Investigation 3 – What are all materials made of?

Table of Contents

INVESTIGATION 3
What are all materials made of?

Overview

In previous investigations, students examined the rules for electrostatic attraction and repulsion. Students observed that like charges repel, and opposite charges attract. They also observed that neutral objects and objects of any charge are attracted to each other. However, at this point, students cannot explain how neutral objects get a charge, or why neutral and charged objects are attracted to each other. In order to answer these questions, students need to understand atomic structure. While many students have memorized the statement "All matter is made of atoms," most have not developed an understanding of atomic theory that they can apply to explain observations of chemical and physical phenomena. The activities in this investigation provide evidence that a particle model of matter explains phenomena such as the compressibility of gases and the smaller than expected change in volume when mixing water and ethanol. Later investigations will continue the historical development of an atomic model that can be used to explain electrostatic interactions.

The Performance Expectations (NGSS)

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.[1]
Note: The gray coloring indicates that this investigation helps build toward this performance expectation, but does not directly address the greyed part. See below for a detailed explanation.

Elements from NGSS (NGSS Lead States, 2013, p.92-93)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas

[1] Gray text indicates aspects of a Performance Expectation that are not directly addressed in these materials.

Overview

Structure and properties of matter: • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	In preparation for developing a model of atomic structure, this investigation provides evidence that materials are made of particles and thus provides a review of 5-PS1-1. (Develop a model to describe that matter is made of particles too small to be seen.) The review is necessary because students often do not have a conceptual model of the particle structure of substances. This model prepares students for an introduction to atomic structure that includes protons and electrons, which can be used to explain electric forces that occur between objects. The atomic model prepares students for using the concept of electric forces between particles to explain the properties of bulk substances, which is the focus of Unit 3.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the performance expectation
Patterns: • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students collect data and compare results as a class to identify patterns. Additionally, the crosscutting concept of scale, proportion, and quantity is significant to this investigation. Students use the particle model of substances to connect macroscopic, observable phenomena with what is happening at the sub-microscopic level. Students are asked to use the microscopic model they develop to explain patterns in observations at the macroscopic scale.
Scientific and engineering practice	
Scientific practice from the NGSS Performance Expectation	How this investigation builds toward the performance expectation

Planning and carrying out investigations: Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	Students do not plan their own investigations, but they do complete investigations and use data collected from hands-on activities and the exploration of simulations as evidence to support claims about the structure and composition of materials. Conducting open-ended investigations, comparing results to identify patterns, and making claims based on those results provides students with experience with investigations which will help them plan and troubleshoot their own investigations later in their science courses.

Objective: Target Model

What should the students' conceptual model include?

- *All substances are made of particles that are too small to be seen.*
- *There is empty space between the particles that make up substances.*

Note: *This investigation explores the beginning of the historical development of the atomic model. Students should already have been introduced to the particle nature of materials. The focus in this investigation is on comparing the explanatory power of the continuous model of materials to that of the particle model.*

Background Knowledge

For several centuries before the start of the Common Era, Greek philosophers debated the nature of matter. These debates centered around a thought experiment: Could an object be cut in half an infinite number of times? Many philosophers believed that the continuous model of matter was correct. According to the continuous model, materials have the same properties throughout. Thus, if an object is cut into smaller and smaller pieces, the properties of the material will always remain the same regardless of how small the pieces get. This model assumes that observations made at the human scale will be the same as observations made at much smaller scales.

However, a few philosophers believed that a different model, the particle model of matter, was correct. According to this model, all materials are made of a collection of smaller particles that group or stick together. These particles are called atoms, *after the Greek word* atomos, *which means "indivisible." If an object is cut into smaller pieces, eventually a component will be reached that can no longer be divided into smaller pieces. Further, the properties of material are dependent on the properties of the particles and the connections between those particles.*

Overview

The particle model went in and out of popularity. But when alchemists, and later chemists, started doing physical experiments instead of thought experiments, there was increasing evidence in support of the particle model of matter. Over time, the particle model of matter developed into our modern model of the atom.

Activities

Activity 3.1	*Can the same piece of paper be cut into pieces indefinitely?*	*20 min.*
Activity 3.2	*Does 5 + 5 always equal 10?*	*60 min.*
Activity 3.3	*Is the particle model always better?*	*45 min.*
Activity 3.4	*Which model best supports our observations?*	*20 min.*

Activity 3.1: Can the same piece of paper be cut into pieces indefinitely?

SUMMARY

In this investigation, students will think about the nature of matter. At the beginning, remind students that they have not answered how objects get charged or why neutral objects are attracted to both positive and negative objects. In order to answer these questions, they need to learn more about what these objects are made of.

The purpose of Activity 3.1 is to encourage students to generate and discuss their initial ideas about the nature of matter. Students will compare the continuous and particle models of matter, and identify which model best matches their ideas. Ask for clarification, but do not evaluate students' responses. Students will have the opportunity to collect evidence and evaluate their own ideas in later activities.

LEARNING GOALS

- Students will ask questions about the building blocks of materials and how they are involved with interactions between charged objects.
- Students will make predictions about the building blocks of materials.

Disciplinary core idea	Crosscutting concept	Scientific and engineering practice
Structure and properties of matter: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Asking questions and defining problems:* Ask questions • that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. • that arise from examining models or a theory, to clarify and/or seek additional information and relationships. • to clarify and refine a model, an explanation, or an engineering problem. (NGSS Appendix F p. 51)

POINTS FOR CONSIDERATION

- Students often struggle with the particle model of matter and applying it to explain phenomena. Students tend to think of phenomena at the macro level and have difficulty imagining what is happening at levels that are too small to be seen.
- Students may believe that a sample of a material can be cut in half indefinitely. This is likely because most students will be using a continuous model of matter. In addition, in math class they learn that there is always another number between any two numbers so they may extrapolate incorrectly here.

- At this point, in order to encourage students to discuss their ideas rather than repeat terms they have learned in previous classes, avoid using the term *atom* until after students have developed a model for the particle nature of matter. Additionally, in this activity, the term *particle* will be used in reference to both atoms and molecules. In the next investigation, students will define atoms. Later, they will develop an idea of molecules.

PREPARATION

Class Time: 20 min.

Materials

- paper
- scissors

Activity 3.1-Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Thought experiment
   a. Revisit the driving question discussion
   b. Demo
   c. Students' initial ideas
   d. Discussion of initial ideas
2. The thoughts of others
   a. Student ideas
   b. Discussion
3. Possible models of matter
   a. Discussion of continuous and particle model of matter
   b. Connecting ideas to the models of matter

Activity 3.1 (Student materials): *Can the same piece of paper be cut into pieces indefinitely?*

Introducing the Lesson

Start by revisiting the DQ board and the driving question for the unit: *Why do some clothes stick together when they come out of the dryer?* Then ask the following questions:

