Grade 5

The Inquiry Project

*Seeing the world through a scientist's eyes*

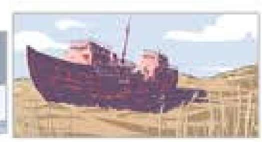
## Grade 5

# Investigating Water Transformations

## Keeping Track of Matter

Grade 3

Grade 4



Grade 5

# The Inquiry Project

*Seeing the world through a scientist's eyes*

This curriculum was developed by TERC, Cambridge, Massachusetts 02140 www.terc.edu. TERC is a not-for-profit education research and development organization dedicated to improving mathematics, science, and technology teaching and learning.

This material is based on work supported by the National Science Foundation under Grant No. DRL-0628245. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect views of the National Science Foundation.

ISBN 978-1483955155

www.terc.edu

# Table of Contents

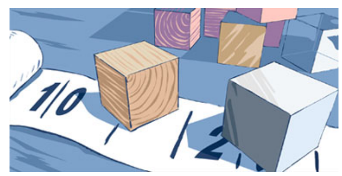
# What is the Inquiry Project?

The Inquiry Project brings together research, curriculum, assessment, and professional development to deepen students understanding of the nature of matter.

## The Curriculum (Grades 3–5)

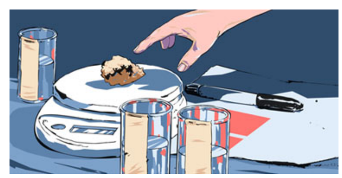
In the Inquiry Curriculum, Grade 3–5 students learn core ideas, scientific practices, and crosscutting concepts to progressively build a rich network of experiences and understanding about the structure and properties of matter. The concepts of **material, weight, volume, and matter** are emphasized as these ideas are essential for all of science and provide the necessary foundation for robust understanding of the particulate model of matter in later grades.

Students use scientific practices that are central to inquiry such as reasoning from evidence, building and using models, and developing explanations. They learn crosscutting concepts that span the disciplines of science, such as system and scale. They work collaboratively with their classmates and teachers, using measurement, mathematical and graphical representations, and discussion to build scientific explanations about objects and materials in the world around them.



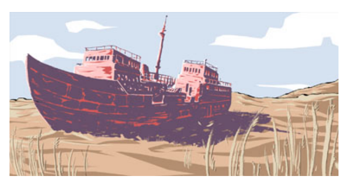
### Grade 3: Investigating Things in My World

In grade 3, investigations of weight and material are front and center and volume is introduced briefly at the end of the unit. Within their investigations, students learn to use data tables and measure lines to represent weight. They express their ideas through discussions, writing, and drawing.



### Grade 4: Investigating Earth Materials

In grade 4, students investigate properties of earth materials. They learn to distinguish and measure weight and volume and investigate their relationships in different solid and liquid materials. By the end of grade 4, students ask which properties of matter stay the same during transformations such as crushing (weathering) and reshaping, and which properties do not.



### Grade 5: Investigating Water Transformations

In grade 5, students investigate properties of gases. They deepen their understanding of matter as they investigate phase change and transformations of water as it freezes, melts, evaporates, and condenses. By the end of grade 5, students are able to describe transformations of water at two scales: the macroscopic or visual scale and in terms of particles that are way too small to see.

## Curriculum Resources

- A teachers' guide
- Student notebook
- A materials kit for student investigations
- A "Curriculum at a Glance" chart
- Embedded assessments
- Child and Scientist Essays (background information)
- Cross-grade concept chart
- Video introduction to the curriculum (on inquiryproject.terc.edu)

## How the Curriculum Works

Each lesson within the curriculum is called an investigation and each unit consists of 16 or 17 investigations. Each investigation (a) introduces an Investigation Question, (b) includes an exploration or data gathering activity, and (c) wraps up with a class discussion so students can make meaning of their work and have a chance to clarify their understanding through talking and listening. Throughout the lesson, students write in their science notebooks, for example, recording their ideas, predictions, and measurements, representing their findings, and proposing explanations.

A complete investigation takes about 50–60 minutes and includes both the firsthand science experiences, literacy-related notebook writing, and whole class discussion. When science classes are scheduled for 45 minutes, teachers are encouraged to find an additional 15 minutes for students to complete their notebook writing or have an unhurried discussion where they practice articulating their ideas and explaining their reasoning.

### The Research

The Inquiry Curriculum is based on extensive research about children's ideas and learning. It is also informed by a 3-year longitudinal study comparing the learning of grade 3–5 children who used the Inquiry Curriculum with those who did not. This study showed that children using the curriculum made more progress in moving from perception-based to model-mediated understanding of materials and matter. (Learn more at inquiryproject.terc.edu, Research Tab)

### Formative Assessment Opportunities

The opportunities for assessment are endless in the Inquiry Curriculum. Anytime you observe what children do, listen to what they say, or review what they've written and drawn, there is opportunity to take account of their ideas and how these ideas are developing. However, watching, listening, and reviewing work must be done with specific questions and criteria in mind. In other words, you need to know explicitly what you are watching, listening, and reviewing work for.

Throughout the Inquiry Curriculum opportunities for assessment are identified and criteria, questions and guidelines for reviewing students' work are provided as part of the lesson description. These opportunities for assessment align with the learning goals, provide ongoing information about students' ideas and help to inform next steps in the learning for both teachers and students. **Student notebooks** and **Concept Cartoons** found within each unit are also opportunities for assessment. (Learn more at inquiryproject.terc.edu, Assessment Tab)

### Professional Development Opportunities

Guidelines for facilitating **Curriculum Implementation Workshops** are provided for each curriculum unit. Through the implementation workshop you'll become familiar with the organization of a unit, its goals and specifics of each investigation. **Talk Science**, professional development is a web-based program aligned with the Inquiry Curriculum to increase the productivity of classroom science discussions. (See inquiryproject.terc.edu, PD Tab)

## Meeting the Vision of the NRC Framework and NGSS Science Standards

Consistent with the new *Science Framework* and *Standards*, the Inquiry Curriculum emphasizes deeper understanding of core ideas, crosscutting concepts, and the practices of science and engineering. The new vision calls for increased coherence. In the Inquiry Curriculum, ideas, concepts and practices progress grade to grade with each supporting the other and developing systematically over multiple years. There is also coherence between curriculum, instruction, and assessment within each grade. Learn more about how the Inquiry Curriculum meets the new vision at: http://doingnewsciencestandards.org

| Central Inquiry Science Concepts | | | | |
|---|---|---|---|---|
| | **Weight** | **Volume** | **Material** | **Matter** |
| **Grade 3** | The weight of objects can be compared using a pan balance and standard (gram) units. | Two solid objects cannot occupy the same space.<br><br>The amount of 3D space that objects occupy can be compared. | Objects can be described in terms of their weight and volume and the materials they are made of (clay, cloth, paper, etc.).<br><br>Materials have observable physical properties such as color, size, texture, flexibility, etc.<br><br>Same size objects can have different weights when they are made of different materials. | Materials can be subdivided into small pieces and the pieces still have weight. |
| **Grade 4** | The weight of solids and/or liquids can be compared using a digital scale and can be represented on a weight line or a table.<br><br>Weight is conserved during crushing and reshaping. | Liquid and solid volumes can be measured in cubic centimeters.<br><br>When immersed, a solid displaces a liquid volume equal to the solid volume. | The relationship between weight and volume (i.e. density) is a property of solid and liquid materials. | Matter can be divided into tiny pieces, and even the tiniest pieces have weight and take up space. |
| **Grade 5** | Weight is conserved during dissolving, freezing, melting, evaporation and condensation. | Volume may not be conserved in phase change. | Air is a mixture of gaseous materials composed of particles too small and spread apart to see.<br><br>Melting, freezing, evaporation and condensation change the form of matter but do not change the material. | Matter is composed of particles that have weight, occupy space, and are too small to see.<br><br>Gases, liquids and solids are all forms of matter and have weight and take up space. |

## What information about the Inquiry Curriculum is on the website?

There is no need to carry the teachers' manual home as the full curriculum and more is freely available on the Inquiry Project website (inquiryproject.terc.edu). On the web, you'll also find:

- Videos cases from classrooms engaged in the curriculum
- Video interviews with scientists that provide insight into scientists' thinking
- Formative assessment examples embedded within the curriculum
- PD support for leading productive discussions

# Overview of Grade 5 Curriculum

## Investigating Water Transformations

### Keeping Track of Matter

We expect puddles to dry up after the rain stops. We are not surprised when drops of water collect on the glass holding our cold drink. However, we never get to see the water that has evaporated from the puddle or see the drops before they appear on the glass. What makes these phenomena possible? They can be explained by one of the most significant realizations in the history of science: that water and all matter is composed of unimaginably large numbers of extremely tiny particles (atoms or molecules). Scientists use the phrase *the particulate nature of matter* to describe this understanding of the composition of matter. Too small to see individually, each of these particles has just a tiny bit of weight and takes up just a tiny bit of space. When countless trillions of particles clump together, they can make an object feel pretty heavy.

