Chemistry Model Lesson

Teacher Edition

Matter Matters

SCALE
SYSTEM-WIDE CHANGE FOR ALL LEARNERS AND EDUCATORS

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Quality Educator Development
California State University Dominguez Hills

BSCS

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Chemistry Model Lesson: Matter Matters

Lesson Overview
In *Matter Matters,* students construct an evidence-based explanation for phases of matter. Their explanations are made from two perspectives: macroscopic and molecular. They use a variety of learning strategies to link what they can observe with their senses (macroscopic view) to the underlying causes of those observations represented by the invisible world of atoms and molecules (molecular view). As students translate back and forth between these two views, they deepen and strengthen their content knowledge regarding California Standards 3d and 3e.

The model lesson is divided into five activities. The Engage activity draws upon students' prior knowledge and curiosity about phases of matter. Students offer their initial ideas about the phases of matter in a burning candle. In the Explore activity, students begin to make sense of matter by seeking patterns in everyday experiences. They use these patterns to categorize everyday examples of each phase of matter and relate these examples to phases of water.

In the Explain activity, students construct explanations of phases of matter by reading about the particle nature of matter. Students learn from a reading passage about the role of molecular motion and intermolecular attraction in determining the phase of matter. They then work with a model of matter at the atomic scale. The model uses one student to represent one particle in a collection of particles of a given phase. In the Elaborate activity, students connect the features of the model to the reading. They elaborate on their knowledge by applying it to an explanation of their original list of common solid, liquid, and gaseous materials.

In the Evaluate activity, students demonstrate what they have learned by revisiting the original candle observations. They use sketches, graphic organizers, and writing to demonstrate both a macroscopic and molecular understanding of the phases of matter.

Goals for the Model Lesson
In this model lesson, students will investigate and be able to answer the following questions:

- What are the macroscopic characteristics of liquids, solids, and gases?
- How does the behavior of particles at the atomic scale explain macroscopic characteristics of solids, liquids, and gases?
- What are effective ways to model microscopic particles in order to understand their behavior?
- How does understanding phases of matter explain the behavior of a burning candle?

Outcomes and Indicators of Success
By the end of this activity, the students will

1. understand that a substance can exist in three phases (solids, liquids, and gases), with each phase having different observable properties.

    They will demonstrate their understanding by

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- identifying phases of matter in a burning candle and a sample of water at various temperatures,
- identifying relevant examples of each phase of matter from common experiences, and
- describing characteristics of each phase based on several examples from everyday circumstances.

2. explain how the macroscopic properties of a particular phase (gas, liquid, and solid) are due to the underlying behavior of particles at the molecular level.

   They will demonstrate their understanding by
   - using the particle model to explain that in solids, particles are held together by strong intermolecular forces, are close together in a ridged structure, and exhibit relatively little energy of motion;
   - using the particle model to explain that in liquids, molecules or atoms are strongly attracted to each other, are close together, but not locked in a single position, and thus move freely past each other; and
   - using the particle model to explain that in gases, molecules or atoms move almost independently of each other, exert very little intermolecular force of attraction, are far apart, and move at high speeds generating a high amount of energy of motion.

3. use inquiry to infer the phase of matter in particular parts of a burning candle.

   They will demonstrate this by
   - generating evidence-based reasons for their prediction of the phase of matter of different candle parts,
   - interpreting correctly a model of particles in three phases, and
   - depicting the particle nature of each phase via labeled sketches.

Learning Outcomes: Grade 8 California Standards

Content

3d. Students know the states of matter (solid, liquid, gas) depend on molecular motion.

- All atoms, and subsequently all molecules, are in constant motion. For any given substance the relative freedom of motion of its atoms or molecules increases from solids to liquids to gases. When a thermometer is inserted into a substance and the temperature is measured, the average atomic or molecular energy of motion is being measured. The state of matter of a given substance therefore depends on the balance between the internal forces that would restrain the motion of the atoms or molecules and the random motions that are in opposition to those restraints.
- The change in phases is evidence of various degrees of atomic and molecular motion. The conditions of temperature and pressure under which most materials change from solid to liquid or liquid to vapor (gas) or gas to plasma have been measured. Those properties are difficult to predict but are highly reproducible for different samples of the same material and can be used to identify substances. Some substances will go from solid to gas directly at one atmosphere pressure. Dry ice, which is frozen carbon

dioxide, is an example. Chemistry handbooks contain the melting points (or freezing points) and boiling points (or condensation temperatures) of most materials usually under one atmosphere pressure. If the pressure is not one atmosphere, those temperatures change. Some substances have more than one stable solid phase at room temperature. Graphite, with its soft black texture and its hard, clear crystalline diamond atomic structure, represents the two solid phases of elemental carbon.

- Water is another example of a substance that undergoes a change in atomic and molecular motion under extreme conditions of temperature and pressure. At one atmosphere pressure, ice forms when water is cooled below zero degrees Celsius (or 32 degrees Fahrenheit). Above the freezing point the average molecular energy of motion of the water molecules is just enough to overcome the attractive forces between the molecules. The water molecules thereby avoid being locked in place and remain liquid. At and below the freezing point, the water molecules become the solid, crystalline material called ice. When liquid water is heated to temperatures of 100 degrees Celsius, molecular motion increases until large groups of water molecules overcome the attractive forces between the molecules. At this point those energetic molecules form bubbles of steam, which are bubbles of gas made not of air but of water. The process in which bubbles of water vapor escape from liquid water is called *boiling.* Continued heating will change the liquid water entirely into vapor instead of raising the temperature of the water above 100 degrees Celsius.

3e. Students know that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

- The atoms or molecules of a solid form a pattern that minimizes the structural energy of the solid consistent with the way in which the atoms or molecules attract at long distances but repel at short distances. The atoms or molecules vibrate about their equilibrium positions in this pattern. When raised above the melting temperature, the atoms or molecules acquire enough energy to slide past one another so that the material, now a liquid, can flow; the density of the liquid remains very close to that of the solid, demonstrating that in a solid or a liquid the atoms stay at about the same average distance.
- If a single atom or molecule acquires enough energy, however, it can pull away from its neighbors and escape to become a molecule of a gas. Gas molecules move about freely and collide randomly with the walls of a container and with each other. The distance between molecules in a gas is much larger than that in a solid or a liquid, and this point may be emphasized when students study density.

Investigation and Experimentation
Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

Evidence of Understanding

- Ability to brainstorm relevant and appropriate examples of states of matter.
- Collection of appropriate evidence for similarities and differences among states of the same matter at both the macro and microscopic levels.
- Accurate explanation, including diagrams, for the microscopic and macroscopic similarities and differences in the states of matter represented in the candle demonstration.
- Completed graph, correctly depicting the relationships between molecular energy of motion and distance between molecules.

"View at a Glance" Graphic Organizer

A one-page overview of the model lesson can help you keep focused on the learning goals and to pace yourself effectively. Consider having a copy of this handy at all times in the lesson. Refer to it often, especially the major concepts which embody this lesson's learning goals.

With students, use the graphic organizer as a visual reminder of the lesson's conceptual structure. Consider making a poster-sized version of the student version and placing it prominently in your classroom. Use it as a way to situate and orientate students in each activity. Doing so decreases students feeling lost and detached.

Advanced Organizer cue:
Helps students build bridges among related concepts by organizing information and activities explicitly.

Matter Matters

ENGAGE – Burning Question
Key Idea: You can activate prior knowledge by making careful observations about phases of matter in a candle.
Activity: Students activate prior knowledge by recording observations of a burning candle.

Linking Question: How do I use trends in my observations to characterize phases of matter?

EXPLORE – It Seems Evident
Key Idea: Patterns of observations help you form general characteristics used to describe and define phases of matter.
Activity: Students form general descriptions of phases of matter based on evidence.

Linking Question: Do general characteristics at the macroscopic scale have a microscopic explanation?