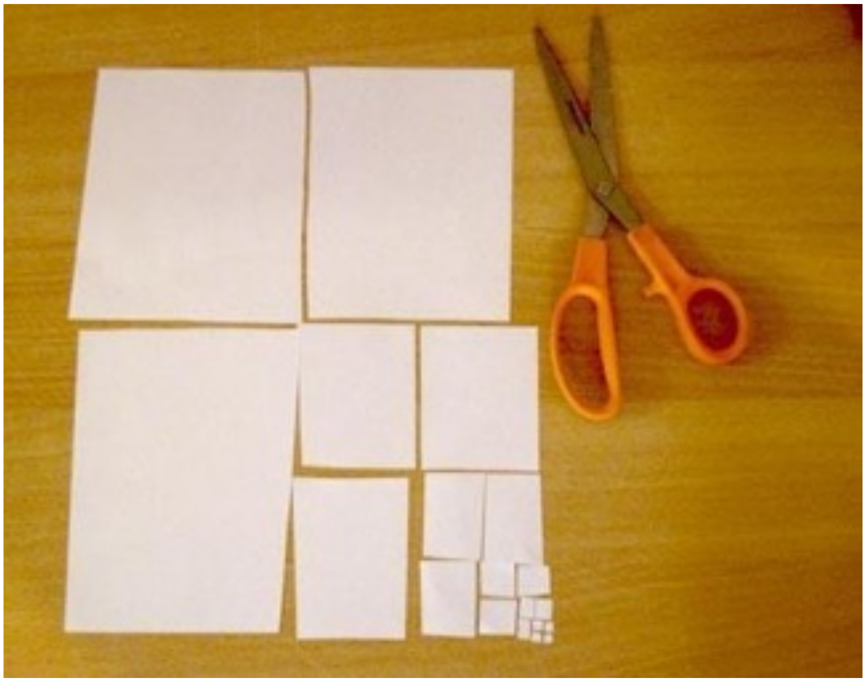
- *What happens to give an object a charge?*
- *How can charged and neutral objects be attracted to each other?*

Let students know that they will be exploring what objects are made of in order to answer these questions.

Note: Students have likely heard about atoms in previous classes; however, students have often simply memorized that "atoms" is the answer to the question, *What are materials made of?* In order to get students to discuss their ideas rather than repeat answers they have heard earlier, we will use the term *particles* in this investigation. In the next investigation, students will learn that these particles can be called *atoms* (and in later units, *molecules*). **However, in this investigation, try to avoid using terms such as *atoms, molecules, atomic*, etc., so that students may share ideas beyond memorized responses.**

Page title:

Thought experiment



If a piece of paper is cut in half, it will become two pieces of paper that are each half the size of the original piece. If one of the half-pieces is cut in half again, it will become two pieces of paper that are each one quarter the size of the original piece.

Discussion
As you discuss this, you can demonstrate by cutting a piece of paper into smaller and smaller pieces.

Possible question:

- *Do you think you would be able to divide an object into smaller and smaller pieces forever? (Be sure to ask students to support their answers.)*

1. If the piece of paper is cut in half over and over again, will there ever be a point at which it is no longer paper? Explain your answer.

Student responses: The questions in this first activity are provided to elicit students' ideas. Students' answers will vary. It is good to review and discuss these answers, but do not evaluate them. At this point, students do not have enough evidence to decide if some answers are better than others.

- Yes. Paper is made from other things, so it is only paper until you cut it into a piece that is only part of the stuff making up the paper.
    - *Ask why? What evidence do you have? Can you describe what these smaller pieces?*
- No. It is always paper, just smaller and smaller pieces of it.
    - *Ask why? What evidence do you have? Is that true for all materials? What makes something paper?*

Share your ideas with a classmate.

Discussion

Sometimes, when people are not able to run experiments to test an idea, they conduct what are known as "thought experiments," in which they use logical arguments to try to convince each other that their idea is correct. Over 2000 years ago an important thought experiment focused on what the result of dividing an object into smaller and smaller pieces would be.

Possible questions:

- *What ideas did you have about this?*
- *Why do you answer yes or no? Do you have any evidence for that?*
- *If you said "yes" what happens when you reach the point where you can't cut it in half?*
- *If you said "no" what does that mean for our physical world? Are there super tiny pieces of various substances everywhere?*

The statements below are intended to give students some terms that they can use to anchor their own ideas. The idea of hypothetically cutting something over and over again is abstract, and students may have a difficult time verbalizing their thoughts. By evaluating some sample responses, students will have the opportunity to clarify their own thinking.

Page title:
The thoughts of others

Here are some ideas that other students shared. As you read through them, compare these responses to your own and consider how they are similar or different.

Student A: "It will still be paper no matter how many times you cut it or how small it gets. When you cut paper in half, it is still paper So no matter how small you cut it, it will always be paper."

Student B: "Paper is made from wood. As you keep cutting the paper smaller and smaller, you will eventually get to the stuff, like wood, that paper is made of. So you will no longer have paper."

Student C: "The paper will eventually get so small that it will turn into dust instead of paper."

Student D: "If you had fancy enough equipment, you could continue dividing the paper into smaller pieces, but eventually it would not be paper anymore. You would have tiny pieces that are different from paper."

2. Which student(s) do you agree with? You may choose more than one.

A. Student A
B. Student B
C. Student C
D. Student D

3. Explain why you agree with the student(s) you chose.

Student responses: The goal of these questions is to begin pushing students to provide reasoning and perhaps get them to explore their own model of matter more deeply. Therefore, none of the options are considered "correct."

- A. I agree with Student A.
  - *Ask how we might test if the smaller piece is still the same as paper.*
- B. I agree with Student B.
  - *Ask for other examples where this might work. What about substances like water, or aluminum?*
- C. I agree with Student C.
  - *What is the difference between dust and paper? Is it just size or is there some other thing that different?*
- D. I agree with Student D.
  - *How would you know it is different from paper?*

Discussion
Be sure to ask to students to express their own ideas, not just state which student(s) they agree with.

Possible questions:

- *What do you think will happen to the paper?*
- *Does anyone have a similar idea?*
- *Does anyone have a different idea?*

Page title:

Possible models of matter

Discussion

Introduce and discuss the following information, or provide students with the definitions of the continuous and particle models of matter and discuss them.

- One of the goals of science is to develop, evaluate, and revise models to explain observations of phenomena. In this investigation, we will examine two models that were developed to help explain why materials behave the way they do. We will observe what happens when two liquids mix, and we will observe how gases behave. Then we will evaluate which of the models best explains our observations.
- Over 2,000 years ago, the ancient Greeks wondered about the structure of matter and why different materials have different properties. There was disagreement about how to explain this. The people involved fell into two groups, each proposing a different model for the structure of matter.
- Some people, like Aristotle, thought that matter is "continuous." According to the continuous model of matter, any material, such as gold, water, or a rock, can be divided into smaller and smaller pieces forever. Each piece, no matter how tiny, looks and behaves like the larger pieces. In other words, the smaller pieces have the same properties as the larger pieces.
- Democritus and Leucippus led a different group, which thought that matter is made of tiny particles that are too small to be seen and cannot be broken down into smaller pieces. This group believed that these particles group or stick together in different combinations to make up all materials. These ideas are the basis of the particle model of matter. According to this model, breaking a rock into smaller and smaller pieces would eventually yield these particles, which would have different properties from rock and would not be able to be to be broken down further.

Student A: "It will still be paper no matter how many times you cut it or how small it gets. When you cut paper in half, it is still paper So no matter how small you cut it, it will always be paper."

Student B: "Paper is made from wood. As you keep cutting the paper smaller and smaller, you will eventually get to the stuff, like wood, that paper is made of. So you will no longer have paper."

Student C: "The paper will eventually get so small that it will turn into dust instead of paper."

Student D: "If you had fancy enough equipment, you could continue dividing things into smaller pieces, but eventually it would not be paper anymore. You would have tiny pieces that are different from paper."

Review the responses of Students A–D again.

Classify each student's answer into one of the following categories: agrees with the continuous model of matter, agrees with the particle model of matter, or does not clearly agree with either model.

For Questions 5–7 you may choose more than one answer.

4. Agree(s) with continuous model of matter

A. Student A
B. Student B
C. Student C
D. Student D

Student responses: This question is intended to elicit student ideas, not form a particular consensus view. The hypothetical student arguments are intended to be somewhat ambiguous.