Particles exist in a constant tension between the chemical bonds, which tend to hold them together, and heat energy, which keeps them in constant motion and tends to cause them break loose from one another. When water particles leave the surface of a puddle or other body of water, via evaporation, it's because of this heat-related energy and motion. These particles maintain their identity as water particles after they have evaporated, but are in the form of a gas we call water vapor.

Without using the terms *molecules* or *atoms*, this curriculum unit provides students with a set of experiences that helps them develop the understanding that particles too small to see can have weight, take up space, and can help us understand the story behind transformations such as puddles evaporating or drops condensing on a glass.

In Section 1, **Water, a liquid**, students are introduced to the mystery of a disappearing sea and the scale at which evaporation can occur. They build their own *mini-lakes*, and review concepts of weight, volume, and *heaviness for size* (the term we use in place of *density*). As students investigate salt dissolving in water they are introduced to three concepts that are central to the goals of this curriculum: 1) the matter we encounter in everyday life at the visible level is composed of tiny particles that are visible only when they are clumped together, and become invisible when they spread apart; 2) these individual particles continue to have weight and take up space even when they are spread apart and are too small to see; and 3) these particles must exist in unimaginably large numbers in order to account for the measurable size and weight of objects in the macroscopic world.

In Section 2, **Water to Vapor**, evaporation and condensation are investigated. Students consider, "What happens to water when it evaporates? Does evaporation destroy water, or does water continue to exist after it evaporates?" As students explore evaporation within a closed system, they also start to see the relationship between condensation and temperature.

In Section 3, **Water to Ice**, students consider how ice and water compare. While at the visible scale most of the properties of ice and water are quite different, the individual particles are identical. Students cannot prove this, but they rely on a combination of data they have collected, scientific reasoning, and finally a computer model as they consider whether or not water and ice are the same material. Students are presented with the scientists' belief that all matter – not just salt or water – is composed of tiny particles too small to see individually. The computer model provides the particle view of the solid-to-liquid transformation of water as well as the relationship between temperature and particle motion.

In Section 4, **Air, a Gas**, students investigate air, a mixture of gases. The class collects data to establish that air has weight, takes up space, and has properties that can be explored and described. Air has much in common with the more tangible forms of matter – solids and liquids – but this form of matter is not visible. Students use the computer model, to investigate the liquid-to-gas transformation of water at the particle level.

In Section 5, **Two Scales**, students draw the connections between transformations at the visible level and their growing understandings of matter at the particle level. They apply their new understandings to their experiences with their mini-lakes and with bodies of water in the real world.

## Inquiry Project Grade 5 Curriculum

# Investigating Water Transformations:  Keeping Track of Matter

| 1. WATER, A LIQUID | 2. WATER TO VAPOR | 3. WATER TO ICE | 4. AIR, A GAS | 5. TWO SCALES |
|---|---|---|---|---|
| **1. Why are these ships in a field?** A PowerPoint presentation poses a mystery and presents a real-world example of a dramatic water transformation. Students start to build class-room-sized mini-lakes to investigate. | **6. What happens to the water?** As students watch with magnifiers, water droplets shrink and disappear. Does evaporation destroy water, or has it gone somewhere else? This question launches a search for the answer. | **10. How are ice and water the same and different?** Students launch this 3-session investigation by contrasting and comparing the properties of ice and water. They also revisit condensation in a different context. | **13. Is air matter?** An exploration with syringes provides evidence that air takes up space. A demonstration comparing air-filled and empty balloons establishes that air has weight. Air is determined to be *matter*. | **17. What's the story behind the graph?** Students annotate their graphs. Their observations include their new understandings of the relationship between macroscopic change and microscopic processes. |
| **2. How can we keep track of our mini-lake materials?** Students are reintroduced to the concepts of volume and *heavy for size*, and finish building their mini-lakes. They learn that everything that has weight and takes up space is *matter*. | **7. What happened to the water?** The class assembles a set of three small closed systems in order to study evaporation. Can this tiny system help us investigate processes that happen in the larger world? | **11. What happens to weight and volume when water freezes?** Students discover that while the volume of a water sample changes as it is frozen, the weight remains the same. Has the material also changed? | **14. What are some properties of air? (1)** Further exploration reveals that air is compressible while water is not. Students develop an annotated drawing (an explanatory model) to explain this difference in properties. | **18. How have our understandings changed?** Students reflect on how the 2-bottle system and other investigation materials have helped them develop new understandings about real-world transformations of water. |
| **3.How does water compare with sand?** As they compare the weights and volumes of materials used in their mini-lakes, students discover the unit weight of water and have additional experience with the concept of *heavy for size* | **8. What is happening in the 2-bottle system?** Students learn about the elements of a system: the boundaries, components, and interactions. They also record the transfor-mations underway in the 2-bottle systems. | **12. What changes and what stays the same as ice melts?** Reasoning suggests that the material itself does not change as ice melts to water. A computer model that highlights water and ice particles reinforces the reasoning. | **15. What are some properties of air? (2)** A demonstration highlights the response of air to heating and cooling. Students develop another annotated drawing to explain this response. | |
| **4. What does a drop of water weigh?** In working with single drops of water, students see that very small things can take up space and have weight, even when that weight does not register on a classroom scale. | **9. Why do the water drops form?** Through a study of water drop patterns in the 2-bottle systems, students begin to understand the relationship between condensation and temperature. | | **16. What are some properties of air? (3)** Students again view a computer model that helps them under-stand the relationship between temperature, particle motion, and the volume of gas. | |
| **5.What changes and what stays the same when salt dissolves in water?** Dissolving salt in a cup of water highlights the fact that even particles too small to see can have weight and take up space. | | | | |

# 1. Water, a Liquid

Our fifth grade story begins with students learning that a major body of water – an inland sea – has evaporated, leaving a fleet of ships resting on dry ground. Does evaporation really happen at that scale? What becomes of all that water? To launch an investigation of water and its transformations, pairs of students use sand, gravel, small stones, and water to build miniature lakes in plastic sandwich boxes. Students observe, modify, and weigh these "mini-lakes" across the curriculum unit. They measure the *weight* and *volume* of the lake materials, compare the *heaviness for size* of water to sand, and determine that each cubic centimeter of water weighs one gram.

All the materials in the mini-lake have weight and take up space, and thus are forms of matter. Does a single drop of water also have weight? While the weight of a drop does not register on the classroom scales, students use their knowledge of the unit weight of water to help them calculate the weight of a single drop. That weight is tiny, but the weight of a bucket of water is significant. How many drops must it take to give a bucket-full its weight? And how many grains of sand combine to give a bucket-full its significant weight? These rhetorical questions, and experiences that follow in later strands, help set the stage for understanding that objects are composed of unimaginable quantities of extremely tiny particles.

Weight becomes an important tool when measuring matter that is invisible. For example, when a weighed quantity of salt is dissolved in water, it disappears. The particles become so small, and so spread apart, we can no longer see them. Does that salt still exist? Its presence can be confirmed because its weight is conserved in the solution.

### Investigations:

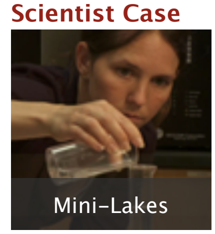
- Investigation 1: Why are these ships in a field?
- Investigation 2: How can we keep track of our mini-lake materials?
- Investigation 3: How does water compare with sand?
- Investigation 4: What does a drop of water weigh?
- Investigation 5: What changes and what stays the same when salt dissolves in water?