EXPLAIN – It's Just a Phase
Key Idea: Understanding particle behavior at the microscopic scale helps you explain macroscopic characteristics of matter.
Activity: Students read about the underlying molecular level explanation of phases of matter and model this using one student to represent one molecule.

or

Linking Question:
How can I apply my knowledge of microscopic particles to a physical model of phases of matter?

ELABORATE – Super Model
Key Idea: Representing microscopic particles with students in a classroom deepens your understanding of matter.
Activity: Students use their model to check and revise their understanding of the particle nature of matter.

Linking Question: How can I link prior knowledge, new explanations, and models to demonstrate understanding of phases of matter in a burning candle?

EVALUATE – Back to the Candle
Key Idea: Building on prior knowledge with new understandings helps you demonstrate what you know about phases of matter.
Activity: Students use multiple forms of representation to demonstrate understanding of phases of matter.

Model Lesson Main Concepts

- Matter commonly exists in three phases: solid, liquid, and gas.
- Each phase of matter has general characteristics, different from one another.
- Macroscopic properties are explained by the behavior of microscopic particles.
- Scientists use inquiry to understand and explain the natural world.

Number of stars displayed indicates number of 50-minute class periods suggested to complete section.

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Background Information
No two substances have the same set of characteristic properties. Some characteristics are chemical in nature, and describe how a substance reacts (or does not react) in the presence of another substance. For example, charcoal can combine with oxygen and burn to form carbon dioxide and water. Iron combines with oxygen to form rust.

Students sometimes equate changes only with chemical properties. In reality, there are both physical and chemical changes, and only chemical changes involve changes in chemical properties. For example, changes of state (boiling, melting, freezing, condensation, evaporation, etc.) are physical changes. The composition of the substance remains the same even if the substance's appearance does not. In a chemical change, however, substances are changed into new substances, with their own unique properties, because of a chemical reaction.

This investigation shows students three common phases (states) of matter: solid, liquid, and gas. Each phase has characteristic properties on the macroscopic and molecular level.

Solids have definite shape and definite volume. A cube of sugar has a definite shape (cube) and a definite volume that can be measured. If the cube of sugar is moved from one container to another, it maintains its shape (cube) and volume. In general, solids are not compressible and do not flow. Solids tend to be relatively dense when compared to the liquid or gas phase of the same substance. One notable exception is water. Water is less dense in its solid phase (ice) than it is in its liquid phase, which is why ice floats on liquid water. The density of ice is 0.917 g/cm^3, while the density of liquid water is 1.00 g/cm^3. The melting point of solids is always a lower temperature than its boiling point.

Atoms and molecules in the solid phase are close together, usually no more than one atomic radius (from about one to dozens of nanometers). These particles are arranged in a regular, repeating pattern called a lattice. The particles of a solid vibrate in place and do not move about freely. Neither do they move fast. Therefore, their kinetic energy (the energy of motion) is relatively low. Particles in a solid are close together and the forces of attraction between molecules are high.

Liquids have indefinite shape and definite volume. A liter of milk has a definite volume (one liter), but an indefinite shape. When a liter of milk in a carton is poured into another container, it maintains its volume (one liter) but takes on the shape of the new container. Liquids take on the shape of their container because they are fluid—they flow. Liquids are relatively incompressible as evidenced by the use of liquids as hydraulic fluids. Attempts to compress liquids generally result in very small volume decreases. Liquids tend to be less dense than their solid counterparts—usually around 10 percent less dense—and significantly denser than their gaseous counterparts. (Again, one notable exception is water. Liquid water is more dense than ice.) A substance in the liquid phase is typically 1,000 times denser than the same substance in the gas phase.

At the molecular level, particles of a liquid are only slightly more distant from each other than solids. But they move past each other with greater kinetic energy. They do not form a lattice structure. The strength effect of intermolecular attraction is slightly less in liquids than in solids because liquid particles have more energy and are less affected by the attractive forces.

Gases have indefinite shape and indefinite volume. For example, consider a balloon full of helium. When the helium is expelled from the balloon into a classroom, it expands to fill the classroom, changing both its shape and its volume. Like liquids, gases are fluid. Gases also diffuse; they spread out and mix with one another without outside assistance. For example, if a container of perfume is opened in the corner of a room, the scent will soon permeate throughout the room, making it difficult to identify the origin of the scent. Unlike liquids and solids, gases are compressible, as evidenced by squeezing a balloon full of air or pumping compressed air into a bicycle or car tire. You might also recognize that a tank of helium contains much more helium than the volume of the tank casing implies. Gases have low densities, often 1/1000 of the density of the same substance in the liquid or solid state.

Molecular gas particles are about 10 times farther apart than liquid or solid particles. Gas particles move fast, resulting in high energy of motion (kinetic energy).

Other phases of matter do exist. Two that have been identified are plasmas and Bose-Einstein condensates. **Plasmas** are somewhat like gases, but composed of electrically charged particles like ions and electrons. Plasmas are found in stars, solar wind, the ionosphere, auroras, and lightning—making them the most common phase of matter in the visible universe. Humans have learned to use plasmas in welding arcs, fluorescent tubes, and "plasma balls" found in novelty stores. **Bose-Einstein condensates** are atoms at a very low temperature that slow down so much that they lose their individual identity. They form a cloud that behaves as a single quantum entity.

Two conditions determine the phase of matter in a closed system: temperature and pressure. At a given pressure, increases in temperature will change a substance from the solid phase to the liquid phase, and then to the gas phase. Conversely, decreases in temperature will likely change a substance from the gas phase to the liquid phase, and then to the solid phase. Heating an ice cube causes it to melt to liquid and then evaporate to a gas. Cooling water vapor causes it to condense to liquid, and further cooling causes it to solidify to form a solid. At a given temperature, an increase in pressure will usually force a transition from gas to liquid, and a decrease in pressure will generally elicit the opposite effect.

The kinetic molecular theory of gases helps to explain the behavior of gases and properties of gases. One part of the kinetic molecular theory of gases is based on ideal gases, which have these characteristics:

- Gases are made up of large numbers of very small particles (atoms and molecules). Most of the volume of a gas is empty space as gas particles are far apart from one another.
- The particles in gases are constantly in motion. The particles move in straight lines, in random directions, and at high speeds compared to particles in a liquid or solid.
- When gas particles collide, their collisions are elastic. That is, no kinetic energy is lost during a collision. (Kinetic energy is conserved.)

- Gas particles do not attract or repel each other.
- The average kinetic energy of particles of a gas is directly proportional to the temperature of the gas.

Unfortunately, there is no such thing as an ideal gas. Real gases fall short of the expectations of ideal gases. Fortunately, the behavior of real gases is close enough to an ideal gas that kinetic molecular theory is still helpful in approximating the behavior of real gases. As particles in the gas phase condense to the liquid phase, the particles slow down and get closer to one another. Attractive forces between particles become a factor, limiting the motion of the particles. (Attractive forces in a liquid include hydrogen bonding, dipole-dipole forces, and London dispersion forces. The same forces are even stronger in solids and include ion-dipole forces, too.) Because the assumptions about ideal gas particles begin to break down as gases form liquids and then solids, the kinetic molecular theory for ideal gases cannot be applied directly to liquid and solids. Instead, scientists use intermolecular attractions in talking about the behavior of liquid and solid particles. This approach recognizes the attractive forces between particles in liquids and in solids and the effect of those forces on the motion of the particles.

Prerequisite Knowledge

All our students come to class with experiences and knowledge from school. By 8^{th} grade, science students are likely to know how to categorize objects and organisms by a set of criteria. For example, by 8^{th} grade, most students can distinguish cubes, pyramids, and spheres, and sort them by kind. They can describe why these objects form three kinds. They can use language (verbal and written) in their descriptions. In this lesson, students use this skill to generate a list of solids, liquids, and gases, then sort them by phase and describe commonalities within a group.