- A. Student A
  - *This answer is consistent with the continuous model. Perhaps ask why it wouldn't be the particle model.*
- B. Student B
  - *If it is no longer paper then have you reached a point where you can't cut paper in half any more?*
- C. Student C
  - *Can you keep cutting the dust in half?*
- D. Student D
  - *Why is this the continuous model and not the particle model?*

5. Agree(s) with particle model of matter

A. Student A
B. Student B
C. Student C
D. Student D

Student responses: This question is intended to elicit student ideas, not form a particular consensus view. The hypothetical student arguments are intended to be somewhat ambiguous.

- A. Student A
  - *Why is this the particle model and not the continuous model?*
- B. Student B
  - *Is wood the part that can't be cut in half?*
- C. Student C
  - *Does the dust represent something you can't cut in half or is it just that it is not paper that can be cut in half any more?*
- D. Student D
  - *This answer is consistent with the particle model. Perhaps ask why it wouldn't be the continuous model.*

6. No clear agreement with either model

A. Student A
B. Student B
C. Student C
D. Student D

Student responses: This question is intended to elicit student ideas, not form a particular consensus view. The hypothetical student arguments are intended to be somewhat ambiguous.

- A. Student A
  - *Why does this not fit into the continuous model? What is ambiguous about this?*
- B. Student B
  - *This answer is one of the more ambiguous answers. Ask why it doesn't fit into either particle or continuous or why it has elements of both.*
- C. Student C
  - *This answer is one of the more ambiguous answers. Ask why it doesn't fit into either particle or continuous or why it has elements of both.*
- D. Student D
  - *Why does this not fit into the particle model? What is ambiguous about this?*

7. How would you classify your answer to the question about cutting paper?

A. Agrees with the continuous model of matter
B. Agrees with the particle model of matter
C. No clear agreement with either model

Student responses: This question is intended to get students to reflect on their initial model. They will have a chance to refine it in later activities.

Discussion

Show a summary of student responses using the teacher report. Use these as jumping off points to get students to clarify their understanding of the particle and continuous models of matter. It's not important to find a "right" answer for classifying any of the responses from Students A–D, just to use these as a scaffold for improving understanding of the particle and continuous models.

Possible questions:

- *Lot's of people thought Student A fell into the continuous model category? Did anyone disagree? Why does it make sense or not make sense? (This style of question could be adapted for other hypothetical student responses.)*
- *What about Student B? Does that mean dust can't be cut in half?*

Also refer to the suggested responses above in the "Student responses" boxes below the previous four questions. There are many suggested discussion questions that are appropriate at this time.

Activity 3.2: Does 5 + 5 always equal 10?

SUMMARY

Students will mix different combinations of water and ethanol, and compare predicted and observed volumes. Students will then explore a simulation that allows them to compare the particle and continuous model of matter. Based on their observations, students will evaluate whether the continuous or particle model best explains why the volume of the water and ethanol mixture is less than the sum of the volumes of the two separate liquids.

In the previous activity, students shared their initial ideas about the nature of matter. The purpose of this activity is for students to gather evidence to begin to make arguments about whether the particle or continuous model of matter is most useful for explaining phenomena. In upcoming activities, students will continue to collect evidence to support one model over the other. Once students have evidence supporting the particle model, they will develop an atomic model that can be used to explain their earlier observations of electrostatic phenomena.

LEARNING GOAL

Students will evaluate whether the continuous or particle model of matter best accounts for their observations of a mixture.

- When water and ethanol are mixed, the total volume is less than the sum of the volumes of the original liquids. The particle model can explain this loss in volume because in a mixture, the different particle shapes may more efficiently pack together.

Disciplinary core idea	Crosscutting concept	Scientific and engineering practice
Structure and properties of matter: Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. (NGSS Lead States, p. 43)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. (NGSS Appendix G, p. 82)	*Obtaining, evaluating, and communicating ideas:* • Evaluate the merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F, p. 65)

POINT FOR CONSIDERATION

Students often have a difficult time understanding the particle nature of matter. As students learn about atoms, they often think of the particles as floating in the material rather than making up the material (i.e., they do not think there is some empty space between the particles even in solids and liquids).

PREPARATION

Class Time: 60 min.

Materials (for each group)

- two 10 mL graduated cylinders (They need to be fairly skinny with at least 1 mL graduations.)
- water
- ethanol (10 mL) in container with lid and droppers
- two stoppers (Each stopper should be the correct size to plug the opening of the graduated cylinder.)

Activity Setup

- Construct a materials kit for each group.
- Print out lab instructions for mixing solutions experiment.

Materials (for demo)

- Two large graduated cylinders (at least 50 mL)
- Enough sand to fill one of the cylinders half way.
- Enough marbles (or other round objects like marbles) to fill one of the cylinders half-way.

SAFETY ISSUES

Ethanol gives off fumes that may be harmful if inhaled. It is also flammable. Make sure students are aware of this and tell them to cover the containers of ethanol with lids when not in use.

HOMEWORK

Worksheet for Activity 3.2: Models of Water and Ethanol (teacher key found here)

Activity 3.2-Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Eliciting students' ideas
    b. Sharing students' initial ideas
2. Mixing liquids activity
    a. Investigation
    b. Discussion of results
    c. Models to explain class results
    d. Revisit Driving Question
3. Computer Simulation - Mixing liquids
    a. Discussion of best explanatory model
    b. Revising models
    c. Return to Driving Question
4. Concluding the Lesson

Activity 3.2 (Student materials): Does 5 + 5 always equal 10?

Introducing the Lesson

Ask students to recall the differences between the continuous and particle models of matter. Remind them that in science, when there are different ideas or models, evidence needs to be used to make a decision about which model best explains or accounts for observations. In this activity, students will test the continuous and particle models by determining which one can best explain what happens when water and ethanol are mixed.

Page title:

Initial ideas

1. [drawing prompt] In the boxes below, draw models to show what you think water, ethanol, and the mixture of the two would look like if you could zoom in and “see” their structure and composition.

[text prompt] Describe how your model represents the various substances.

Water
Ethanol
Mixture

Student responses: This question is intended to elicit students' initial ideas. They could use either a particle or continuous model as a basis for their speculation about liquids.

- Students often drive squiggly or wavy lines to represent the liquids
- Students may be familiar with a common symbol for water molecules and may draw that or a variation on that

2. In drawing your models, did you use the continuous model of matter or the particle model of matter?

A. Continuous model of matter

B. Particle model of matter

Student responses:

- A. Continuous model of matter
  - *Why does your model represent a continuous model?*
- B. Particle model of matter
  - *Why does your model represent a particle model?*

Discussion

You may want to have a whole-class discussion of students' ideas and representations. Use the portal report to show student work.

Possible questions:

- *What are common patterns?*
- *Who would like to present their model?*
- *Which of these seem to represent the particle model and which the continuous model?*

Page title:

Mixing liquids

In this activity, you will make observations of the behavior of matter. Later, you will evaluate the continuous and particle models of matter to see if one of the models better explains your observations. This will give you some evidence that you can use to evaluate the two models of matter.

After completing the experiment described in the handout linked below, return to this activity to answer the following questions.

Experiment Instructions: Mixing Liquids

Note: When the same liquids are mixed together (water with water, ethanol with ethanol), the volumes are additive. However, when 50 mL of water and 50 mL of ethanol are mixed, the resulting volume is about 95 mL.

3. How does the observed volume of the water/water mixture compare with the total volume you calculated?

A. The mixture had a greater volume than expected (higher than my calculation).
B. The mixture had a lower volume than expected (lower than my calculation).
C. The volume of the mixture was what I expected (equal to my calculation).