### The Child and the Scientist

**The Child:** What makes the particulate model of matter so challenging for students?

**The Scientist:**
What are materials made of?

**Scientist Case**




Watch Laurie Baise doing the mini-lake investigations

Available online at inquiryproject.terc.edu

### Letters from the Engineer

While students use science practices to deepen their understanding of scientific ideas throughout this curriculum, some of their investigations bridge to the engineering world. To highlight some of the instances where students engage in an engineering practice or gain insight into the engineer's world, the curriculum includes *Letters from the Engineer*. Look for these letters (in the special boxes) and read them to the class.

**The Child's Ideas for *1. Water, a Liquid***

# What makes the particulate model of matter so challenging for students?

The particulate model of matter is one of the central ideas in modern science, as well as in middle- and high-school curriculum. Thinking about materials in particulate (as well as atomic-molecular) terms is critically important in *all* science disciplines—not only physics and chemistry, but also Earth science and astronomy, genetics and molecular biology, and neuroscience. Students cannot achieve science literacy without understanding this profound idea.

*At first blush, the claims made about the wild activity going on at a nanoscopic scale might seem like an unbelievable "fairy tale."*

Yet, research has shown that students not only have great difficulty *believing* this idea to be true—they find it counter—intuitive that all matter is made of discrete, spaced particles in constant motion; they also have great difficulty even *understanding* many of its key aspects. For example:

- Students often do not appreciate the *tiny size* and scale of the particles, instead confusing them with dust particles or with germs or cells that can be seen with a simple microscope.
- Students often do not recognize that the discrete particles *are* the matter itself; instead, when learning about particles of water (or some other material), they may think they are little pieces of stuff floating *in* the water, rather than the water (or other material) itself.
- Students often do not think of particles of specific materials (e.g., water and iron) as *pre-existing units* that have a fixed size, shape, and weight even across physical changes; instead they may think these particles are created when something is broken into little bits. Therefore their sizes, weights, and shapes can be quite variable and changeable. Further, they may think these tiny particles, when small enough, no longer take up space or have weight at all.
- Students often do not realize that properties at the particulate level can dramatically differ from those they observe in everyday objects; instead, they expect that the particles to be like what they observe. Thus, if something is solid or liquid, red or green, hard or soft, then it must be made of particles that are themselves solid or liquid, red or green, and hard or soft.

Why do students have all these difficulties? One reason is that the nature of materials on an atomic scale is so profoundly different from how materials *appear* macroscopically. Tables appear to be made of continuous, unmoving stuff. How can they be made of constantly moving particles separated by empty space? Ice, water, and water vapor are each different. How can they all be composed of the same kind of particles? At first blush, the claims made about the wild activity going on at a nanoscopic scale might seem like an unbelievable "fairy tale."

Another reason is that children harbor ideas based on interactions with large-scale objects that are *fundamentally incompatible* with the particulate theory. They trust their senses to reveal what things are like. If they see it, it is there; if it feels heavy, it has weight. Material objects you see, feel, and touch are fundamentally different from "ethereal" things like air, heat, light, or thoughts. Indeed, they often group "air" with "heat and light" as examples of "nonstuff."

Imagine then the puzzlement children experience when told of the existence of particles of a material that are too small to see, feel, or touch. Certainly these can't be the material itself, but rather some ethereal thing or impurity "in" the stuff. Children think that even small pieces of clay are weightless because they have no "felt weight," so how can they possibly believe that much tinier particles have any weight? Thus, coming to accept these tiny invisible particles as the constituents of matter calls for profound changes in their concepts of matter and weight.

Still another (related) reason for children's difficulties is that the ways scientists learn how the world works are quite different from children's everyday sense-making. For example, in trying to figure out what materials are like, scientists carefully measure what changes and stays the same when things melt and dissolve. They use their imaginations to explain what they see and then evaluate how well their ideas account for results and make accurate predictions.

Although children certainly can be astute observers with wonderful imaginations, they typically do not apply their imaginations and observations for scientific model building and testing. Thus, understanding the particulate model of matter calls for more sophisticated sense-making in children. Further, it calls for a shift from thinking of models as *little replicas* that should *look like* the thing modeled, to thinking of models as *conjectures* of what something may be like at a scale too small to see that can *explain* observed results.

Other reasons for children's difficulties relate to how the particulate model is taught in schools, including: a) introducing the idea *too soon* before foundational understandings are in place; b) introducing *too many details* at once rather than letting students gradually add complexity to the idea; c) presenting the ideas as "*facts*" rather than as explanatory conjectures; and d) *failing to discuss* obvious *objections* to these ideas by helping students answer fundamental questions like:

- How can something that is invisible be *matter*?
- How can the same *stuff* be hard, runny, or invisible?
- How can something be a *good model* if it doesn't look like what you see?

Prior research shows that the best way to help students develop new ideas is to be respectful of them as thinkers and learners, build from their initial ideas, and appeal to their desire to make sense of how things work. We need to encourage them to make drawings of their ideas about unseen events so they can grasp the implications of their ideas, as well as discuss and contrast their ideas with those of others. We need to give them *reason to believe* new ideas by introducing them to observations that are puzzling given their initial ideas — such as why the weight of an ice cube remains the same when melted — but that can be explained in terms of the particulate model. We need to help them imagine the atomic scale when thinking about the smallest particle of a material and to allow them to reflect and discuss initial objections to the model. Finally we need to acknowledge that even when we have given them reasons to believe, we haven't "proved" the theory nor have students fully understood it. Their understanding is still a work in progress.

In doing all these things, however, we will not only have helped students to begin to understand elements of the particulate model of matter, but also (equally importantly) helped them begin to understand the power of the "what if" game that is at the heart of all of science.

—Carol L. Smith

**The Scientist's Essay for *1. Water, a Liquid***

## What are materials made of?

When you start paying attention to the materials around you, the most stunning thing is their extraordinary diversity — from gases so insubstantial we almost forget they exist, to lead bricks; from clear water to thick, smelly tar, from stretchy rubber to brittle glass, from rocks to living tissue. Yet science has shown that all of this vast array of substances, without exception, is comprised of a small assortment of building blocks, something like the way a modest set of Lego shapes can be used to construct an immense variety of structures.

> *"if you keep breaking down any uniform material — like water, or aluminum — into smaller and smaller pieces, you will eventually get to a smallest unit, or fundamental particle of that material"*

There are actually two pieces to this assertion about the fundamental structure of matter. The first is that if you keep breaking down any uniform material — like water, or aluminum — into smaller and smaller pieces, you will eventually get to a smallest unit, or fundamental particle of that material. These particles, unimaginably tiny and numerous, can combine like minuscule Lego blocks to make the water drop or aluminum picture frame that we can see and handle. We can call this the *particulate model* of matter, and it is the focus of our present curriculum.

There's a further step, which is that those fundamental particles — molecules — can be further broken down into yet smaller entities — atoms, of which there are only about 100 different kinds. Just a handful of them (carbon and hydrogen and a few others) can be combined into so many different kinds of molecule that just studying them is an entire field of chemistry — as well as the basis for all of biology. We will not get to the *atomic model* in the present curriculum, but we are laying the foundations for it.

How do we know? These ideas about the fundamental structure of matter at the tiniest of scales arose from detailed study of what changes and what doesn't when matter is transformed from one form to another, processes like melting, freezing, evaporating, condensing and dissolving. (There is another set of processes described by words like burning, or corroding, that we are leaving to future chemistry classes.) To the casual observer, it seems like just about everything changes in these transformations. When water freezes it becomes hard and brittle, its color changes, its density changes — it seems to have become an entirely different material. When water evaporates it seems to simply disappear, and the same is true of salt or sugar when we dissolve it in water. Yet on closer examination, we find evidence that the changes are not as complete as they appear. For one thing, it is possible to recover the original material. If we warm up the ice, the water reappears. If we place a chilled piece of glass over the water as it evaporates, we collect drops of liquid water. If we allow the salt solution to sit until the liquid evaporates, we find the salt left behind. (Chemical transformations, like burning a piece of paper, are not so easily reversed, but in principle it's always possible.)