Students are likely able to represent an idea, concept, or thought with a sketch. They can easily draw their idea of something concrete like a palm tree. A more abstract example is when you ask students to represent the heat coming from a flame. In this lesson, students use drawings to represent their ideas about atoms and molecules as particles. This activity does not assume that they know about the particle nature of matter, but rather that they have some skill in representing ideas with sketches.

Another skill students are likely to have before 8^{th} grade is placing information into tables, and interpreting information already in tables. Their ability to do this will vary widely, but it is not likely to be a completely new experience. Students use these skills in this lesson map to connect one idea to another. Expect them to associate ideas from one column in the table with items in the adjacent column.

In science content, students will already know that materials are different because they exhibit different properties. They may not know the difference between chemical and physical properties, but they will know that ice is “hard” and water at room temperature doesn’t float a penny.

Commonly Held Misconceptions
Students harbor ideas about the natural world. Sometimes those ideas match the laws of nature. Often they do not. Effective teaching helps students build on existing ideas to construct ways of thinking consistent with our current understanding of the universe.

Pinpoint students' existing ideas before teaching new concepts and skills. This helps you spend time where it's needed the most. Inspect the commonly held beliefs listed below. Listen for them in conversations between students and with you. You will hear these misconceptions in two common speech patterns. One is "sloppy synonyms." For example, students often think that density and weight are interchangeable conceptually. When you hear students exchange science concept words inappropriately, use it as an opportunity to teach. Try questions like, "What do you mean by density?" or "It sounds like you think density and weight are the same. Is that what you're saying?" to assess exactly what students believe. Then, based on your judgment, you can address their misconceptions.

Another speech pattern to listen for is ill-referenced pronouns. When students cannot track a pronoun to a specific concept, it is frequently due to muddled or incorrect conceptions. For example, you could be probing students' beliefs about phases of matter by asking, "What happens to the space between molecules in a gas when you push down on a bicycle pump?" Students might respond, "It gets all thick in the middle." You could simply ask them to explain what they meant by "it" and gain valuable insight into their current beliefs.

- Phases of matter represent different substances. This misconception likely results from students' directly observable experiences. They see how different a solid phase is from its gas phase and think the difference is sufficient enough to conclude that the phases are different in kind. But when students begin to understand the particle nature of matter (matter is made from atoms and molecules), they realize that water molecules retain their formula in all phases. Any change to the formula results in a chemical change compared to a physical change.

- Some substances, like iron, do not exist in gas phase. A vast majority of pure substances exist as solid, liquid, and gas. The melting points and boiling points, however, are vastly different, an indication of the relative strength of intermolecular attractions. Students tend to think that since they have never seen gaseous iron, that it could not exist. As they gain experience, this misconception goes away with relative ease.

- Gases are most dense where a container has been "squeezed". Gas particles randomly collide and fill the entire container. Thus, the pressure inside a gas-filled container is equally distributed.

- Solids and liquids are not compressible. The space between particles in liquids and solids is small relative to gases. But particles in both liquids and solids can be pushed closer together, albeit with great pressure. An indication of this is the thermal expansion of solids and liquids.

- Gases are not made of particles, but solids and liquids are. Many students find it difficult believing that gases are made of tiny particles. After all, we can swish our hands through gas and cannot do so through a solid. With time, you can help them understand how wind, air pressure in tires, and helium in balloons have to be made from material with mass in order to behave the way they do.

Literacy Strategies
Identify ahead of time the literacy strategies that are most appropriate and effective with your students. This includes different ways to break up readings (pair-share read-aloud, class reading, assigning as homework), developing word walls, or glossaries. Multiple forms of representation are vital to reinforce student learning, including web-based video, sketching and drawing, kinesthetic activities, hands-on stations, text and reading, and discussion with student colleagues. Identify other strategies to be sure to reach English Language Learners (ELL) and Special Education students in your class as well.

The BSCS 5E Instructional Model
You will see that activities in this model lesson are structured using the BSCS 5E instructional model. This helps you be a more effective teacher. Using this instructional framework helps you *Engage* students, *Explore* scientific relationships, *Explain* key content, *Elaborate* on those concepts, and *Evaluate* or assess students' understanding. A summary is shown in Figure T1.

The 5E instructional model also makes it easy for you to weave key elements of scientific inquiry into your teaching. This is important because inquiry in the classroom models the process of science. Inquiry lets students be learners by doing science. This is a hands-on, and perhaps more realistic approach to the more formalized "scientific method." When you guide students with inquiry, you implement steps of the scientific method.

Stage	Possible Student Behavior	Possible Teacher Strategy
Engage	Asks questions such as, "Why did this happen? What do I already know about this? What can I find out about this? How can I solve this problem?" Shows interest in the topic.	Creates interest. Generates curiosity. Raises questions and problems. Elicits responses that uncover student knowledge about the concept/topic.
Explore	Thinks creatively within the limits of the activity. Tests predictions and hypotheses. Forms new predictions and hypotheses. Tries alternatives to solve a problem and discusses them with others. Records observations and ideas. Suspends judgment. Tests ideas.	Encourages students to work together without direct instruction from the teacher. Observes and listens to students as they interact. Asks probing questions to redirect students' investigations when necessary. Provides time for students to puzzle through problems. Acts as a consultant for students.
Explain	Explains thinking, ideas and possible solutions or answers to other students. Listens critically to other students' explanations. Questions other students' explanations. Listens to and tries to comprehend explanations offered by the teacher. Refers to previous activities. Uses recorded data in explanations.	Encourages students to explain concepts and definitions in their own words. Asks for justification (evidence) and clarification from students. Formally provides definitions, explanations, and new vocabulary. Uses students' previous experiences as the basis for explaining concepts.
Elaborate	Applies scientific concepts, labels, definitions, explanations, and skills in new, but similar situations. Uses previous information to ask questions, propose solutions, make decisions, design experiments. Draws reasonable conclusions from evidence. Records observations and explanations.	Expects students to use vocabulary, definitions, and explanations provided previously in new context. Encourages students to apply the concepts and skills in new situations. Reminds students of alternative explanations. Refers students to alternative explanations.
Evaluate	Checks for understanding among peers. Answers open-ended questions by using observations, evidence, and previously accepted explanations. Demonstrates an understanding or knowledge of the concept or skill. Evaluates his or her own progress and knowledge. Asks related questions that would encourage future investigations.	Refers students to existing data and evidence and asks, "What do you know? Why do you think...?" Observes students as they apply new concepts and skills. Assesses students' knowledge and/or skills. Looks for evidence that students have changed their thinking. Allows students to assess their learning and group process skills. Asks open-ended questions such as, "Why do you think...? What evidence do you have? What do you know about the problem? How would you answer the question?"

Figure T1: BSCS 5E Instructional Model ***Table adapted from LAUSD Science instructional Guide Grades 6, 7, 8 (2001)***

Engage
Burning Question

In this Engage activity, students make and record observations of a burning candle and give their initial ideas about the phases of matter they see. The emphasis is on using their senses to make macroscopic observations and on beginning to link evidence to conclusions by communicating their ideas verbally and in writing.

Before You Teach

Materials
For the teacher
safety goggles
candle
lighter or match

Advance Preparation
Locate a large, standard candle that produces an easy-to-see flame. Practice igniting the white trail of wax (paraffin) by having a match or lighter ready, then blowing out the candle flame. You will see a thin ribbon of "smoke" rising from the wick. You will also see the tip of the wick glowing red for a few moments. Place the burning match or lighter in the white line of smoke you see rising from the glowing wick. The trail will ignite. In turn, the burning wax will re-light the wick. The smoke trail is likely to be *solid* wax since you can see the characteristic white color of undyed paraffin. The match flame melts, then rapidly vaporizes the wax (turns it to gas). The gas phase of the wax ignites. This combustion produces heat, which rapidly melts and vaporizes the remaining solid wax in the trail. The burning trail of wax re-ignites the glowing wick. If you wait too long, the wick burns out and the trail will not re-light the wick.

