas.

This article describes a two-phase lesson structure (Figures 1 and 2) that uses a simulation to promote student engagement and reasoning in lessons with disciplinary core ideas for secondary school students. In phase 1, an idea-eliciting discussion, students observe a focusing event and then develop explanations and initial models without information from the teacher. This phase happens before a simulation is projected. In phase 2, a guided-modeling discussion, the projected simulation encourages students to reason about the model and to determine how they could modify and improve their initial explanations. Questions based on the images in the simulation are used to exploit complexities of the simulation as opportunities for active student reasoning.

This lesson occurs about two weeks into the Matter and Molecule curriculum (Lee et al. 1993). During lessons in the previous two weeks, students have worked on developing a particulate model of matter and describing it as composed of molecules in motion. The differences among the three states of water have been linked to the arrangement and movement of water molecules.
Lesson goal

Understanding the particulate theory of matter as outlined in NGSS MS-PS1: Matter and Its Interactions involves students developing a mechanistic explanation of how observable macro-phenomena can be caused by the collective, invisible dynamic action of molecules (disciplinary core idea PS1.A: Structure and Properties of Matter; NGSS Lead States 2013). The specific objective of this lesson is to have students explain the observable force of resistance as caused by the invisible action of trillions of molecules of gas bouncing against the wall of the plunger on a syringe. The guiding question of the lesson is “How does the particulate model explain the behavior of water or air when attempts are made to compress them?”

Phase 1: Idea-eliciting discussion

In this phase, as a focusing event, the teacher describes a hands-on activity and shows students the apparatus they will use in the activity (an example is described below). Students are asked to individually generate a model to predict what will happen and explain why it will happen before performing the activity or receiving content information from the teacher. Students record their prediction, results, and explanations in their notebook. Asking students to invent models to explain phenomena fosters active engagement and learning and reveals previous knowledge. After making their models, small groups of students do the activity, share their results in a whole-class discussion, listen to each other’s results and ideas, and engage in scientific reasoning. During this sharing and discussion, the teacher gains diagnostic feedback on student thinking and insights into their understanding of the concept to be investigated. The teacher does not evaluate student models at this stage, since the goal is to draw out students’ ideas and encourage them to clearly articulate their point of view. The ideas discussed can diverge significantly from the target model. The big challenge of the idea-eliciting discussion is for the teacher to stay neutral while attempting to comprehend, not evaluate, student models.

Specific lesson example

In this lesson, the focusing event involves the compression of gas in a closed syringe. Students are asked to explore and observe the characteristics of a liquid- and gas-filled syringe. Wearing indirectly vented chemical splash goggles, students first receive a clear, 100 mL open syringe filled with air and are asked to make a drawing of how molecules of air are distributed inside and outside of the syringe and to predict what will happen when the syringe is compressed. Students observe the degrees of compressibility found in liquids and gases by filling their syringes with water, placing a cap tightly over the end of the syringe so nothing can escape,
and then attempting to push the plunger inside the syringe cylinder.

They repeat this experiment with air. When students push on an air-filled syringe, they are able to squeeze about 60 mL of air down to about 15 mL. (A few students are surprised when they push enough to blow out the side of the syringe or pop off the cap. Hence the importance of students wearing safety glasses.) Students are then asked to revise their molecular model of a liquid and a gas by discussing the following questions in their notebooks: Why didn’t the water-filled syringe compress but an air-filled syringe did? How can invisible air feel like a solid object when compressed?

As students work on recording the results and
revising their models, the teacher walks around the room to determine student thinking but does not attempt to correct or evaluate student responses. Some students draw air molecules compressing in an open syringe without the student pushing on the plunger (Figure 3). Discussion with students reveals that this idea is based on a preconception about the relative size of the opening in the syringe compared to the air molecules and that syringe geometry would trap the air molecules, “letting molecules come in but not let them out.” Exploring divergent student ideas in a whole-class discussion fosters norms for student participation and reasoning and provides additional diagnostic feedback on the state of student models and their ability to reason with them. This 10-minute discussion is facilitated by a think-pair-share structure, which gives students with special needs a chance to discuss their reasoning in small groups before sharing their ideas with the large group.

**Guided-modeling discussion**

In phase 2, the guided-modeling discussion, the teacher helps students modify their models by incorporating...
ing ideas students can infer from a projected simulation (see Resource for a link to the simulation used in the specific example below). For 15 minutes, the teacher explores different segments of the particulate model of a gas by using the computer simulation’s controls to pause and start the motion of the molecules and modify the variables, such as the number of molecules and size of the container holding the molecules of the gas. The simulation used here is a complex but directly observable representation of normally invisible aspects of the model.