Student responses: The actual volume may be slightly less than the calculated total if enough drops of water our left in the other cylinder; however, the mixture should be the same or very close to the same as the calculation. Students should record their observations.

- A. The mixture had a greater volume than expected (higher than my calculation).
    - *Ask students if they can think of what may have caused this. Suggest they may need to make careful measurements.*
- B. The mixture had a lower volume than expected (lower than my calculation).
    - *Are there reasons that could account for this? Drops on side not being measured?*
- **C. The volume of the mixture was what I expected (equal to my calculation).**

4. How does the observed volume of the ethanol/ethanol mixture compare with the total volume you calculated?

A. The mixture had a greater volume than expected (higher than my calculation).
B. The mixture had a lower volume than expected (lower than my calculation).
C. The volume of the mixture was what I expected (equal to my calculation).

Student responses: If measurements were recorded carefully and all of the liquid was transferred into the same container, the measured volume of the mixture should equal or be very close to the calculated amount. Students should record their actual results.

- A. The mixture had a greater volume than expected (higher than my calculation).
  - *Double-check your calculations and measurements.*
- B. The mixture had a lower volume than expected (lower than my calculation).
  - *Double-check your calculations and measurements.*
  - *Are there reasons that could account for this? Drops on side not being measured?*
- **C. The volume of the mixture was what I expected (equal to my calculation).**

5. How does the observed volume of the water/ethanol mixture compare with the total volume you calculated?

A. The mixture had a greater volume than expected (higher than my calculation).
B. The mixture had a lower volume than expected (lower than my calculation).
C. The volume of the mixture was what I expected (equal to my calculation).

Supplemental content: Water and ethanol molecules have different sizes and shapes, so when they are mixed together, they pack more efficiently and have less overall empty space between the molecules. This causes the combined volume to be lower than the sum of the two liquids being mixed together. Generally, when water and ethanol mix about 5% of the volume is lost, so 5 mL of water and 5 mL of ethanol will produce about 9.5 mL of mixture.

Clarification - This question is just to record students' actual observations which may be different due to procedural errors.

Student responses:

- A. The mixture had a greater volume than expected (higher than my calculation).
  - *Double-check your calculations and measurements.*
- **B. The mixture had a lower volume than expected (lower than my calculation).**
- C. The volume of the mixture was what I expected (equal to my calculation).
  - *Double-check your calculations and measurements.*

Discussion
Have students place their results on the board, so everyone can see the class data. You may also or alternatively present student answers to the previous questions using the teacher report which will summarize the results using histograms that will help show the trend in overall observations.

Possible questions:

- *What patterns do you see?*
- *Why do you think the water and ethanol mixture takes up less space than the separate liquids?*

Tip: Students might say that evaporation or drops left in the other graduated cylinder or on the stopper could account for the loss in volume when the ethanol and water were mixed. This is a good hypothesis that should be tested. It can be tested by doing a demonstration that involves measuring the mass of water and ethanol before mixing and the total mass of the mixture. Alternatively, students can add drops of water until the volume adds up, and then determine if it is likely that much water was stuck to the other cylinder. Students should see that the loss in mass due to drops sticking to the other cylinder is significantly less than the loss in volume of the mixture. If you have students do this, make sure they use stoppers while recording the masses, because ethanol evaporates quickly.

This could be a good opportunity to discuss scientific methods. Ask students how they can test whether or not evaporation is the cause.

6. What patterns do you see in the class data regarding observations of mixing water + water, ethanol + ethanol, and water + ethanol.

Supplemental content: When the liquids are the same, the volume of the mixture is the same as the total calculated by adding the original volumes. However, when the water and ethanol are mixed, the volume is not the same as the calculated total. It is less. This is due to the fact that the molecules can pack more efficiently when the shapes and sizes of the molecules differ from each other.

Clarification - Students are not expected to provide a mechanism here.

Student responses: Students should have a general description of the patterns. They should come to a consensus as a class on the patterns.

- Water and water and ethanol and ethanol added up as expected, but water and ethanol was less than the calculated amount.
- I always find there is less than I calculated.
    - *Make sure students are using the class data and not their individual observations.*
- They are all different
    - *Help students identify patterns in the class data. What is similar? This may be an opportunity to discuss experimental error to reach a consensus on what is acceptable variation and what is a real difference in volume.*
- I sometimes find more than calculated.
    - *Ask if this is a common observation in the class data. What is the pattern?*

7. [drawing prompt] Draw a model that explains the volume you observed after mixing the water and ethanol. You can use the particle model, continuous model, or your own model—whichever model you think best explains your observations.

[text prompt] Explain your model.

Water
Ethanol
Mixture

Student responses: Students are still developing an explanation for this phenomenon. They are not expected to have developed a consensus at this point.

- Students may draw water molecules or other particles to show the two substances mixing.
- Students may draw an image of the experiment or a macro-scale diagram representing their observations.
    - *Ask students if this fits a definition of the models.*

Revisiting the Driving Question

Display a variety of students' or groups' models. Ask students to evaluate the relationship between each model and their observations of the volume when water and ethanol were mixed.

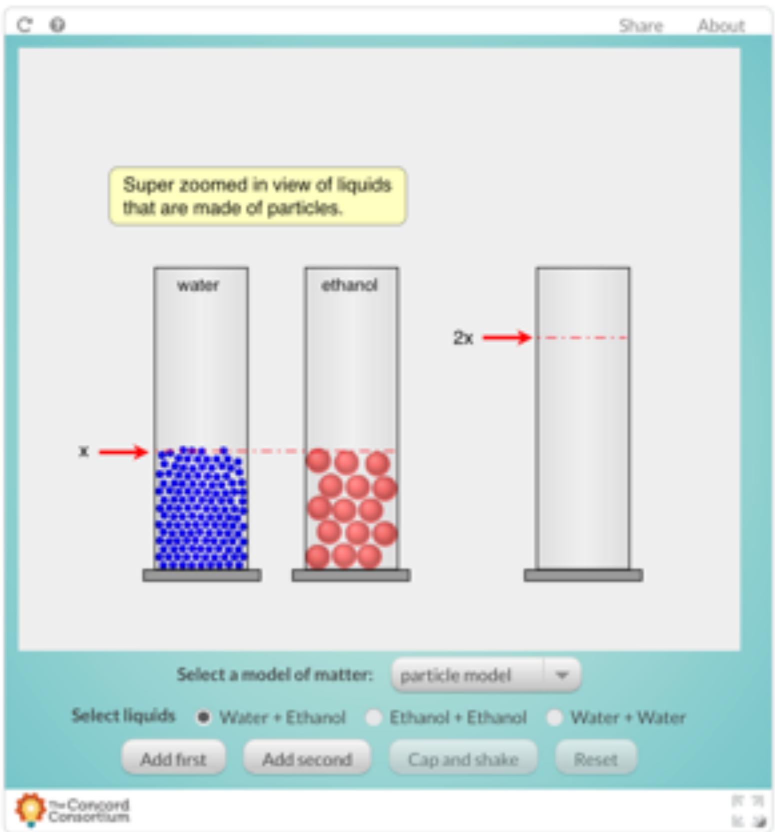
Possible questions:

- *How does this model explain the change in volume?*
- *What patterns do you see when comparing these models? Are there similarities or differences in how students (or groups) accounted for the change in volume?*

Page title:

Computer simulation

In science, a model is considered useful if it can explain observations. The following simulation will provide more evidence to help you decide whether the continuous model or particle model provides a better explanation for your observations of mixing liquids.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/Mixing-polar-nonpolar-particle.json

Try simulating the experiments you did with mixing liquids. Be sure to try both the particle model and continuous model options.