Moreover, if we are careful, we can discover something else that remains constant: the total amount of matter, as indicated by its weight. The weight of the ice is the same as the weight of the water that froze. The weight of the salt solution is equal to the weight of the water plus the weight of the salt before it was dissolved. And if we're very careful we can even show that the water vapor is not weightless, but in fact has exactly the weight of the water that evaporated to produce it. Why should that be so?

The particulate model provides a very natural way to explain these observations. If water, ice and water vapor are all different ways of organizing the same bunch of tiny "water particles" — like different structures made from the same set of Legos — then it makes sense that the total weight doesn't change, and that you can always get back to the state you started with. These observations by themselves do not prove that the particulate model is true, but they are the beginnings of a vast web of phenomena that all point in that direction.

It took a century of careful experiments and intricate reasoning for the particulate model to become widely accepted by the scientific community, so we don't expect that these few experiences will enable students to understand all its implications, let alone convince them of its validity. We do hope to give them a taste of the "What if?" game that is in many ways at the heart of science. "What if" there are tiny "water particles", far too small to see, but that still have weight and take up space? Would that help explain the way water, ice and water vapor behave? What other observations or tests can I think of that would either support or contradict that model?

* Strictly speaking, what remains constant is its *mass*. Scientists distinguish between *mass*, which is a measure of the amount of matter, and *weight*, which is how hard Earth's gravity pulls on the matter. The distinction is sometimes important, but for our present purposes, the two quantities are interchangeable.

—Roger Tobin

## 1. Water, a Liquid: Investigation 1

# *Why are these ships in a field?*

## Plan Investigation 1

*Why are these ships in a field?* Part of the answer is evaporation, but how could evaporation happen at this scale? And where is all that water now? The investigations students encounter over the next few weeks shed light on this mystery. By the end of the unit, they know the full story behind the ships in the field.

This unit investigates transformations of water over time and we begin with the example of a lake. It's not practical to study an actual lake, but what if we could we simplify and shrink things down to the size of a sandwich box? Could a simplified version of a lake help us understand some important processes that occur within larger bodies of water? Students begin building their own mini-lakes, but do not complete them until the next science class. As they build, they keep track of the amount of material in their lake. This “accounting” provides a way to study how and why materials change. Students will continue to observe their mini-lakes throughout the unit. Find a good place in your classroom to keep the collection of lakes — your class's own Lake District!

By the end of this investigation students will understand how to weigh the amount of each material in their mini-lake.

### Learning Goals

- Understand that the classroom mini-lakes will help students understand the processes that occur in real lakes
- Measuring and recording weight is a way to keep track of materials

| Sequence of experiences | | |
|---|---|---|
| 1. Introduce the unit | All Class | 5 Mins |
| 2. Elicit ideas | All Class | 10 Mins |
| 3. Introduce the mini-lakes | All Class | 5 Mins |
| 4. Weigh materials | Pairs | 25 Mins |

### Materials and Preparation

Preparation:

- Read *Why are these ships in a field?* (See Resource Quick Links)
- Science Notebook for each student
- Prepare 12 index cards, 3 labeled “120 grams”; 3 labeled “130 grams”; 3 labeled “140 grams” and 3 labeled “150 grams”

For the class:

- Post the investigation question in a place where all students can see it.
- Set of images of "ships in a field" (pdf or ppt formats) or notebook pages[pdf].
- Computer and a system for projecting the images if using electronic presentation.
- Prepare a sample mini-lake. Use 120g of sand and 120g of gravel to prepare a small lake bottom and shoreline in a sandwich box. Add 120g of water and a few small rocks around the perimeter of the shoreline.
- Have one set of materials available for use during the introduction.

For each group:
*(Each group assumes 4 students. You may need to adjust the groups to suit your class size and configuration.)*


- 1 6in strip of masking tape
- 2 index cards, as prepared above
- 2 plastic spoons
- 2 sandwich boxes with covers
- 2 12oz cups 2/3 full of sand
- 2 12oz cups 2/3 full of gravel
- 2 12oz cups 2/3 full of water
- 2 12oz cups each holding 8 small rocks
- 8 plastic vials with covers
- 1 digital scale; Number and assign each scale to a group for use throughout the curriculum. This will help students get consistent results in the event of small differences between scales.

> **Note:** Students weigh the sandwich boxes and covers in this investigation. **They do not assemble mini-lakes until the next investigation.**

## 1. Introduce the new science unit

Discussion 5 Mins

Explain that the topic of this new science unit is *water* and the different ways it can change or transform. Explain that students will be engaged in a series of investigations. Each class will start with a question to investigate; sometimes the class will need more than one session to answer a question.

***Letter from the Engineer***
*You may know something about the work that scientists do. Some study the stars and planets. Some study the different plants and animals on Earth. Some study the non-living parts of Earth, such as the rocks, ice, and oceans. All scientists study the natural world to learn more about how it works. They notice changes and they try to understand why the changes are happening. They ask questions, and they often work with other scientists to try to find the answers. For example, scientists might ask, "Why did the birds that use to come here every summer stop coming? What happened? What is different now?" Scientists can spend years trying to answer their own questions. They make careful observations, they take notes, and they work to make sense of the information or data they have collected.*

*Scientists sometimes work with engineers, but the main job of an engineer is different than the scientist's. The main job of an engineer is to solve problems, usually to provide people with something they need or want. Engineers also ask themselves questions, but their questions are about the problems they solve. They ask, "How can we build a car that uses less gasoline?" or "How can we build a robot that will help scientists explore Mars?" Engineers also study the materials that are used to make objects. They might ask, "Will this object work better if it is made from plastic or made from wood?" or "How can we make this glass stronger, so if something hits it, it will not break?"*

*In your investigations you will be thinking like a scientist most of the time, but there will also be times when you will need to think like an engineer, and solve problems that will then help you to learn more about the natural world.*

*Look for more Letters from the Engineer. These will point out some of the times when thinking like an engineer is important.*

## 2. Elicit ideas

Discussion 10 Mins

### Purpose of the discussion:

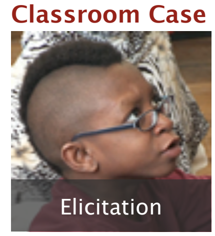
The purpose of this discussion is to uncover student ideas about what happened to the water on which the ships once floated.

### Engage students in the focus question

*Why are these ships in a field?*

Engage students by situating the learning in a real world context. Show students the set of images in the Power Point presentation or in the front of their Science Notebooks. Present the situation as a mystery as you share today's investigation question. If you need to distribute the science notebooks, tell students they will learn more about using the notebooks later in the class. For now, the focus is just on the images in the front section of the notebooks.

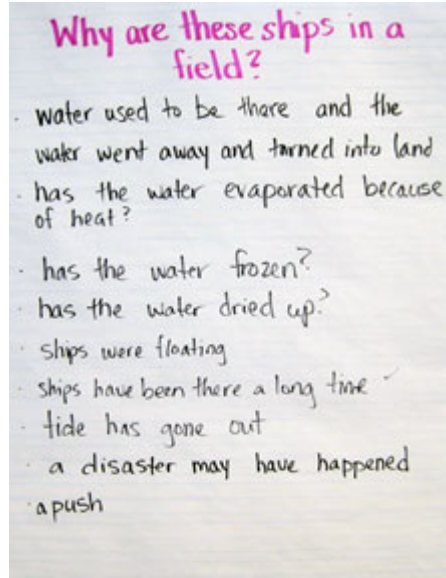
**Classroom Case**




The Role of Elicitation Discussions

Available online at inquiryproject.terc.edu

Ask students briefly to share ideas in their small groups. Then have groups report their ideas to the class. Ask students to listen carefully. Do they see connections between their own ideas and those of others? Do the suggestions of others inspire new ideas? Make a list of the different possibilities that students suggest. Expect all students to participate.




Explain that the class will not attempt to determine an answer to the investigation question today. As they investigate additional questions this new science unit students will find out what happens in situations such as the one shown in the photographs.

**Summarize the discussion**

Using the same language students have used, summarize their list of possible explanations.

## 3. Introduce the mini-lakes

All Class 5 Mins

Reiterate that the focus of the new science unit is to study water and the ways in which it can change or transform. Since it's difficult for the class to study an actual lake, students will build small lakes that they can study in the classroom.