While the simulation is a strong statement of the model, there is more to using a simulation than simply showing it. Research has demonstrated (Lowe 2003) that dynamic simulations can make greater processing demands on students than static images and that students need help determining which parts of a simulation’s complex visual displays are most important. The complexity of a simulation creates a space for asking students to interpret and reason with the dynamic model represented by the simulation. Questions based on the images from the simulation are used to support student reasoning toward a convergence on the target model. Each time the simulation is modified, it provides a new projected image. In this way, the simulation serves as a reservoir of easily generated and accurate images, each representing different states of the model.

**Specific example**

To explain the behavior of a compressed gas, students need to understand how molecules in a gas can generate a force that can resist the force of a plunger. The PhET gas-properties simulation (available for free online; see Resource and Figure 4) depicts the invisible dynamic el-
elements of the particulate model of gas. The simulation allows the teacher to pump different numbers of gas molecules into a box and see how the pressure changes when the teacher changes the box’s volume. Pressure is represented by a figure pushing on the box. This simulation permits the teacher to run the model multiple times with different number of molecules and box sizes. A discussion of this simulation should develop the mental imagery of bouncing molecules and link that imagery to the force produced by a compressed gas.

**Image-based questions**

Image-based questions (Figure 5) support the comprehension of a simulation by focusing students’ attention and reasoning on its most conceptually salient features. Orienting, situating, highlighting, linking, and predicting are categories of image-based questions that are asked in whole-class mode while the simulation is being projected in the front of the class. These questions are useful for navigating the guided-modeling discussion.

**Orienting and situating**

To orient students to the simulation, the teacher displays the gas-properties simulation and checks to see if students have made the connection between static simulation and the syringe. The teacher asks all students to hold up their syringe and overlay it visually on top of the image projected of the simulation. This orients students (Figure 6) to the visible and macroscopic parts of the model, namely the syringe, wall, and plunger. The teacher situates them in the simulation by suggesting that the figure in the simulation pushing on the wall is analogous to students pushing on the plunger of the syringe. The teacher then checks in to see if students understand that the dots on the screen in the simulation represent the invisible air molecules in the syringe.

**Highlighting**

In the exchange between the teacher and a student described in Figure 7, the teacher focuses students on conceptually important features of a cause or an effect in the image. The teacher does not emphasize the link between cause and effect but instead attempts to clarify one side of the causal chain. For example, in Figure 7, the teacher asks students to focus on, or highlight, one side of the causal chain, the molecules hitting the plunger.

**Linking**

The next stage of the discussion focuses on the link between cause and effect between elements of a complex visual. For example, the teacher asks students to link the behavior of molecules to the force needed to compress a syringe full of air (Figure 8). After highlighting the cause (molecules hitting the plunger) and the effect (having to push hard to keep the gas compressed), the teacher asks students to put these observations together and articulate the link between the cause and effect.
Students do the reasoning and are able make the links of the collective action of molecules and pressure.

Predicting

The next stage of the guided-modeling discussion focuses on using the simulation for making and testing predictions about how the simulation will look or behave in future situations. In this example, by changing the number of gas molecules in the chamber, the teacher could discuss two extreme cases of the syringe, one with only a few molecules and one packed full of molecules (Figure 9). While the simulation is paused, students predict how each extreme case would affect the force needed to compress the gas syringe. The teacher then uses highlighting and linking questions (Figure 5) to ask students to explain the behavior of the simulation in these two extreme cases and support their reasoning (Figure 10).

**Conclusion**

This suggested two-phase lesson (Figures 1 and 2) first explores divergent student thinking as students generate initial explanations of a focusing event and then uses a simulation to engage and support student reasoning toward a convergence on the target model. Image-based questions (Figure 5) prompt students to reason and use the simulation to evaluate and modify their model. This article describes only one lesson along a series that will be needed to get students to full
understanding of the performance expectation and the disciplinary core content.

Due to the flexibility of this specific simulation to alter variables, it is easy to obtain projected images of different states of the model, and each image gives the teacher an opportunity to discuss how the rate at which molecules collide with the plunger affects the forces on the plunger. Each time the simulation is modified, it provides a new projected image. In this way, the simulation serves as a reservoir of easily generated and accurate images, each representing different states of the model. The ability to generate multiple images makes the simulation useful for planning. Each image provided by the simulation supports the teacher with an opportunity to strategically plan sequences of the model-based questions and discussion (Figure 2).

The expanding library of free, web-based computer simulations online offers great opportunities for asking students to generate, evaluate, and modify scientific models. These lesson structures and strategies help teachers offer ways to take advantage of these modeling opportunities.

### References


### Resource

Gas properties simulation—http://phet.colorado.edu/en/simulation/gas-properties

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