Cautions
Both you and your students should wear safety goggles during the candle demonstration. Model safe lab technique by tying your hair back if it is long.

As You Teach

Strategies

Getting Started
Staging a lesson for maximum learning involves generating positive anticipation—the kind that inspires self motivation. For 8^{th} graders, this often involves piquing their curiosity by connecting science to their everyday lives. For example, walk to the center of class and ask if you can sit in one of the student chairs. You position yourself over the chair, but suspend your body just before sitting and ask, "What would happen if you removed the solid chair?" After students respond, ask them why air "allows you to fall, but the solid chair will support you." Ask them to imagine replacing the chair with a "liquid chair." "What happens then?" you ask.

Now you have captured their curiosity. They want to learn about the differences that phases of matter make. Have them read the short introduction to the model lesson found on page 3 and study the figure of the boy pulling the trash can (figure 1). Remind students that they will be learning about phases of matter from both the macroscopic and molecular views.

Process and Procedure

In Step 1, show students the candle first, then help them prepare their notebook for making observations.

Visuals:
Helps students generate mental pictures to connect information, make sense, and enhance long-term memory.

Emphasize allowing generous space for sketches, labels, and captions for explanations. Light the candle and ask them to begin sketching. Walk around the room to monitor the size, clarity, and accuracy of their sketches. Monitor how well students follow instructions for proper labeling as shown in Steps 1a–b. Assess this by looking at their work *in process*. If they omit a portion of the label, remind them what to include. However, at this stage of the activity, resist the temptation to correct their labels about the phase of matter, even if they ask you, “Is this right?” At this point, you are activating their prior knowledge about phases of matter so they can eventually use evidence-based reasons to modify their thinking. Knowing students’ initial state of understanding is an essential part of ongoing (also called formative) assessment. As they learn, their answers will slowly change. Monitoring this change is a large part of formative assessment.

In Steps 2 and 3, find out if students transfer what they learned about labeling from Steps 1a-b to this new observation. If they don’t make labeled sketches of the white trail of candle “smoke” without prompting, this gives you important assessment feedback. It could mean that students do not understand the instructions due to reading or other language problems. It might mean they do not see the same observations as you and others see. Some students might indicate they think including labels on sketches is a waste of time since they know what they see and therefore do not need to write it down. Consider mentioning the importance of keeping an active record to all scientific endeavors. Active records refer to the monitoring of observations in an ongoing fashion. This allows scientists to reflect on how their thoughts have evolved due to new evidence. Recording only the final result removes the possibility of “learning as-you-go.”

In Step 4, monitor the sharing process.

Think-Pair-Share strategies:
Help students check their thinking and ability to communicate in a peer setting where feedback is ongoing.

Encourage active listening. Consider modeling this for students by showing them key body-language clues associated with paying attention. Request that students use their sketches and labels as “props” (a sort of visual aid) during their explanation. Watch for them to point to and read from their notebooks. Often, this process helps them catch mistakes they have made or makes them rethink their original ideas. Be certain to restate that the "correctness" of their answers is not as important in this step as the accurate and respectful sharing of ideas. Accuracy will certainly come, but later.

In Step 5, encourage teams to generate as many examples as possible (more than 5). A greater number of examples gives students more convincing evidence for the general characteristics of each phase. If you see a misplaced example (e.g., clouds in the gas column) request that the team confer with other teams. Usually, lively discussion ensues. Resist telling them where to place any example. At the end of the lesson, the students will be able to identify the phase of matter using evidence-based reasoning.

Answers to Reflect and Connect

1. You have heard and used the word *phase* in everyday life. For example, the Moon goes through different phases monthly. Or a friend might be in a bad mood and you say, "Oh, he's just going through a phase." Compare and contrast these uses of the word *phase* to the way it is used in this activity.

   Students' answers will vary, but all should recognize that words such as phase have meanings that depend on context. A large part of the value of activating prior knowledge is pinpointing the proper context of the concepts in question. Context is very important for English language learners. Look for student answers to describe a clear distinction among the various uses of phase mentioned here. Phases of the Moon refer to the periodic changes in appearance on the Moon. "Going through a phase" means the person is acting a certain way, usually contrary to normal behavior, for a period of time. With a burning candle, phase refers to the state of matter that candle wax exists in under certain conditions.

2. In Step 5, you and a teammate placed examples in different columns based on the phase of matter. Describe what you did when you were unsure or disagreed about where to place an example. If you did not disagree, describe the way you used observations to place each example in the correct column.

   Answers will vary, but all answers should go beyond a few words reply. The key feature to look for is students' referral to evidence in either agreeing or disagreeing. That is, when they decide to place an item in a column, they should base their decision on what they see, not on the simple fact that they both ended up placing the item in the same column. Emphasize the importance of using observations to make important decisions.

Explore
It Seems Evident

In this Explore activity, students make and record observations of you demonstrating three phases of water. These observations are of the macroscopic properties of water. They use their observations to categorize each phase of water. Then students look for trends in the everyday materials they placed in the solid, liquid, and gas categories. With these trends in mind, students devise a set of general characteristics for each phase of matter.

Before You Teach

Materials
For the teacher
hot plate or Bunsen burner
250 mL beaker
water
ice
tea kettle
cooking pan
½ cup sugar (sucrose)

Advance Preparation
Locate a hot plate or Bunsen burner, 250 mL beaker, ice, and a tea kettle. Make sure you have enough ice for multiple class periods. Preheat the water in the beaker and tea kettle to save time and decrease student disengagement.

Caution
Both you and your students should wear safety goggles during the candle demonstration.

As You Teach

Strategies

Getting Started
Stage this activity by helping students see the importance of clear and reproducible ways to categorize phases of matter. You can do this by placing a beaker full of water in front of class, then holding some sugar (sucrose) in a spoon over the water. Ask students what phase of matter the sucrose is, then ask what will happen when you add solid sucrose to the water and stir. After dissolving, ask them in what phase of matter does sucrose exist now.

Some students will say the sugar is liquid and others will say it is just dissolved, without offering more detail. You can have a cooking pan and burner ready to show them what melting sucrose (liquid) looks like (it is a clear, viscous liquid before it turns brown or carmelizes). Point out that liquid sugar melts at a temperature that is much higher than liquid water. Ask students how both the sugar in water and sugar in the heated pan can be liquid sugar.

The obvious contradiction gives you the opportunity to emphasize the need for clear and reproducible description for phases of matter. That is what they will explore in this activity.

By the way, dissolving sucrose is a chemical process not a phase change. The chemical and physical properties of sucrose change when it is dissolved in water while only the physical properties of sucrose change when it is melted and before it begins to carmelize (another chemical process).

Process and Procedure

In Step 1, consider a reciprocal reading strategy.

Reciprocal reading strategies:
Help students break down readings into smaller chunks of information and then construct their own meaning.

One version of reciprocal reading involves pairs of students. Student A reads a sentence and student B asks, “What does that sentence mean?” Student A explains the sentence. If there are words student A doesn’t understand, you provide a dictionary or tell the team the word’s meaning. Roles are reversed for the next sentence until the reading is complete. This version of reciprocal reading is best used with relatively short readings, which is a good place to train students.

In Step 2, direct the discussion to focus on differences between scientific evidence and subjective opinion or evaluation. A key attribute of scientific evidence is reproducibility. That is, do different people make the same observation over and over again? For example, all people observe that a penny falls through gas, but not through a table. But not all people think a shimmering ice cube is pretty. A scientific way of categorizing phases of matter involves clear, reproducible, evidence-based descriptions.