> **Note:** Each pair of students will build a mini-lake and track changes across an extended period of time.

Briefly, elicit students' ideas about what natural materials they would expect to find in a lake.

*What are some natural materials you might find in a lake?*

Show the miniature lake you have made. It's simpler than an actual lake, but it has some of the important materials: sand, gravel, rocks, water, and something to hold all the components together. Explain that they'll use their mini-lakes to help understand some things about real lakes, and learn more about how those ships ended up in a field.

Students will start to make their lakes today. Show them the materials they will use to make their mini-lakes: sand, gravel, a few small rocks, fresh water, and the boxes that will hold everything together.

One important question they'll investigate is:

*How do these lakes change, and how do they stay the same, as time passes?*

Explain that since they will study their lakes for changes that occur, they'll need to know how much of each material is in their lakes. Before the materials are mixed together in the lakes, it's important to weigh each component. In the next session, they measure the volumes of the components.

### Introduce the digital scales

Show students the digital scale. There are some things they should know in order to get accurate weight measurements:

- Be sure the scale reads zero once it is turned on and before weighing something. If it does not read zero, push the button labeled ON / ZERO to set it at zero.
- Scientists use grams, not ounces, for weight measurement. Make sure a small "g" for "grams" is in the corner of the display. If the letters are "oz" (for ounces), push the button labeled KG / LB to change the weight measurement to grams.
- These scales are designed to weigh small objects. Overloading them may cause them to stop working. Be careful to not push down on them or place heavy items on them.

## 4. Weigh materials for the mini-lakes

Pairs 25 Mins Notebook

### Introduce Science Notebooks

Distribute Science Notebooks to the class and read the letter inside the front cover. Highlight the following points about notebook use:

- Scientists keep a written record of their questions, predictions, the data they collect (drawing, tables, graphs, notes, etc.), and their conclusions. You'll use your notebooks as scientists use theirs.
- Science classes begin with opening notebooks and recording the date. Notebooks are used throughout the class to record data, ideas, and questions as they arise.
- Use your notebooks to look back at predictions, procedures, data, conclusions, and ideas, so that procedures can be repeated. Your notebook will help you see how your ideas are growing and changing.
- Use your notebooks just for things related to science. Drawings or notes that are not related to your science work could make it more difficult to find information you need later on.

Identify pairs of students who will work together on a mini-lake. Distribute materials.

### Introduce tare weight

Introduce tare weight with one of the empty plastic vials:

> *If you put some sand in this plastic vial, cover it, and put it on the scale, and the scale reads 150 grams, do you have 150 grams of sand in the container?*
>
> - No. There will be less than 150 grams of sand in the container, because the container and cover weigh something. To weigh 150 grams of sand, we'll need the scale to read 150 plus the weight of the container and cover.

Introduce the term "tare weight" (tare rhymes with air). This is the term used to describe the weight of an empty container, including its cover. It's important to know tare weight in order to determine the weight of just the material that's in a container. Ask groups to put an empty vial and its cover on the digital scale. Is there agreement about the weight of the vial and cover? Once students determine the tare weight, have them record it on the *[Making mini-lakes]* page in their Science Notebooks.

### Weigh materials

The weight on the index card indicates the weight of sand, gravel, and water students will add to the vials. There is no specific weight of rocks students should use.

- Have students weigh the assigned amount of sand, gravel, and water, as well as the rocks, in the vials. They can use the plastic spoons to make small adjustments to the weight.
- Remind them to include the cover as they weigh the vials of materials.
- They should also weigh the sandwich box and cover, and record all weights in the Weight column of the table on the *[Making mini-lakes]* page of their Science Notebooks.
- Each pair should end up with four covered vials, which they will use in the next class. The vials of gravel, sand, and water should all have the same weights.
- Have pairs label their vials with their initials, using the masking tape.

**Note:** The only data students enter on this page during Investigation 1 are the vial tare weight (including cover) and the Weight data in the table. In Investigation 2 they will enter the Volume data, the weight of the completed mini-lake, and answer the reflection questions.

Tell students that in the next science class they will measure the volumes of the lake materials, add the materials to the sandwich boxes, and design their lakes.

## 1. Water, a Liquid: Investigation 2

# *How can we keep track of our mini-lake materials?*

## Plan Investigation 2

In this investigation, students measure the volume of each material they will add to their mini-lake, study the relationship between weights and volumes, and then assemble their lakes.

In the process, they are likely to discover that the weights of the individual materials in their mini-lake do not add up to the weight of the completed lake. Why the difference? When we expect one outcome and get another, it's important to make sense of the unanticipated result. This puzzle solving is particularly important in science, where the goal is to build new understandings of how the natural world "works." Such differences call for scientists to review their work and try to figure out why expectations don't match outcomes.

By the end of this investigation students will understand that weight and volume can help them to keep track of changes in their mini-lakes. They will also understand the importance of seeking an explanation for an unexpected outcome.

**Formative Assessment**

*Do students understand that volume is the amount of 3-dimensional space sand (or gravel or water) takes up inside a vial?*

Available online at inquiryproject.terc.edu

### Learning Goals

- Understand the concept of volume
- Understand the importance of identifying possible sources of measurement error

| Sequence of experiences | | |
|---|---|---|
| 1. Review volume | All Class | 15 Mins |
| 2. Collect data and build mini-lakes | Pairs | 20 Mins |
| 3. Make meaning | All Class | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- On a classroom calendar, write the number 1 on the date students complete their mini-lakes (today), and add consecutive numbers for every day, including weekends, through the time period you expect you'll need to complete the curriculum unit.

For each group:

- 1 digital scale; numbered by group
- 1 12in strip of masking tape
- 1 12oz cup holding 30 centimeter cubes
- 2 12oz cups
- 2 100ml graduated cylinders
- 2 funnels; conical paper cups with 1/2" snipped off the end
- 2 sandwich boxes with covers
- 2 sets of four vials holding sand, gravel, rocks, and water (from previous investigation)


> **Note:** Your students will need to know how to work with a 2-axis time plot to make entries into the **Weight of mini-lake over time** plot.

## 1. Review volume

Small Groups | 15 Mins | Notebook

In the last session, students carefully weighed each material that will be used to make their mini-lakes. Today they measure the volume of the sand, gravel, and water and then construct their mini-lakes. They don't measure volume of the rocks, which have been weighed and can be counted.

Explain that knowing the amount of these materials will help them to keep track of changes that may occur in their mini-lakes. They have one more set of important measurements to make.

Introduce the investigation question:

*How can we keep track of our mini-lake materials?*

Distribute materials. Ask students to leave the caps on the vials for now and to set the vial of rocks aside. The rocks will be the last material added to the mini-lakes.

### Review the concept of volume

*You have three vials that all have the exact same weight. How would you describe the volumes?*

- The volumes (amount of space each material takes up) are different. The water sample has the greatest volume. The sand sample has the least volume.

Highlight the three-dimensional nature of volume measurement, for example, by enclosing a space with your two hands, as if you were holding a large ball.

Have students pick up a centimeter cube. The cubic centimeter is the unit of measure for volume, just as the gram is the unit of measure for weight. One cube takes up one cubic centimeter of space.

### Estimate volume

Ask students to estimate the volume of their sample of sand.

*How many centimeter cubes do you estimate it would take to equal the amount of space* *taken up by the sand in your vial?*

**Note:** The volume of sand ranges from approximately 75cc to 95cc, depending on the weight a team was assigned. The goal of having students make this estimate is to see if they focus on the *amount of space* taken up by the sand. Do they confuse volume with the *height* of sand in the vial, the *perimeter* of the vial, the *area* of the vial bottom, or possibly the *weight* of the sand? Students are not expected to generate an accurate estimate.

Tell students to work in pairs, and that they'll have just a few minutes to make this volume estimate and record it in their Science Notebooks. Note that different pairs of students have different volumes of sand. Students record their data on the *[Making mini-lakes]* page in their Science Notebooks.

Ask students to share their estimates. Listen for estimates that seem surprisingly low (did they confuse volume with height, area, or perimeter?), and ones that are equal to the weight of their sand (did they confuse volume with weight?). Ask a few students to describe how they arrived at their estimate.