8. Which model better matches the observations you made when mixing real liquids?

A. The particle model.
B. The continuous model.

9. Explain why you chose the particle or continuous model in the previous question.

Student responses:

- **A. The results matched my experiment.**
  - *Provide more details. Be specific. Perhaps explain why you didn't choose the other model.*
- B. The continuous model looks more like liquids.
  - *Ask if their experiment shows the same mixing pattern as expected for the continuous model. Look back at the class data, which should have shown a reduced combined volume for water and ethanol. This contradicts what the continuous model predicts.*

10. Use your observations of the simulation to explain why mixing ethanol and water results in a measured, combined volume that is less than the sum of the original volumes.

Student responses: We are still looking to provide evidence here for one of the models of matter. In the next activity they will gather more evidence for the particle model, so it is OK if consensus has not been reached yet on which one is better at explaining phenomena. If it seems that everyone has decided it is the particle model, then talk about how the model should work for other phenomena.

- The smaller particles can fill in between the gaps between smaller particles.

Demonstration

Understanding that the packing of two different sized particles can be more efficient when mixed together is difficult for students. A demonstration that helps get this point across is the mixing of sand and some larger "particles" like marbles.

1. Get two identical graduated cylinders (50 mL or greater) and fill one halfway with sand, and one halfway with marbles.
2. Have a student measure the volume of each one and put that on the board.
3. Then sum the two volumes and show the answer.
4. Ask the students to predict what they think the measurement of the mixture will be.
5. Pour the sand into the cylinder with the marbles. And put the combined measurement on the board. It should be significantly less than the sum of the two separate volumes.

Possible questions:

- *Was the combined volume what you expected it to be? Why?*
- *How does this help explain what you observed in the model?*
- *How might this help explain what you observed when you mixed real liquids?*

11. Revisit the model of mixing water and ethanol that you drew after the hands-on experiment. Do the components in that initial model explain your observations of water and ethanol? If not, what revisions would you make to your model?

Student responses: Students will likely have started with a wide variety of models. The key point is to see if they can apply their models to the observed phenomena. Use the following discussion to review student models and how they might need to be updated to account for the shrinking volume of some mixed liquids.

- I had particles before and the particles can explain why the liquid volume decreases because the particles fill in spaces between other particles.
- I did not include particles before, but particles explain why the volume changes because the particles can pack tighter together.

Revisiting the Driving Question
Display students' models from Question 7 (just before the simulation).

Discuss and compare the different models. Ask students what changes they would make to the models in light of their new evidence and begin to develop a consensus about the nature of matter.

Possible questions:
- *What do you notice looking across the models?*
- *How are they similar? How are they different?*
- *What do you think is being represented here (referring to specific models)?*

Once students have observed and discussed various aspects of the different models, ask them to start to evaluate which ones best account for the observations of mixing water and ethanol.

Possible questions:
- *What would you change about these models at this point?*
- *What evidence can we use to improve these models?*
- *Which models best explain our observations?*

As students work toward coming to an agreement about which model best explains their observations of mixing water and ethanol, as well as of the simulation, make sure they base their critiques and arguments on evidence from these observations.

Through this discussion, students should come to the consensus that the particle model best explains their observations of mixing water and ethanol. Have the class select representative models to post on the class driving question board.

Once students agree that the particle model best explains their observations of mixing water and ethanol, ask if the particle model is always best or just in the case of mixing water and ethanol.
Possible questions:
- *If water is made of particles, why is the actual volume of mixing water with water the same as the total calculated by adding the original volumes?*
- *Is the particle model always better than the continuous model? Think about how matter behaves. Can the particle model explain other phenomena?*

If students are still not convinced that the volume of the mixture of ethanol and water is less than the total of the original volumes, you can display the computer simulation and discuss students' observations of mixing water and water or ethanol and ethanol.

Homework: Worksheet for Activity 3.2
Models of Water and Ethanol

Activity 3.3: Is the particle model always better?

SUMMARY

So far in this investigation, students have been asked to evaluate the particle model through their observations of liquids. Students will now be asked to evaluate if the particle model adequately explains phenomena involving gases. In this activity, students will record several observations of gases to inform their questions about whether gas is matter (has mass and takes up space) and how it behaves when students manipulate a syringe. Students will apply the particle model to explain those observations.

LEARNING GOAL

Students will use the particle model of matter to explain their observations of the characteristics of gases.

- Clarification: Gas has mass, so it must be made of something that is not visible. Gas can also be compressed. The particle model can account for both of these phenomena.
- Gas particles have mass but are spread apart and too small to be seen. Since gas particles are spread out, gas can be compressed by reducing the space between the particles.

Disciplinary core idea	Crosscutting concept	Scientific and engineering practice
Structure and properties of Matter: Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model that shows gases are made of matter particles that are too small to see and that are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. (NGSS Lead States, p. 43)	*Scale, Proportion, and Quantity:* Students recognize that patterns observable at one scale may not be observable or exist at other scales and that some systems can only be studied indirectly as they are too small to observe directly. (NGSS Appendix G p. 84)	*Developing and Using Models:* • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F p. 53)

POINT FOR CONSIDERATION

Many students think that gas is made of nothing and has no mass. They may have difficulty understanding that gases have mass and therefore must be made up of matter.

PREPARATION

Class Time: 45 min.

Materials (for each group)

- syringe with hole in plunger (see image)
- syringe stopper
- nail
- digital balance (sensitive to 1/100 of a gram)
- Water to put into the syringe

Activity Setup

- Make a hole in the plunger of each syringe near the end of the plunger (see image). This can be done by heating the nail and using tongs to push the nail through the plunger, melting a hole (this should be done in a fume hood). Alternatively, drill a hole.
- Print the handout for this activity.

HOMEWORK

- Reading for Activity 3.3: Claims, Evidence, and Reasoning

Activity 3.3-Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Models
    a. Introducing the lesson
    b. Students' initial ideas
    c. Sharing students' initial ideas
2. Determining the mass of air
    a. Investigation
    b. Discussion of results
    c. Scientific explanations
    d. Models
    e. Sharing explanations and models
3. Thinking about the syringe experiment
    a. Investigation with syringe
    b. Model
4. Syringe simulation
    a. Simulation
    b. Explanations
    c. Concluding the lesson

Activity 3.3 (Student materials): Is the particle model always better?

Introducing the Lesson

Review the Worksheet for Activity 3.2. Ask students to share which models they selected as being able to account for their observations of mixing water and ethanol. (Note: Students may select different models for different reasons.) The purpose of this discussion is to reinforce the idea that different models can be used to explain the same phenomena. Even though different models can be used to explain the same phenomena, that does not mean that all models are acceptable. It is important to emphasize that models should be evaluated based on how well they account for observations of the phenomena. Be careful not to judge students' responses; instead, encourage students to share a variety of ideas.

Possible questions:

- *Which model do you think best depicts what happened when water and ethanol were mixed? How does the model account for your observations?*
- *Did anyone else pick a different model?*
- *I noticed no one has mentioned picking model ____. Did anyone pick that one? Why or why not?*

This activity asks students to apply the particle model to a new situation. Models are most useful when they can be used to explain and predict a variety of phenomena.

Possible questions:

- *Does the particle model apply to other states of matter? Be sure to ask students to explain their answers.*
- *If the particle model works for gases as well as liquids, what will that tell us about the model?*

Page title:
Models

In Activity 2 you began to evaluate which model of matter (particle or continuous) could better explain observations of mixing liquids. In this activity you will gather more evidence to support one of those models of matter by exploring additional phenomena—this time focusing on the behavior of gases.