In Step 3, assess students’ developing understanding of scientific evidence by reading what they write in this step. Consider asking several individuals to state their evidence for a common example of material in a certain phase. Ask the class to help evaluate each piece of evidence rather than you being the one to say it is or is not proper evidence.

In Step 4, you will need ice cubes, liquid water in a beaker, and boiling water in a tea kettle to demonstrate the three phases of water. This step allows students to observe, make a claim, and use their observations as evidence to support their claim.

A tea kettle with a narrow neck works best because it helps you point out the difference between steam (water vapor) and condensed water (cloud). When the water is boiling vigorously, the first few centimeters of water jetting from the spout will be transparent. Water vapor is transparent. After a short distance, the water vapor (also called steam) cools and condenses. We see this condensed water as a cloud-like form billowing away from the spout. If you heat the spout with an additional flame, the cloud will disappear or form much farther from the spout than before. In the same way, the white contrails from high-flying jet aircraft appear well behind the jet’s engines. Between the engine and contrail is water vapor, which is transparent. The contrail is condensed water vapor or ice.

Students will record observations of the three different phases of water. Insist that students use sketches and labels (as in the Engage activity) to record observations of water. Ask students to begin thinking about similarities and differences between what they see in the three phases of water. Resist the temptation to tell them each phase of water, even if they ask. Require them to use their list of examples of everyday circumstances to find the best match between the phase attributes of water and the characteristics they are starting to notice in their table from Step 5 in the Engage activity. Remind them that they can revisit their notebook and modify remarks based on ongoing learning.

Formative assessment:
Helps students check their understanding "in progress" and models the nature of science by adding to prior knowledge based on new evidence.

Students will revisit the table from Step 5 in the Engage activity and label the phases they see (ice, liquid water, steam) with the table column headings (solid, liquid, gas). Students will provide evidence from their observations to explain their labels.

Answers to Reflect and Connect

1. Study the list of examples each team member offered in Step 5 of the Engage activity and write a general set of characteristics of each phase of matter.

   Student responses will vary, but need to contain some common elements. In almost all cases, students will list macroscopic characteristics (unless they already know about atomic-level explanations).

   Some general characteristics for the phases of matter:

   Gases
   - *low density*
   - *conform to shape of their container*
   - *volume decrease when pressure increases (constant temperature)*
   - *volume increases when temperature increases (constant pressure)*
   - *solids and liquid material falls through them*

   Liquids
   - *slightly compressible*
   - *usually expand when heated*
   - *take the shape of their container*
   - *flow*
   - *solids can pass through liquids*

Solids

- *retain their shape regardless of the presence of a container*
- *usually the densest phase of matter for a pure substance*
- *require greater force to "break apart" than liquid and gas for the same substance*

2. Sketch your initial ideas for each phase of matter from the molecular viewpoint. What do you think matter looks like at the molecular level for each phase of matter?

   This question allows you to make an initial assessment of what students think about the particle nature of matter. Look for particles very close together in solids, about as close as in liquids but not in any regular pattern, and very far apart in gases. Do not correct them at this point. But do help them link observations to their initial drawings. For example, if they draw gas particles almost as close to each other as liquid particles, then ask which affects them more when they belly-flop off the high dive: falling through air or falling through water.

   By 8th grade, many students will have heard of atoms and sketch them as circles or dots on a page. If you notice a student who does not have this initial sense of the particle nature of matter, consider having a few models of crystals around to help these students.

   To help students think about the macroscopic implications of the molecular structure, you could ask students to compare this model of a solid and also a box of loose balls to a student. Then ask, "Which one acts like a solid when I try to pass my hand through it?" You can ask the same question about liquids.

   What students are not likely to show in their sketches are intermolecular attractions and molecular motion. They will include these ideas after reading a passage about phases of matter.

Explain
It's Just a Phase

Students begin to construct their own explanations of phases of matter by first gaining knowledge, then applying that knowledge to a physical model. The emphasis in the reading is on explaining macroscopic behavior using the underlying particle nature of matter. But since picturing atoms and molecules can be difficult, students engage in a physical model of atom-sized particles in three phases. In this model, one student represents one atom-sized particle.

Before You Teach

Advance Preparation
Plan ahead for enough open space to accommodate the number of students you will use in the one-student-one-molecule model. This probably means being able to move desks to the perimeter of the classroom. If space won't allow, use fewer students in the model.

Cautions
none

As You Teach

Strategies

Getting Started
Set the intellectual tone for this activity by asking the class a seemingly simple question, "How do you know that gases are made of something?"

Question cues: Help students think about and reason with new information by activating prior knowledge and connecting it to new information.

Some students will offer evidence like the wind blows down a house or air keeps your car suspended above the road because of pressure in your tires. Then probe further by asking, "But if you can't see some gases, like air, then how can it be made of something?"

Some students will mention that gases are made of tiny particles that we cannot see, which you can counter by asking, "Then why can you see most solids? Aren't they made from the same particles?" At this point, lead the discussion to the need to find out more about the microscopic nature of matter. And since much of this information has been known for many years, students will take advantage of this information by reading it.

Process and Procedure

In Step 1, have students inspect the T-table in Step 5 of this activity for its organization and content.

T-tables:
Represent a visual strategy that helps students organize complex information spatially, which fosters relating and recalling information.

Remind them that they are not expected to know the terms or concepts now or how to complete the table. Rather, explain how looking at the table ahead of time prepares their mind for recognizing the key ideas. Once they recognize the key ideas, they are more likely to work with and understand them. Remind them that learning takes time, requires lots of discussion, and often involves changing your original answer based on new evidence.

In Step 2, consider employing a reading strategy that is appropriate for your students. Two example reading strategies are described below.

Reciprocal reading (Five Words and Picture):
A reading strategy that helps students develop an understanding of key concepts from a science content–rich reading.

Five Words and Picture

A. Divide the class into small groups—no more than four students in each group. (Three per group is better than five per group.)

B. Number the groups: 1, 2, 3, 4, or 5. You may have more than one group with the same number.

C. Be aware that groups 2, 3 and 4 have the most challenging reading focus, so consider differentiating your instruction based on this information.

- The 1's focus on *Water Everywhere*
- The 2's focus on *The Molecular View*, paragraphs 1–5.
- The 3's focus on *The Molecular View*, paragraphs 6–8.
- The 4's focus on *Intermolecular Attractions*
- The 5's focus on *It's Just a Phase, But It Matters*

D. Use these instructions with all students. The instructions tell students how to make a poster regarding what they read.

- Take note of what images come to mind as you read the assigned passages to yourself. Keep in mind that you will be asked to provide evidence from the reading as rationale for your drawing.
- As a group, decide what images would best convey what is in the passage. For example if the passage were comparing and contrasting sharks and dolphins, then the images on the paper might include images of the shark's and dolphin's dorsal fins and also the caudal fins.
- The goal of the poster is to illustrate the points made in the reading.

- The last caveat is that you may use words, but no more than five total. Symbols like number signs (#), and percent signs (%) are okay as well. Use as many as you like, BUT only 5 words or less.

E. Set up a “share out” among teams. A share out allows teachers time to pursue some needed formative assessment. As with any presentation, each member of the group needs to participate. While the group is presenting, the teacher notes who, if any, may have developed a misconception around what they read. Sometimes this can be culled out when the student is heard when responding to another person other than the teacher.

F. If there are illustrations on the poster that you feel were not represented in the reading, this would be a good time to ask the students to provide evidence in the reading that gives inspiration to the drawing.

G. The order of presentations also can be a valuable instructional tool. As students are illustrating their posters, make notes on what order the presentations could best take place. There are several concerns:
- Will there be enough time for all groups to present?
  - If so, see next concern.
  - If not, be sure that the posters presented cover all the necessary points, so misconceptions do not continue.
- Are there posters that miss the mark by not covering all the points? If so, allow these posters to go first, and have the students ask questions. When students believe they have a product that will contribute to the conversation, the students tend to stay engaged longer.