## 2. Measure volumes and assemble mini-lakes

Pairs 20 Mins Notebook

### Introduce the graduated cylinder

Show students a graduated cylinder. Point out that it is a tool for measuring the volume of liquids or the bulk volume of granular materials such as sand or gravel. The numbers on the cylinder refer to milliliters (ml). Each milliliter takes up the same amount of space as a cubic centimeter (1cc = 1ml).

The paper cups with the tips cut off will serve as funnels when pouring materials into the graduated cylinders. **MEASURE THE VOLUME OF THE DRY MATERIALS FIRST.**

**What is bulk volume?** Bulk volume is a term used to define the amount of space taken up by a granular material such as salt, sand, or gravel. Bulk volume includes the volume of the grains and the volume of the spaces between the grains. To measure bulk volume, pour the granular material into a graduated cylinder and read the volume as if it were a liquid.

### Measure volumes and assemble mini-lakes

Have students use the steps outlined in their Science Notebook to guide them through the process of measuring the volumes and assembling their mini-lakes. Students record thier volume data on the *[Making mini-lakes]* page in their Science Notebooks.

Add these reminders:

- Complete the steps in order.
- Students should keep the vial of water covered and wait to measure its volume until they are ready to add water to the mini-lakes.
- Students will need to measure the volume of water in two steps, because the graduated cylinder will not measure more than 100cc of water at a time.

### Record the weight of the completed mini-lake

In addition to recording the weight of the completed mini-lake on the *[Making mini-lakes]* page in their Science Notebooks, students need to record it in two other places:

1. In the *[Data Table: Weight of mini-lake]*:
   Have students find the Data Table in their Science Notebooks. The classroom calendar should provide students with both the date and the "day number." Today is Day 1 of the mini-lakes' existence.
2. In the graph labeled *[Weight of mini-lake over time]*:
   Demonstrate how to add the weight of the completed mini-lake to the graph in the Science Notebook. Some students will need help interpreting the scales on the horizontal (Day #) and vertical (Weight g) axes.

Each time students weigh their mini-lake, they will record the weight in both the table and the graph. Explain that, by weighing the completed lake and recording that weight today, students will be able to tell if the weight has changed the next time they weigh it.

Students should answer the *[Reflection]* questions in their Science Notebooks.

> ***Letter from the Engineer***
> ***Scientists, Engineers, and Models***
>
> *Just as you have done with your mini-lakes, scientists and engineers often create what they call a **physical model** of something in the real world. Like your mini-lakes, these physical models are not toys; they are tools designed to help us to learn more about the way something in the world works. In this case you are studying a part of the natural world — a lake. Building and investigating a physical model of a lake is helpful because a real lake is very large and not something you can easily visit every day to investigate it directly.*
>
> *Models need to be designed very thoughtfully. For example, putting sand and rocks into your mini-lakes is fine because most real lakes have sand and rocks in them. If you decided to put blue Jell-O in your mini-lake, it might still look like a lake but you would not learn anything about water.*
>
> *Some physical models are larger then the actual object, and others are smaller. The size depends on what will be helpful or useful. A globe is a physical model of the Earth. Because it is so small, you can see whole oceans, continents, large rivers and lakes, and see where the different countries are located. A model of an ant might be much larger than an actual ant, so you could see things and learn things that you might not discover on an actual ant.*

## 3. Make meaning

All Class 10 Mins

### Review norms for science discussions

Explain that an important part of science is explaining our ideas and asking questions so we can all learn from each other. Remind students that it's important to listen to each other, support their ideas with evidence, and build on each other's ideas.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Purpose of the discussion

The purpose of this discussion is for students to jointly construct explanations for why the weight of the completed lake differs from the weight of the sum of its parts, and to understand the limitations of their digital scales.

**Scales:** The weight of the completed lake is likely to be different than the sum of the parts. Why? The classroom scales round weight to the closest gram. This means that, for each individual component of the mini-lakes, the measured weight can differ from the actual weight by plus or minus a half gram. The measured weight of the completed lake should be more accurate than the sum of the measured weights of the parts.

### Engage students in the focus question

*How do you explain the difference between the weight of the completed lake and the weight of the sum of its parts?*

Ask students to return to the *[Making mini-lakes]* page in their Science Notebooks. Direct their attention to two places where they have recorded weight: the row in the table labeled *Sum of the weights*; and the line of text below the table that reads *Weight of the completed mini-lake*.

Did students get the same weight in both places? For most, the two numbers will be different.

Give students time to consider the data and offer responses; this is a challenging question. Listen carefully to student ideas, ask them to explain their reasoning, and encourage them to build on or add to each other's ideas.

*Which weight do you think is more reliable, and why?*

If no one mentions that the scales sometimes flickered between two weights, ask:

*How many of you noticed your scale flickering back and forth between one number and another? For example, the scale might read 120 … 119 … 120 … 119 … 120.*

*What do you think was happening?*

- The weight was in between two numbers and the scale does not show fractions of a gram. Even when the scale is not flickering, the weight it displays is always rounded to the closest gram.

*The focus question is, "How do you explain the difference between the weight of the completed lake and the weight of the sum of its parts?" Does this information about rounding help you to answer the focus question?*

- Weighing the whole lake gives us a more reliable weight because it involves just one measurement, which could be inaccurate by as much as a half-gram. Weighing each of the 5 components means that there are 5 measurements, each of which could be inaccurate by as much as a half-gram.

### Summarize the discussion and recap the investigation

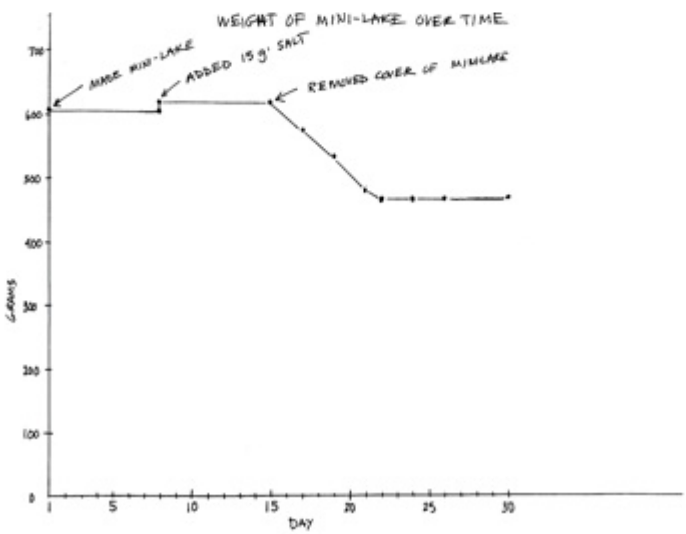
Using the same language students have used, summarize their main ideas. Include the following key ideas:

- The classroom scales do not measure fractions of a gram so they are always rounding to the closest gram. This rounding is a *possible source of error* when using the scales.
- Because every measurement can be as much as a half-gram different than the actual weight, the weight of the completed mini-lake is likely to be more accurate than the sum of the weights of the different materials.

As you recap the investigation, be sure there is understanding of these points:

- The mini-lake is a simple, small version of a real lake.
- Measurements of the weight and volume will help students keep track of any changes that may occur over time.
- Today students considered possible sources of error in their measurements. They will continue to keep sources of error in mind throughout the unit.

> **Weighing the Mini-lakes**
>
> Students are asked to weigh their mini-lakes in just 6 of the 18 Investigations. However, collecting weight data more frequently – even daily – will give students a more complete story of how this system changes over time.
>
> In Investigations 2, 5, and 7, the weighing is integral to the work, and should happen as part of those Investigations. Time for weighing the mini-lakes is also built into Investigations 8, 9, and 17, but the weighing is separate from the focus of those specific Investigations.
>
> If possible, except for Investigations 2, 5, and 7, have students weigh their mini-lakes before school, just before science class, or during lunch or recess. This will allow students to collect the additional data, and will open up more time for discussions or writing in Investigations 8, 9, and 17.




### A sneak preview:

The graph **Weight of Mini-Lake over Time** is an example of what students develop over the course of the next few weeks. Students add data points to the graph as they collect the data. They will not add explanation notes to the graph until after they have finished adding all of the data points.