1. [drawing prompt] Draw a model of what you think air would look like if you could zoom in and see its structure and composition, just like you did for the liquids.

[text prompt] Explain how this model is similar to and different from your model of liquids.

Student responses: This is an initial model that they will refine during the activity, so exploration of student ideas is appropriate, not evaluation for correctness.

2. Like liquids, are gases made of particles?

A. Yes
B. No
C. Maybe

Student responses: This question is intended to take the temperature of the room and get a sense of where students are at. You may ask them to elaborate, or just notice the distribution of answers and move on.

3. Do gases have mass?

A. Yes
B. No
C. Maybe

Student responses: This question is intended to take the temperature of the room and get a sense of where students are at. You may ask them to elaborate or point out that they will do an experiment to find out.

Discussion
Consider asking students to share their models. If students' models are similar, a whole-class discussion may not be very informative.

Possible questions:

- *What is being represented in your model?*
- *What does that representation communicate?*

Page title:
Determining the mass of air

In this activity you will do an experiment to test if air has mass.

After completing the experiment described in the handout linked below, return to this activity to answer the following questions.

Experiment Instructions: Measuring the mass of air

Note: The "empty" syringe needs to contain the same volume as the syringe full of air. This is why students are instructed to seal the syringe, pull back the plunger, and use a nail to prop the plunger in place. Once students have recorded the mass of this system, all they need to do is open the stopcock to unseal the syringe and allow air in.

4. How did the mass of the open syringe compare to the mass of the closed syringe?

A. The open syringe had more mass.
B. The open syringe had less mass.
C. The open syringe had the same mass.

Supplemental content: When the syringe is sealed and pulled back, there is very little air in the space inside the syringe. After opening the stopcock air rushes in to fill the empty space and so the syringe, with more air now in it, should have a higher mass.

Clarification - This question is intended to record students' actual observations, which may differ based on procedural errors.

Student responses: There should be consensus that this is what occurred. You may want students to record their results on the board as they take measurements to see trends in the class data.

- A. The open syringe had more mass.
- B. The open syringe had less mass.
  - *Double check your measurements. Did you keep the same volume reading on the syringe for both measurements?*
- C. The open syringe had the same mass.
  - *Did you make sure the syringe was completely sealed before pulling the plunger back?*
  - *Did it stay sealed until you took the first measurement?*

Discussion
Previously in this unit, students have been asked to make claims and support them with evidence. Now students will be asked to write complete scientific explanations. Before students answer the following questions, in which they are asked to write their claim, evidence, and reasoning, give them the following information about scientific explanations and discuss what might be included in students' explanations.

Scientists use evidence to answer questions, but they also build on work that has been done before. Thus, a complete scientific explanation includes the following: a claim that answers a scientific question, evidence that supports the claim, and reasoning that ties the claim and evidence together using accepted scientific theories and models.

Possible questions:
- *What evidence do we have that can help us form and support our claim about gases and mass?*
- *What ideas have we agreed on as a class that can help us support our claim?*

Develop a complete scientific explanation to answer the following question: *Is gas matter?* Write your claim, evidence, and reasoning below.

5. **Claim** - Make a claim that answers the question, *Is gas matter?*

Student responses:
- Yes, gas is matter.
- Yes.
  - *A claim should make a specific statement, not just say yes or no. Push them to include what they specifically want to support as a claim.*
- No.
  - *A claim should make a specific statement, not just say yes or no. Push them to include what they specifically want to support as a claim.*
- No, gas is not matter.
  - *Go back to the class data and ask students for evidence of this claim.*

6. **Evidence** - Cite evidence you have that supports your claim.

Supplemental content: The open syringe had more mass than the sealed syringe. When the syringe was opened you could hear air moving into the syringe.

Clarification - It will be tempting for students to include reasoning when providing evidence. Help them to see that evidence is usually based on a description of a measurement or observation, and to resist including reasoning here. Later this scaffolding will be removed and students will be asked for a scientific explanation in which one answer should contain a claim, evidence, and reasoning. However, it is beneficial to clearly understand the difference so their first attempts at scientific explanation are scaffolded with separate claim, evidence, and reasoning.

Student responses:

- The syringe had more mass when the air was in it.
- When the syringe was opened, air came in and the syringe had more mass, so air has mass.

7. **Reasoning** - Connect your answer to other scientific work by using ideas that your class has agreed on to tie the evidence to your claim.

Supplemental content: The definition of matter is that it has mass and takes up space. Because the syringe had more mass when it was opened, something with mass had to have entered the syringe. The only thing that could have entered was air and there was a sound of air moving into the syringe at the moment it was opened. So, the air must have provided the extra mass measured for the open syringe.

Clarification - The reasoning pulls in accepted scientific ideas to support the claim and connect the claim and evidence. should be linked here, so both need to be included in the reasoning.

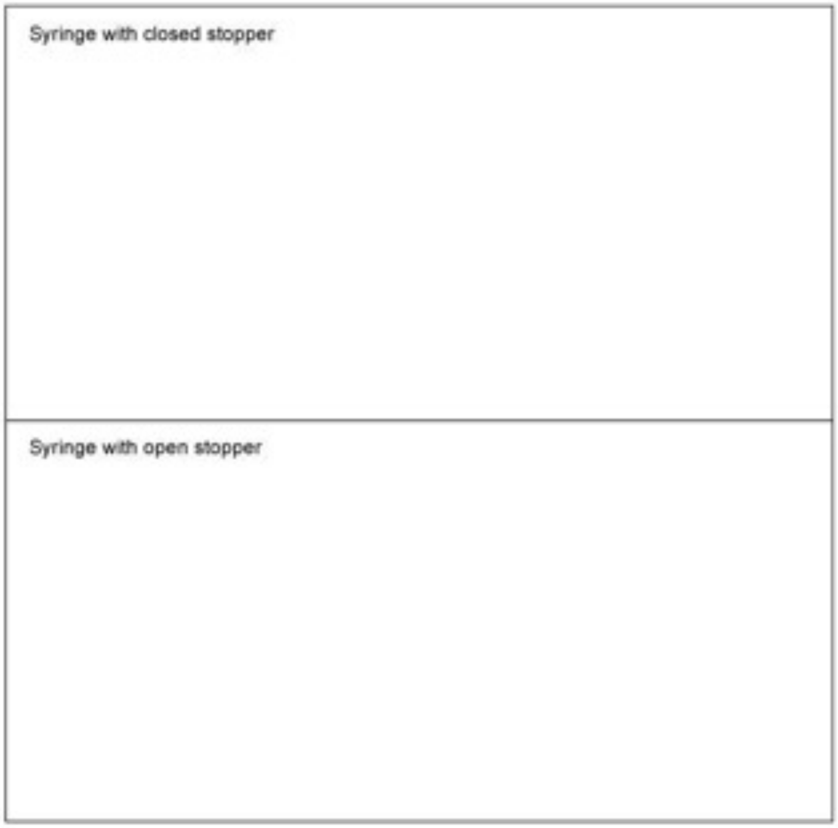
Student responses:

- Matter has mass. The open syringe had more mass which supports the idea that gas is matter because it has mass.
- The open syringe had more mass.
  - *This is actually evidence, not reasoning. It is common for an evidence statement to be taken as implicitly having some inference as to what it means. Push students to explicitly declare* ***how*** *the evidence supports their claim.*
- When the syringe had air in it it weighed more.
  - *This is better but still lacks explicit links between the claim and the evidence. Ask them why they think it was the air that increased the mass.*

Tip: The form of the answer for this question is a common framework for scientific explanations. Based on this framework, a complete scientific explanation should include a claim that is based on evidence, a description of the evidence that supports the claim, and reasoning that ties the evidence and claim together (see the examples in the Expert answer boxes above). If this is a new framework for students, they will likely need help developing their explanations. In particular, students tend to struggle with differentiating between evidence (data that supports the claim) and reasoning (the use of scientific ideas to tie the evidence to the claim). Use student work to find examples that will help the class understand what is expected for claim, evidence, and reasoning.