Reciprocal reading (Word Sort and Concept Map):
Reading strategies that help students develop an understanding of key concepts from a science content–rich reading.

Word Sort and Concept Map

Sometimes struggling readers have difficulty understanding the connections among concepts when those concepts are presented in written language. That is, they have difficulty interpreting linguistic syntax. But present these same relationships spatially and many students understand. Linking their spatial understanding back to traditional reading passages helps students become better readers.

Concept maps help many students become better readers. The following steps represent one of many techniques of using word sorts and concept maps to increase literacy skills in science reading.

A. In pre-reading, teams of two students write the following key concept words (one word or phrase per 3 × 5-inch card): solid, liquid, gas, ice molecules, liquid water molecules, water vapor molecules, highest energy molecules, lowest energy molecules, medium energy molecules, molecules move fast, molecules move past each other, molecules only vibrate, strong attraction, weak attraction, medium attraction.

B. Word Sort: Teams arrange these words (cards) on the table top before them in a spatial arrangement that makes the most sense to them, based on their prior knowledge about these concepts. Give students the general instruction that more closely related terms need to be placed closer together than less related words. As student pairs arrange the terms, they should discuss their reasons for proposed arrangements. Along with activating prior knowledge, this raises questions that students can answer by reading the section that follows, which sets a purpose for reading.

C. Teams read the *Water Works!* passage carefully, always checking their card arrangement as they read.

D. In post-reading, teams inspect their original concept map (arrangement of cards). They make adjustments based on what they read. Student pairs should discuss and point out references in the text to justify changes in the arrangement of terms.

E. They transfer the map into their notebook or on to a piece of paper and include connecting arrows and a caption of explanation for each connecting arrow.

Figure T2 shows a partial concept map.

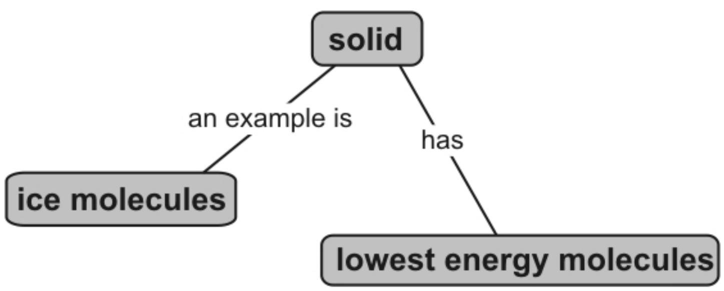

Figure T2: Example concept map.

Process and Procedure—continued

In Step 3, use the reading to introduce the idea of models as scientists think of them. You could ask students to read the passage and write several examples of models in their notebooks. Facilitate a class discussion in which students share examples of their models. Most examples will be physical models, like a doll or model airplane. These are indeed models, but frequently scientists use conceptual models in which objects in the model represent things that are impossible to see. Mention this distinction to students so they are prepared to use and learn from the model in the next step.

In Step 4, students will model the molecules in different phases—solid, liquid, and gas.

Determine how open-ended you want to have this modeling activity by using knowledge of your students' abilities. Because the modeling activity is connected to the reading exercise, you might have to adjust this activity to help student understanding of this model. Your role with these students is to consult as they "learn forward" in their modeling attempts.

Depending on your students' reading level you might need to establish the idea that one student represents one particle (or molecule). You can do this by asking the class, "If we were going to model matter with students in this classroom, what would one student represent?"

Total Physical Response:
Helps students gain conceptual understanding through kinesthetic action.

Student Modeling Activity

- Once you establish that one student represents one particle (or molecule) at the molecular scale, select a volunteer to stand next to you and act out what he or she thinks the particle will do in various temperature conditions.

- Allow other students in the class to offer suggestions to the volunteer on how he or she should adjust his or her movement.

  Example: When you ask how the volunteer would move in high temperature environments, students ought to describe fast-moving particles (or molecules). The volunteer must move (not stand in one place) and move randomly, bouncing off imaginary container walls.

- Select another volunteer to represent another particle (or molecule) of the same type. Proceed through different temperatures, but this time make sure that molecules collide. Introduce the concept of molecular motion and how it connects to collision energy—the faster the particles travel, the more energy of collision.

- Introduce intermolecular attractions by asking your two volunteers to "cool down". Ask the class what will happen to the separation distance. Make sure the volunteers continue to move, but with less energy of motion (slower), which results in less separation distance.

  As the volunteers get closer to each other, ask the class if the "particles" (or molecules) are more likely or less likely to be attracted when they are close. Then ask how to represent that attraction. The class could suggest tying the volunteers together with ropes or rubber bands, which are good ideas but cumbersome. Suggest holding hands and request the volunteer's model molecular motion when there is some intermolecular attraction (hand-holding). They will move past each other, but not very far. This models a liquid.

- For solids, lower the temperature even more. Ask the class to suggest what happens to molecular motion and intermolecular attraction. Then ask them how the volunteers could model both concepts. Eventually, the volunteers need to lock arms (stronger intermolecular attraction) and vibrate in place with feet stationary (solid).

- Finally, check for understanding by getting the entire class involved. Move desks aside and use the borders they make as the container wall. Place all class members together and ask them to model a gas (monitor overenthusiastic "molecules"). Make sure that motion is random and continuous. Lower the temperature and evaluate how the class responds. Look for students who are not slowing down and not beginning to hold hands. This could indicate they do not understand how temperature affects molecular motion and intermolecular attraction.

In Step 5, emphasize the importance of individual learning by asking students to complete the T-table on their own. Remind students that scientists always check their work and this step is coming up. A sample completed T-table is shown in Figure T3.

You might want to do one row together as a whole class, so students have a guide to complete the table.

Molecular model	**How was this molecular model represented in the classroom model we just performed?**
one particle (or molecule) of a pure substance	one student
all the particles (or molecules) in a sample of pure substance	full class
distance between the particles (or molecules) in a pure substance	distance between students
particles (or molecules) in the solid phase of matter such as ice (or wax before the wick is lit)	when students are closest together, locking arms
particles (or molecules) in the liquid phase of matter such as water (or wax around the lit wick)	when students are close together but still moving past each other and only holding hands
particles (or molecules) in the gas phase of matter such as steam (or wax in the smoke that can be re–lighted); smoke particles are solid and do not ignite	when students are moving freely at high speed and not holding each other
particles (or molecules) are in constant random motion, regardless of the phases of matter	students moving

Figure T3: Completed example of model features T-table. Student answers will vary, but should convey these essential ideas.

In Step 6, ask students to read aloud what they have written in their individual T-tables. Emphasize respectful and attentive listening. Monitor that reading and listening roles are reversed. Listen for different view points and consider using any you notice as a way to clarify ideas for the entire class.

Formative Assessments (*Reflect and Connect* questions):
Help you monitor the ongoing learning of your students so you can make appropriate adjustments in your teaching.

Answers to Reflect and Connect

1. In which phase of matter do particles have more energy of motion? Explain how you know, based on what you have seen and learned in these lessons.
   The gas phase has the most energy of motion, on average, per molecule. Macroscopic evidence of this is that for a given number of particles, the gas phase occupies more volume then a liquid or solid. .

2. How does an increase in the temperature (the energy of motion) for a constant number of particles in a gas affect the space between particles? Explain this relationship by completing the following statement appropriately:

   If the energy of motion of the particles in a gas increases, then the distance between particles *increases* because *the attraction between particles is amost non existent because velocity of the particles and their distance apart are both large.*

   See Figure T4 for a sample sketch graph.