---

### Before Investigation 4: Introduce 315 Dots Per Page

Sometime before Investigations 4 or 5, set aside five minutes, outside of science class, to introduce *315 Dots per Page*. Let this experience stand on its own for now. This gives students time to mull over the idea that when very tiny particles (or dots) are widely spread apart from one another, they are too small and too spread out to see.

When they get to Investigation 5, students find their experience with the dot sheets helpful as they try to explain why dissolved salt is invisible. The experience can also help them explain why water particles become invisible after evaporation.

## 1. Water, a Liquid: Investigation 3

# *How does water compare with sand?*

## Plan Investigation 3

In the previous investigation, students sought to explain a difference in weight between the entire mini-lake and the sum of its parts. In this investigation the issue of measurement discrepancy emerges again. The likely reason is a combination of factors: limitations of our measurement tools, and limitations of human perception.

Today, as students explore the ways in which sand and water are the same and different, they discover that a gram of sand has less volume than a gram of water. Sand is "heavy for size" in comparison with water. Students also discover that a gram of water has a volume of one cubic centimeter (and vice versa), but in the process they confront the fact that measurements do not always provide us with precisely accurate information about the quantity of matter we are investigating.

By the end of this investigation students will recognize that sand is "heavy for size" in comparison with water, that one cubic centimeter of water weighs one gram, and that the process of measurement includes taking into account possible sources of error.

### Learning Goals

- Understand that one cubic centimeter of water weighs one gram and one gram of water has a volume of 1 cubic centimeter
- Understand that measurement includes taking into account possible sources of error

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Share the data | Small Groups | 20 Mins |
| 3. Add properties to T-chart | Discussion | 5 Mins |
| 4. Make meaning | Individual | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Make a class T-chart titled, "Comparison of Water and Sand"; an example is found in Step 1.
- Make a class data table titled, "Weight and Volume of Water and Sand" with weight data entered and sorted in Column 2; an example is found in Step 2.

For each group:

- 1 capped vial completely filled with water
- 1 capped vial completely filled with sand

**Note:** If possible, have teams enter their data in Columns 1, 3, and 4 prior to the start of Investigation 3. Student data is found on the *[Making mini-lakes]* page in the Science Notebook.

## 1. Ask the question

All Class 10 Mins

Sand and water are two of the materials used in the mini-lakes. They are also components of real lakes. Today's investigation question is:

*How does water compare with sand?*

Have students address the question by thinking about ways in which water and sand are the same, and ways in which they are different. Use the T-chart to record their ideas.

**Comparison of Water and Sand (T-chart)**

| Same | |
|---|---|
| Both can be poured<br>Both have weight<br>Both take up space | |
| **Different** | |
| **Water** | **Sand** |
| transparent<br>liquid<br>etc. | opaque<br>solid<br>etc. |

## 2. Share the data

All Class 20 Mins Notebook

**Note:** The full class data set can reveal patterns about the weight-volume relationship of water and sand, but it can also present students with more information than they are ready to process. Using different colors to highlight the water data column and the sand data column will help students focus on just those columns. Before starting to discuss this data, hide the Sand Volume data, and focus on just the water data.

Remind students that they have already collected lots of data about water and sand as they made their mini-lakes. They continue to think about how sand and water compare as they analyze this collection of data.

If they have not already done so, students should record in the table their team initials and the volumes of water and sand they used in their mini-lake. Student data is found on *[Making mini-lakes]* page in the Science Notebook.

### Review the water data

Highlight rows in which the Weight and Water Volume *are the same*. If no team has the exact same value for the weight and volume of water, highlight the rows in which the values are closest. Ask students to focus on just those rows.

*What can you say about the weight and volume data in the highlighted rows?*

- The weight of the water and the volume of the water are the same number (or almost the same number).

*We see that (150g) of water take up (150cc) of space, and (120g) of water take up (120cc) of space. How much space do you think 50g of water will take up? (Or 1 g of water?)*

- 50cc (1cc)

*What do you notice about the rows that are not highlighted?*

- The weight and volume are not exactly the same number, but they are very close.

**Weight and Volume of Water and Sand**

| Team | Weight | Water Volume | Sand Volume |
|---|---|---|---|
| Team 1 | **150g** | 150cc | 94cc |
| Team 2 | **150g** | 149cc | 94cc |
| Team 3 | **150g** | 150cc | 92cc |
| Team 4 | **140g** | 141cc | 87cc |
| Team 5 | **140g** | 140cc | 88cc |
| Team 6 | **140g** | 140cc | 87cc |
| Team 7 | **130g** | 128cc | 82cc |
| Team 8 | **130g** | 130cc | 81cc |
| Team 9 | **130g** | 130cc | 81cc |
| Team10 | **120g** | 120cc | 75cc |
| Team 11 | **120g** | 120cc | 76cc |
| Team 12 | **120g** | 122cc | 75cc |

Interactive Table

Explain that making exact weight measurements is not always possible with our scales since these only measure to the nearest gram, so not all water data has the same number for weight and volume. The ones that are not the same are very close.

> **Note:** When scientists created the metric system, they decided that the weight of one cubic centimeter of water would be called a *gram*. Each gram of water takes up exactly one cubic centimeter of space.

### Use a concept cartoon

Give the class a few minutes to write a response to the concept cartoon *[Weight and volume data]* in the Science Notebook. Explain that the task is to figure out which two students in the concept cartoon investigated a sample of *water* and to explain the reasons they think so. This cartoon reinforces the fact that 1cc of water weighs 1 gram, and that small errors are typically a part of measurement.

### Review the sand data

Return to the class data. Reveal the Sand Volume column. Highlight the volume and the weight of sand in one row.

It may help students understand the organization of the data table if a volunteer reads the information provided in the row you have highlighted.

Example: Team 3 found a weight of 150g of water had a volume of 150cc. Team 3 found a weight of 150g of sand had a volume of 92cc.

*Does a 1g sample of sand have a volume that is equal to, more, or less than the volume of 1g of water?*

- Each 1g of sand takes less than 1cc. 150g of sand take up 92cc of space.

Point out that sand is heavy for its size compared with water.

*Whenever there are equal weights of sand and water, which will have a greater volume, sand or water?*

- water

**Review heavy for size**
Point out the containers of water and sand you have distributed. Ask students to take turns holding one in each hand and comparing the weights.

*How do the volumes compare?*

- The volumes are equal.

*How do the weights compare?*

- The sand is heavier than the water.

Point out that as long as the volumes are equal, sand is a material that is heavy for its size compared with water. For samples of any size - as long as the size of the samples is the same, sand will weigh more than water.

*Can you think of a material that might be heavier for size than sand?*

- solid rock (there are no air spaces between the particles), copper, steel

*Do you think it is possible to have a container of water that weighs more than a container of sand?*

- Yes, if you have a lot of water and a small amount of sand, the water will weigh more.

## 3. Add properties to T-chart

All Class 5 Mins

*How does water compare with sand?*

Add the new information that students have discovered as they analyzed the mini-lake data, in the T-chart, under *Different*:

- 1g of water equals 1cc (conversely, 1 cc of water weighs 1g.
- 1g of sand has a volume that is less than 1cc (conversely, 1cc of sand weighs more than 1g.)

### Define matter

Introduce matter. Explain that matter is anything that has weight and takes up space. Since sand and water both have weight and both take up space, both of them are considered matter. Add it to the T-chart, under Same:

- Both water and sand are matter.

The rocks, gravel, and the plastic box that are used in the mini-lakes are also matter. Some examples of things that do not have weight and do not take up space include a *sound*, a *shadow*, and a *dream*.

## 4. Make meaning

All Class 10 Mins

Remind students that this is the second investigation in a row where measurement data were actually different than what might have been expected. Direct their attention to the class table: three groups started with the same weight of sand but the measured volumes were not always the same.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Purpose of the discussion

The purpose of this discussion is for students to jointly construct explanations regarding the discrepant sand and water data they have collected, explanations that are consistent with their observations and evidence.