8. [drawing prompt] Draw a model of the air in the syringe that explains why the mass of the syringe when the stopper was closed differed from the mass when the stopper was open. [draw tool with chart below as background]

[text prompt] How does your model explain your observations of the mass of the syringe?



Student responses: A gain in mass alone is not enough to support the particle nature of matter, but it does provide evidence that gas is just a form of matter, like liquids and solids. It is OK if their model is not particulate here, but you might ask about consistency with their liquid models drawn in the previous activity. They will have a chance to test the particulate nature of gases as they do more experiments with the syringe.

Discussion
Discuss what it means that air has mass to establish that gas is matter (takes up space and has mass). At this point, students may have either a continuous or particle model for gas. This is okay, since they have not yet assessed the evidence for gas. However, there should be a class consensus that air has mass and is therefore matter.

Page title:
Thinking about the syringe experiment

The questions below suggest some other experiments to do with the syringe. While doing the experiments consider if the particle or continuous model of matter better explains what you observe.

9. [drawing prompt] Fill the syringe with air and then close the stopper. Now try to push the plunger into the syringe. Draw a model that explains what happened when you compressed the gas in the syringe.

[text prompt] How does your model explain your observations?
[draw tool with chart below as background]

Syringe with gas before it is compressed	Syringe with gas compressed

Student responses: Regardless of an answer that shows a continuous or particle nature of matter, push students to justify their answer. Why did they choose one model over the other?

- Particles that are spaced out then clumped closer together.
- Something that looks more like a continuous model. Colored in, possibly with wisps of air.

10. Starting with the syringe fully pushed in, try pulling back the plunger with the stopper open and then with the stopper closed. What do you notice?

Supplemental content: If the stopper is closed it is very hard to pull back on the plunger and when I let go the plunger goes back to being at zero. If the stopper is open, it is easy to move the plunger and it stays wherever I put it.

Clarification - Students may talk about the plunger being sucked into the syringe if the syringe is sealed when the plunger is pulled back. This might be a good opportunity to ask where the pulling force could come from. How is that accounted for in the different models?

Student responses: Students tend to write as minimally as possible. Push for details. This questions is just asking for observations, not explanations.

- It's harder to move the syringe when the stopper is closed.
- It's easier to move the syringe when the stopper is open.

11. Fill the syringe partway with water and close the stopper. Now try to push the plunger into the syringe. Draw a model that explains what happened when you compressed the water in the syringe.

[text prompt] How does your model explain your observations?
[draw tool with chart below as background]

Syringe with water before it is compressed	Syringe with water compressed

Student responses: Regardless of an answer that shows a continuous or particle nature of matter, push students to justify their answer. Why did they choose one model over the other?

- Particles that are spaced out then clumped closer together.
- Something that looks more like a continuous model. Colored in, possibly with wisps of air.

12. Compare your models for water and for air. How do your models explain differences in observations when you compressed water vs. air?

Student responses:

- Particles of water are closer together than particles of air, and therefore it is harder to compress water than air
- Something that looks more like a continuous model. Continuous matter that water is made of is softer, easier to compress than air.

Discussion
Review the student models showing what happens when gas and water are compressed in a sealed syringe.

Possible questions:

- *What is similar and what is different between these models?*
- *Which ones represent the particle and continuous models?*
- *Who would like to argue for the particle model? How about the continuous model?*
- *Why is it harder to compress water than air?*
- *How might structure of matter in water be different from that of air to account for your observations?*

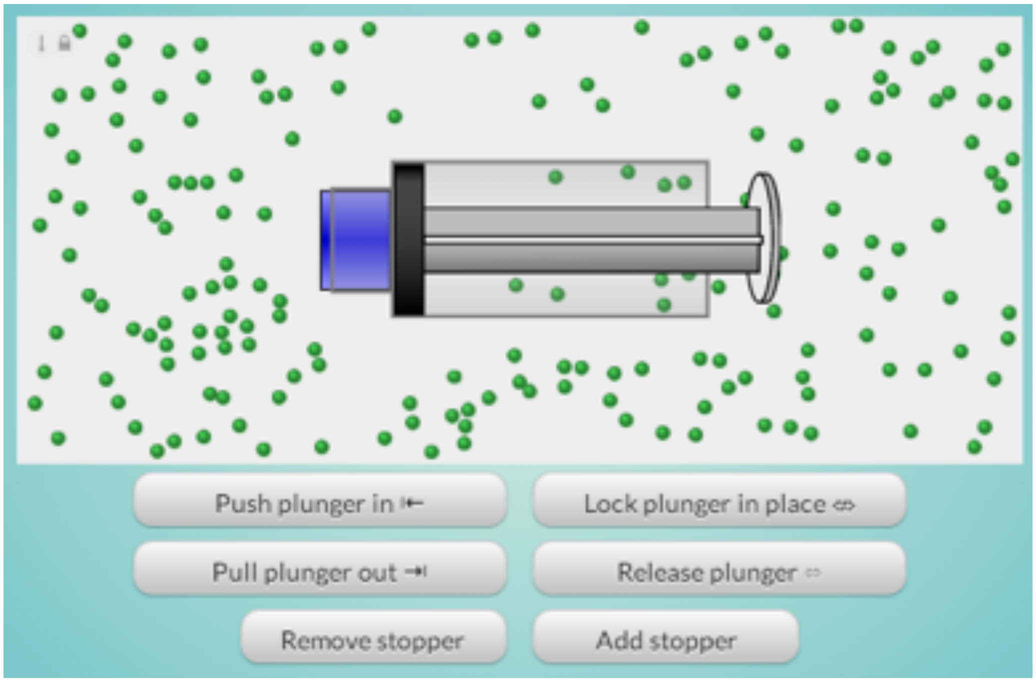
Then bring up the second exploration they tried, the one in which they start with an empty syringe and describe what happened.

Possible questions:

- *What did you see happen?*
- *Why do you think the syringe is hard to pull back when sealed?*
- *What is inside the syringe now if the seal prevented air from going in?*
- *What does the particle model have to say about these observations? What about the continuous model?*

Page title:
Syringe simulation

This simulation assumes that gases are made of tiny particles. Set up the model in various ways, simulating what you just did with the real syringe, to see how well a particle model might explain your observations.



Simulation link: http://lab.concord.org/embeddable.html#interactives/interactions/syringe.json

12. Revisit your initial model of a gas (the first question of this activity). How is your model explain gas compression in a way that is similar to or different from what you see in the interactive model on this page?

Student responses: At this point the class should be moving toward consensus that the particulate model also works for gases. Depending on what their initial models were they may need to make many or virtually no changes.

- I had particles and when the particles are compressed, the space between the particles is smaller.
- I had a drawing of air, but showing the particles helps explain what happens when the air is compressed.

13. Write a scientific explanation that answers the question, *How is it possible to compress a given amount of air into a smaller space?* In your explanation be sure to include the following:

- **Claim - your answer to the question**
- **Evidence - observations or data**
- **Reasoning - thinking that includes ideas the class has agreed on and connects your evidence to your claim**

Sample responses: Watch out for incomplete answers, those missing reasoning, evidence or a clear claim.