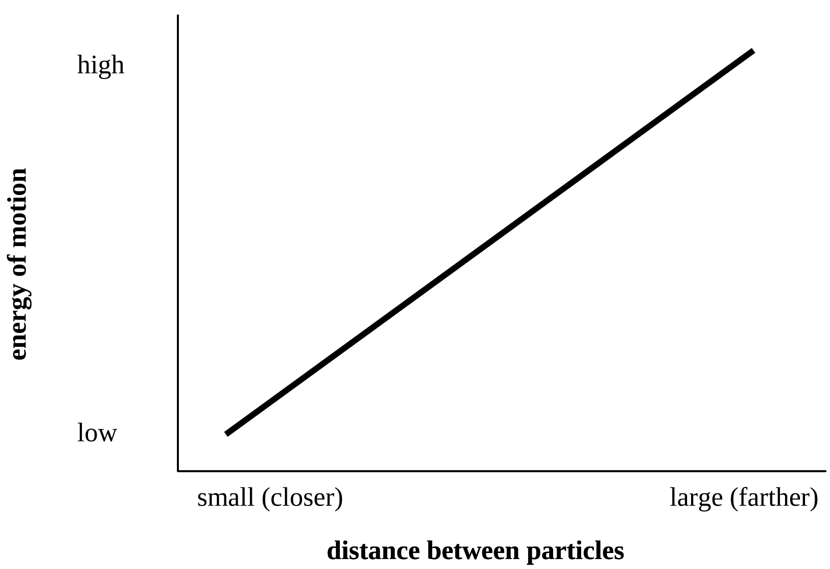

Figure T4: Example completed relationship between energy of motion and distance between particles graph. Notice that a large separation distance corresponds to a high energy of motion. A linear relationship between energy of motion and distance works only for gas particles.

3. In which phase of matter do attractions between particles affect motion the most?

Teacher Pages

In solids, particles exert attractive forces on each other strong enough to limit their motion to vibration in place. A sketch should show particles vibrating in close proximity to each other, with a caption that describes forces strong enough to hold the particles in place.

Elaborate
Super Model

In this Elaborate activity, students apply what they know about modeling phases of matter to verify their understanding from the reading passage, *Water Works!* They compare and contrast each phase of matter using a Venn diagram, then use a T-table to explicitly link key features of the one-student-one-molecule model to the reading.

Before You Teach

Advance Preparation
If you elect to present a class display of the T-table and Venn diagram from this activity, arrange ahead of time for the needed materials. These could include smart board, computer projection tools, large-sized Post-it pads, or an overhead projector.

Cautions
none

As You Teach

Strategies

Getting Started
Emphasize to students that one important application of new knowledge is its use to revise initial work. The notion of going back and "fixing" answers based on new evidence may seem foreign to some students. Explain to them the role of making and explaining revisions in science. That is, science is not about writing out correct answers for teachers, rather it is about thinking, investigating, learning, making mistakes, and then learning from those mistakes based on new evidence.

Process and Procedure

In Step 1, the class will create a Venn diagram for the phases of matter.

Visuals (Venn diagram):
Help students generate mental pictures that enhance long-term memory by reconfiguring information spatially.

a. Ask students to generate lists (of similarities and/or differences between phases of matter) first.
b. Draw the Venn diagram.
c. Explain the parts of the Venn diagram.
d. Help students organize their lists (from Step 1a) onto the Venn diagram.

Point out that the circles (and therefore what they know) overlap. Where the circles overlap represents similarities. Where the circles do not overlap represents unique features or attributes.

For example, the overlap between liquid and gas should express the idea that both phases are fluids (they take the shape of their containers and flow). After modeling one section, ask students to complete the remaining sections. Use your judgment for debriefing techniques with the entire class. A sample Venn diagram is shown in Figure T5.

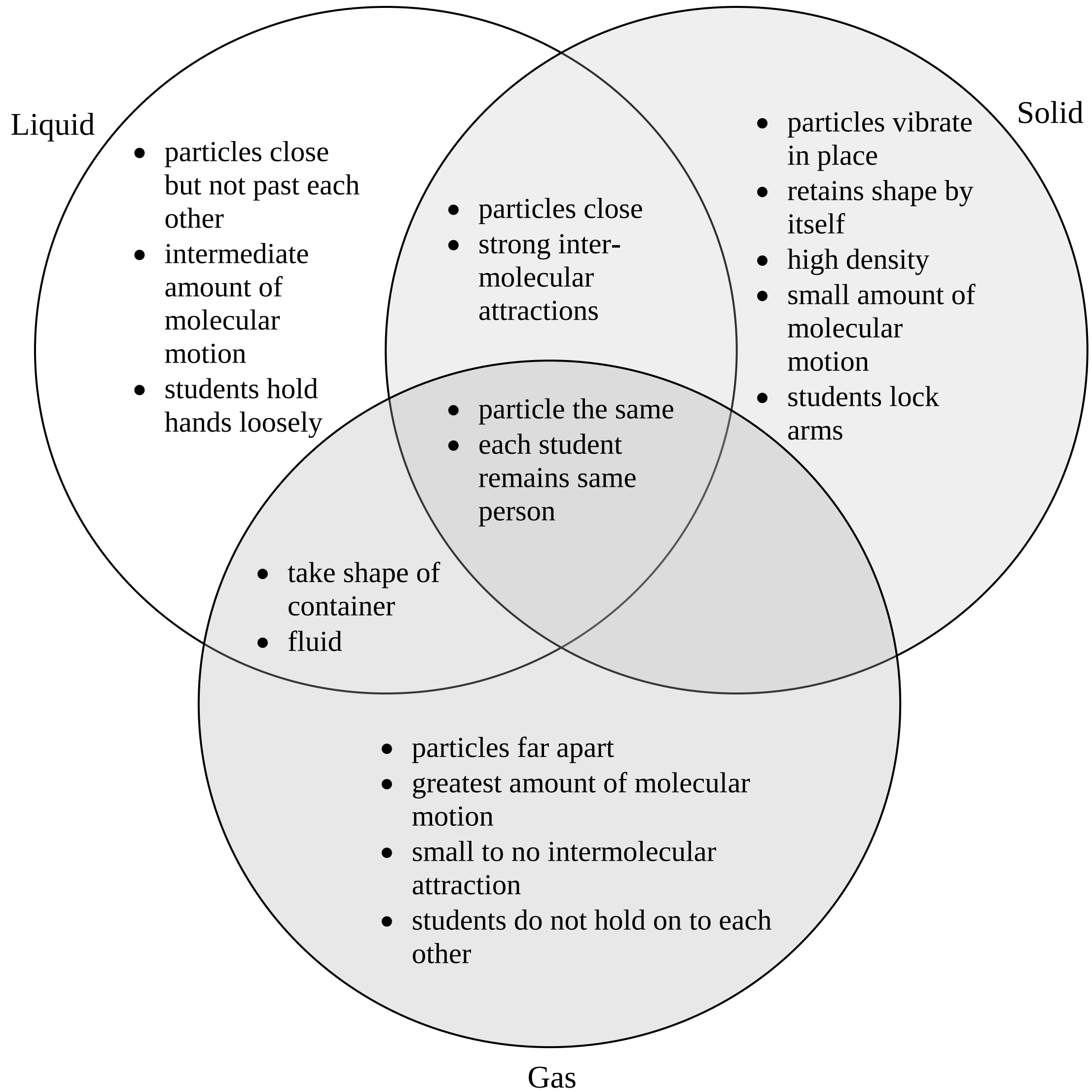

Figure T5: Venn diagram. The exact student phrasing will vary, but the essential ideas should match.

In Step 2, emphasize the role of revision in the scientific process. Explain that scientists have initial ideas, and then collect evidence on those ideas. They analyze the evidence to see if their original ideas are valid. If the evidence suggests modification of the original idea, then scientists make those revisions being certain to explain how new evidence led to the revision. This implies that nothing is erased. Instead, old ideas can be crossed out or coded to make it clear to outside observers how thinking has developed.

Lead students to revise their T-table from Step 5 in the Explain activity. Insist on an explanation of why any revision was made. Explanations must be connected to evidence and reasoning.

In Step 3, students evaluate the "student-as-particle" model. One way to think about model evaluation is verification. That is, scientists try to confirm that their model agrees with accepted or current knowledge about nature. If they do not do this, then the model could lead to incorrect ideas.

Authoritative or well-accepted readings are one source for verification. Students can think about each feature or action in the model and find a reference to that feature or action in the *Water Works!* reading. This activity also helps students review the content in the reading, which increases reading comprehension. This table can help English language learners and below grade level readers.

Scientists evaluate models since every model has pluses and minuses. Models are not exact duplications of the phenomenon under study. Effective models behave very similarly to natural processes, but have limitations. Scientists articulate these limitations in order to place interpretations resulting from the model in a frame of reference. This frame of reference allows scientists to know when the model is valid and when its predictions are tenuous—when to "trust" the model.

Explain the role of verifying, evaluating, and summarizing a model to students. Then get them started by helping them complete one row of the table. Allow time for them to complete the remaining rows and then conduct an appropriate all-class debrief. Figure T6 shows a sample table.

Summarizing strategy:
Helps students reorganize complex information to make sense of new information, identify key information, restructure information for their own purposes.

Classroom Model feature	How does this feature agree with the *Water Works* reading? Why?
When molecules slow down, they get closer together.	Students move slower with less distance between them.
one molecule of a pure substance	One student as one molecule works well because neither students nor molecules change "formula" from phase to phase and students can hold onto other students with different strengths, which shows differing intermolecular attraction.

Teacher Pages

Model feature	How does this feature agree with the *Water Works* reading? Why?
all the molecules in a sample of pure substance	Full class as an entire sample of a pure substance works well as long as each student is considered the exact same molecule. In reality, students are different people, with different size and arm strength when holding on to each other. Different students move at slightly different speeds even at the same "temperature", which is a good model of actual particles in a sample.
distance between the molecules in a pure substance	Distance between students works well to represent distance between molecules except that with real molecules the intermolecular attractions govern separation distance. With students, the separation distance is determined subjectively, not by actual attractions between students.
particles in the solid phase of matter such as ice (or wax before the wick is lighted)	Students close together and locking arms to represent solids works well as long as student's feet don't move and students form a regular pattern or arrangement. Real solids do this naturally, but students in the model have no such natural "driving force".
particles in the liquid phase of matter such as water (or wax around the lit wick)	Students close together and holding hands represents liquids well since liquid molecules are about as close as in solids, but move past each other. One problem with the model is that students holding hands remain associated with one or two students. In real liquids, molecules can move far from another molecule over time. But again, there is no feature of the model compelling the arrangement of students other than their thinking.
particles in the gas phase of matter such as steam (or wax in the smoke that can be re–lighted)	Students far apart and moving fast represent fast moving gas molecules with little intermolecular attraction well. One exception is that heat supplies the energy of motion to molecules and student thinking provides the reasons to move in the model.
particles are in constant random motion, regardless of the phases of matter	Student motion as molecular motion works well.
other….	

Figure T6: Completed example of model feature comparison with *Water Works!* reading table. The exact phrasing will vary from student to student, but the key ideas should agree.

Answers to Reflect and Connect

1. Think about a bottle of perfume. You stand at one end of a large room and your friend opens the bottle while standing at the opposite end of the room. She doesn’t blow on the opened top. Create a model to explain, at the molecular level, why you smell the perfume after several minutes. Sketch your model and include highlight comments and a caption that explains the model.

   Students might sketch tiny particles coming from the perfume bottle and spreading slowly across the room. These particles should be far apart (not like a solid) and somehow show constant, random motion. Other students might draw students getting out of class (like getting out of the perfume bottle) and spreading across the entire school campus during lunch break (like perfume molecule eventually getting across the room).

Teacher Pages

Evaluate
Back to the Candle

In this Evaluate activity, students demonstrate what they have learned about phases of matter in two ways. First they generate multiple forms explaining key words and phrases important to understanding phases of matter. Those forms are sketches, graphic organizers, and sentences. Next, students characterize solids, liquids, and gases in a table using examples from their experiences in this model lesson and science content concepts.

Before You Teach

Advance Preparation
No special advanced preparation is required for this activity. You may want to review various ways to represent knowledge that are acceptable to you, and familiarize yourself with reasonable answers to the states of matter table in figure T7.

As You Teach

Strategies

Getting Started
Reflect carefully on your particular group of students before assigning the tasks in this activity. Some will need some initial help to know what you mean by forms of representing knowledge. Remind them of the sketches, graphic organizers, sentences, and diagrams they have produced in this model lesson. Emphasize that you expect them to use many of the same methods, but with different content. They are not allowed to simply copy or repeat the essence of what they have already done. This is a demonstration of their knowledge, not a copying exercise.

Process and Procedure

In Step 1, help students know what you mean by “review”. Use active review strategies—ones that require students to generate or reconfigure knowledge. You could adjust the reading strategies discussed in association with the reading *Water Works* or create your own review strategy. With any strategy you choose, motivate students to track how their thinking has evolved rather than focusing only on the final idea. This helps them place science content knowledge in a rich evidence-based context. With this context, they can better recognize and avoid misconceptions.

In Step 2, accept a wide range of students’ approaches to each category of representation (sketch, graphic organizer, caption). For example, give equal credit to 2-dimensional and 3-dimensional sketches. Both can convey student understanding of phases of matter on molecular and macroscopic levels. Use narrow evaluation criteria for the science content expressed within any approach. For example, if student sketches show molecules in the solid, liquid, and gas phases with about the same separation distance, then mark this response as low proficiency. The following are suggested criteria for each form of representation.

Sketch

- candle with liquid wax in bowl under wick and flame along with proper labels
- blowup sketches of solid, liquid, and gas that are directly linked to the macroscopic candle view
- highlight comments (annotations) close to each phase of candle wax indicating macroscopic and microscopic characteristics; gas phase in or near candle flame where combustion takes place

Graphic Organizer

- can be T-table, Venn diagram, concept map, or some other spatial arrangement of key concepts in a way that links two or more concepts and explains that link
- needs to not be a copy of any graphic organizer in this lesson
- possible "new" graphic organizers could include the table in Step 3 of the Elaborate activity, a Venn diagram with 2 circles showing the similarities and differences between candle wax and water in three phases, or a concept map using the terms listed in Step 1 of the Explore activity (see the reading strategies for the *Water Works!* article for a sense of how to make concept maps)

Caption

The caption needs to be in paragraph form and convey students' understanding of the concepts listed in Step 1. The narrative must not be a list of definitions; rather it needs to use the key concepts within the context of explaining what a reader is seeing in their candle sketch.

Answers to Reflect and Connect

1. Complete the following table to demonstrate your understanding of states of matter. Your answers will show similarities and differences between water and wax in three phases of matter.

Summarizing strategies:
Help students reorganize complex information so they can make sense of it.

See figure T7.

Teacher Pages

	Solid	Liquid	Gas
Example from water	ice	water in a container ready to drink	steam is water gas
Example from wax	wax that can rest on the table without flowing; usually opaque	clear material in bowl at base of wick and sometimes dripping down side	gaseous wax is in the flame near the wick which is hot enough to vaporize wax
Temperature (low, medium, high)	lowest temperature relative to liquid and gas for a given substance	temperature is between solid and gas	highest temperature of any phase for a particular substance
Average distance between molecules	closest	intermediate	farthest
Strength of intermolecular attraction	strongest	intermediate	weakest
Amount of energy of motion	least	intermediate between solid and gas	greatest
Speed of molecules	slowest, vibrate in place within a repeating pattern	slightly faster than solids; particles can move past each other	a lot faster than liquid

Figure T7: Example completed states of matter table. Look for responses that indicate a trend or relationship among phases of matter.