- Air can be compressed into a tighter space because air is made of particles and there is space between the particles. When the syringe was sealed with air inside, it can be compressed, but you cannot compress the syringe all the way to zero. In air, you can push the particles closer together, but when they get too tight the particles push back.
- Because there is space between the air particles.
  - *This answer only has an incomplete claim. There is no evidence or reasoning.*
- Air is made from particles, so when you squeeze it you can squeeze it together.
  - *This has a claim (although it lacks a statement about how the particles are spaced), and it has minimal evidence. More detail is needed. Reasoning should draw upon the particle model of matter. There is no explicit reasoning here.*

Concluding the Lesson

This is an important time to have a whole-class discussion of students' ideas and representations. Have each of several groups agree on a model to share. Display the groups' models and ask students to note similarities and differences. How do the models account for their observations?

This is also an important time to revisit the idea of what is between the particles that make up matter. Make sure students have agreed on the idea that the particles are not in another material.

Possible questions:

- *Is there anything between the particles of air?*
- *If the particles that make up air were floating in a material, would you be able to compress the syringe?*
- *How can you use the information from the simulation to explain your observations for compressing air vs. water?*
- *How might the structure or arrangement of particles in water and air differ to account for your observations?*

Students should gain from this discussion an understanding of the usefulness and generalizability of the particle model. Place a consensus model (or a set of models) on the DQ board.

Push student to think about the idea of spaces between particles and how this is a powerful idea to explain various observations including why it is easier to compress air than water.

Homework
Reading for Activity 3.3: Claims, Evidence, and Reasoning

Activity 3.4: Which model best supports our observations?

SUMMARY

Students have now collected evidence about liquids and gases and applied the particle model to their observations. Students will conclude this investigation by determining whether the continuous or particle model of matter best accounts for their observations. They will also be asked to return to their initial models about cutting paper so that they can edit or add to their previous models using the evidence they have subsequently gathered.

LEARNING GOAL

Students will use evidence obtained in this investigation to support the theory that matter is made of particles too small to be seen.

- The observations of mixing water and ethanol, and of measuring gases in a syringe, are best explained using the particle model.

Disciplinary core idea	Crosscutting concept	Scientific and engineering practice
Structure and properties of matter: Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. (NGSS Lead States, p. 43)	*Scale, Proportion, and Quantity:* Students recognize that patterns observable at one scale may not be observable or exist at other scales and that some systems can only be studied indirectly as they are too small to observe directly. (NGSS Appendix G p. 84)	*Engaging in argument from evidence:* • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Make and defend a claim based on the effectiveness of a design solution that reflects scientific knowledge (NGSS Appendix F p. 63)

PREPARATION

Class Time: 20 min.

Activity 3.4-Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Particle vs. continuous model of matter

    a. Discussion

    b. Student evaluation of evidence and models using previous activities

2. An interactive timeline

    a. Concluding the lesson

Activity 3.4 (Student materials): Which model best supports our observations?

Discussion

Review the Claims, Evidence, and Reasoning homework. Have students present their answers.

Possible questions:

- *Who would like to share their claim?*
- *Let's hear some evidence.*
- *One of the most difficult things to do initially is separate evidence and reasoning. Does this answer include any reasoning?*
- *Does anyone want to share an "evidence" answer that they are not sure about? The goal is not to have the right answer, but to use our answers to better understand how to write a good scientific explanation.*
- *How about reasoning? Is anyone willing to share their answer? We are looking for explicit links between claim and evidence. Who sees that in this answer? Is there any way to improve it?*

Inform students that during the next activity they will select which model of matter best accounts for their observations and justify their selection using evidence.

Possible questions:

- *What are the different models of matter?*
- *What evidence have we gathered that provides some information about the usefulness of these models?*

Page title:

Particle vs. continuous model of matter

1. Does the particle or continuous model of matter better match your observations of liquids and gases?

A. The particle model
B. The continuous model

2. Provide two examples of observations from the activities in this investigation to use as evidence to support your argument. Explain why those observations support your choice for a particle or continuous model of matter.

Student responses:

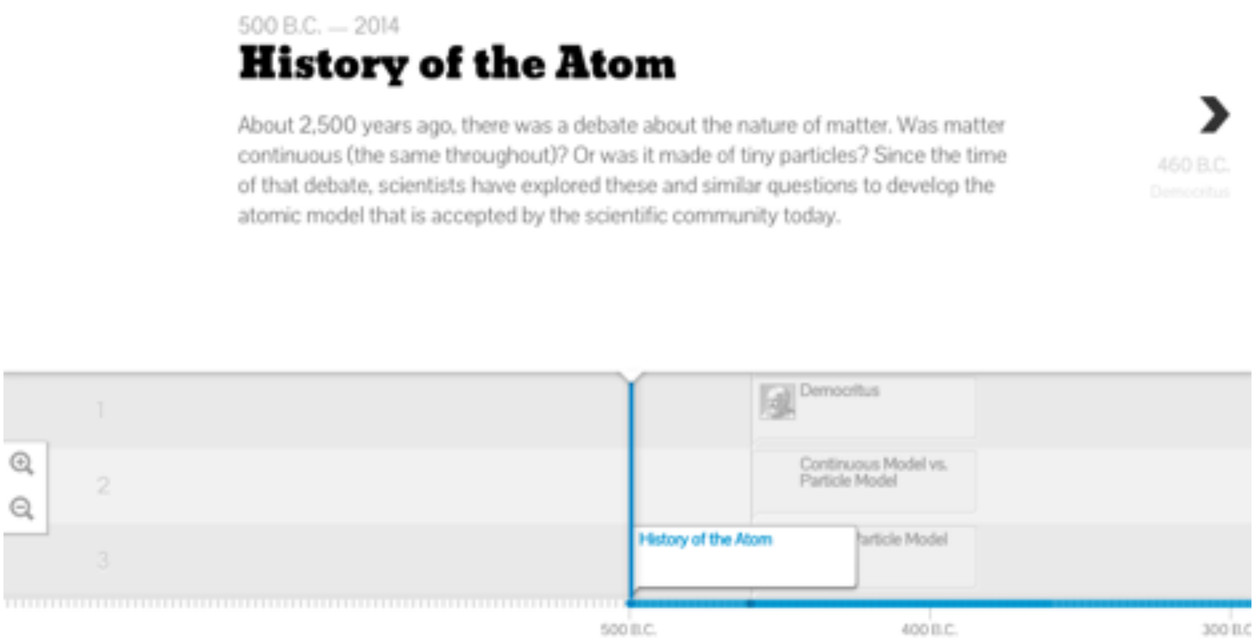
- A. The particle model - Mixing water and ethanol makes a smaller than expected volume and you can compress a gas.
    - *These are observations, but they lack an explanation of why they support a particle or continuous model of matter.*

3. Return to your earlier ideas about what would happen if you cut a piece of paper in half over and over again. Do you still agree with your original claim (that you could or could not cut the paper in half forever)? What changes would you make to your original ideas and what evidence and reasoning caused you to change your thinking?

Student responses: Their initial claims were likely not based on much evidence. The answer here asking about evidence that may have caused a change in thinking could be similar to the previous question. Focus more on their description of what needed to change from their original model.

Page title:

An interactive timeline



[Click here for link to live timeline]

Concluding the Lesson
Have students look at the timeline and review the evidence they collected during these activities. Note that even though you click the forward button to see different components of the timeline, they all refer to the same time period.

Possible questions:
- *What was the debate about the nature of matter?*
- *Which model best explains the evidence we saw? Can you give me an example and explain your thinking?*
- *Are there any other examples?*
- *Does anyone disagree? Does anyone think the other model best explains the evidence?*