### Engage students in the focus question

*Our data show that when water samples have equal weights, the measured volumes are not always equal. The same is true for sand. What are some possible explanations?*

- The scales round measurements to the nearest gram
- There are limits to how accurately our eyes can see things.
- The way the water surface curves up when it touches the wall of the graduated cylinder makes it difficult to read the exact volume.
- When measuring the volume of sand, the surface is not perfectly flat, so it's difficult to see what the exact volume is.
- When the volume is more than 100cc's it has to be measured in two parts, because our graduated cylinders hold just 100cc. The small errors for each measurement are combined.

*Since small errors are just a part of making measurements, what are some things to do to get the most accurate data possible?*

- Measure very carefully to avoid the errors that are possible to avoid.
- Make the same measurement twice, or have two different people make a measurement.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas. Include the following key ideas:

- Small errors are just a part of measurement and very difficult to avoid.
- Some errors are caused by the equipment we use.
- Some errors occur because our eyes cannot see exactly what the measurement really is.

As you recap the investigation, be sure there is understanding of these points:

- 1g of water has a volume of 1cc and 1g of sand has a volume that is less than 1cc.
- 1 cc of water weighs 1g and 1cc of sand weighs more than 1g.
- Both sand and water are *matter* because they have weight and take up space.
- Small measurement errors are almost always present. Realizing this means we can be more prepared to notice patterns even when there are small variations in the data. For example, we realize that 1g of water has a volume of 1cc, even though some of the values for volume did not exactly match the values for weight.

---

### Reminder: Introduce 315 Dots Per Page

Don‘t forget a 5 minute introduction to *315 Dots per Page* prior to Investigation 4.

1. Water, a Liquid:  Investigation 4

# *What does a drop of water weigh?*

## Plan Investigation 4

How would we measure the weight of a single drop of water? When we put a drop of water on our classroom scale, it doesn't register any weight at all.

In this session students use a small dropper and a basic understanding of fractions to figure out the weight of a single drop of water. Why is this important? This starts a sequence of investigations in which students extend their understanding of what it means for an object to have weight. They progress from experience with objects that have clearly perceptible weight to objects for which weight is barely perceptible, such as a single drop of water. Eventually they consider particles too small to see, whose weight becomes apparent only when billions of them are present.

By the end of this investigation students will understand that when a sample of material is too small to weigh on their scales, they can use their knowledge of unit weight and volume to calculate the weight. They will also deepen their understanding that even the tiniest objects, such a single grain of sand, have weight.

### Learning Goals

- Understand that very small things have weight

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Develop a strategy | All Class | 10 Mins |
| 3. Explore | Individual | 15 Mins |
| 4. Share the results | All Class | 5 Mins |
| 5. Make meaning | All Class | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Make a class table titled, "What does a drop of water weigh?"; an example is found in Step 4.
- 1 digital scale


For each group:

- 2 12oz cups approximately1/2 full of water
- 4 1cc droppers (1cc small syringe)
- 4 centimeter cubes
- 4 paper towels

## 1. Ask the question

All Class 5 Mins

We know how to weigh the amount of water in our mini-lakes, but how could we weigh the water in a raindrop? Introduce today's investigation question:

*What does a drop of water weigh?*

Give students a chance to share ideas. Challenge students to help refine the question:

*Are all drops the same size?*

*What size drop of water do we weigh?*

*Can we control the size of a drop?*

*Can we rely on the classroom scale to provide the answer?*

Acknowledge that drops can be different sizes, and explain that the class has a tool–a dropper–that makes a drop of a certain size.

Show students the dropper. The class will address today's investigation question by determining the weight of a drop from this dropper.

Revise the investigation question to read:

*What does a drop of water from our classroom dropper weigh?*

Post the rephrased investigation question.

## 2. Develop a strategy

All Class 15 Mins

*Now that we've improved this question, how can we go about answering it?*

**Strategy 1: Use the scale.**

It's likely someone will suggest putting one or more drops on a scale. Explain that if we had more accurate scales, this strategy could work.

Demonstrate placing a single drop of water on the scale. The scale will not register any weight. Even when placing multiple drops of water on the scale, one drop at a time, it's unlikely these scales will register weight. If they did, the weight would be rounded to the nearest gram, providing inaccurate results.

Encourage students to come up with another strategy.

**Strategy 2: Use the information that 1 cubic centimeter of water weighs 1 gram.**

*There is a way to use something we discovered in the last investigation–that one cubic centimeter of water weighs one gram–to help us answer the investigation question. How might counting the drops in 1cc of water help us?*

*If we could make just 2 drops of water from one whole cubic centimeter of water, what would each of those drops weigh?*

*If we could make 10 drops of water from one whole cubic centimeter of water, what would each of those drops weigh?*

### Fill and weigh a dropper

Place one empty dropper on a classroom scale and read the weight (approximately 3g).

> *If I add exactly one cubic centimeter of water to this dropper, what do you predict it will weigh?*

Point out that the dropper has marks on it that allow us to add exactly one cubic centimeter of water. Demonstrate a standard procedure for accurately filling the dropper with 1cc of water:

- Push the plunger as far as it will go into the barrel of the dropper.
- Put the tip of the dropper in a cup of water and slowly pull on the plunger to completely fill the dropper.
- Point the tip of the dropper towards the ceiling and tap the barrel with a finger until all air bubbles have risen out of the water.
- Carefully depress the plunger until the black ring of the seal aligns with the 1cc mark.

Place the dropper on the scale again. It should weigh one gram more than its weight when empty.

### Demonstrate making drops

To answer the question, What does a drop of water from our classroom dropper weigh?, it's important that everyone use the same tool in the same way in order to get accurate results. Demonstrate a standard procedure to make drops:

- Hold the dropper vertically, tip down, about 1 inch above a desk top.
- Gently push the plunger to release one drop of water.
- Move the dropper sideways about 2 inches and release another drop.
- Form a line of 5 or 6 drops.

Keeping the drops separate from one another makes it possible to count them after the dropper is empty, in the event someone loses count while making the drops.

## 3. Explore

Individual 5 Mins

Distribute the materials. Students use the paper towel for drying desktops after counting the drops. The purpose of the centimeter cube is to show the volume of the 1cc dropper in another shape – to reinforce the size of 1cc of water. Each cubic centimeter takes up the same amount of space, as the one cubic centimeter of water students will add to their droppers.

Emphasize the importance of everyone using standard procedure for both filling and emptying the droppers. Ask students to practice once before they use the droppers to get a final count.

Students should make a long row of drops on their desktops as they slowly empty the dropper, keeping the tip about 1 inch above the desktop.

**Note:** Since the droppers can become a distraction, collect them as soon as students have completed their actual count.

## 4. Share the results

All Class 10 Mins Notebook

Survey the class for the results and enter their data in a class chart, asking each student to determine the weight of one drop once they provide the number of drops made.

**What does a drop of water weigh?**

| Weight of water | Number of drops | Weight of 1 drop |
|---|---|---|
| **1g** | 29 | $1/29^{th}$g |
| **1g** | 30 | $1/30^{th}$g |
| **1g** | 32 | $1/32^{nd}$g |
| **etc.** | | |

Address the investigation question:

*What does a drop of water from our classroom dropper weigh? Does a drop of water weigh more or less than one gram?*

- approximately $1/30^{th}$ of a gram?

Have students complete the Science Notebook page *[Reflecting on the weight of small bits of matter]*.

**Note:** Here is another example of small differences in a situation where one might expect everyone to get the same result. Students should understand the possible reasons for the differences and agree to select a "typical" value for the weight of one drop.

## 5. Make meaning

All Class 10 Mins

Acknowledge that students have just finished some interesting work; they used mathematics to figure out the weight of something that was too light for the classroom scale to sense.

### Purpose of the discussion

The purpose of this discussion is for students to jointly construct explanations for how objects such as a bucket of water or sand can have significant weight, given that a single drop of water or grain of sand has no perceptible weight.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Engage students in the focus question

*If a drop of water weighs just 1/30th of a gram, how do you explain why a bucket of water is so heavy?*

- There are many, many drops of water in a bucket full of water.
- Each drop contributes something to the total weight of the bucket of water.

Allow time for students to formulate responses. Engage all by asking for others to share their own explanations and to respond to the explanations of others.

*Do you think a single grain of sand weighs anything? Explain your answer.*

- If students claim "yes", what reasoning can they provide to support their claim?
- If students claim "no", ask for the explanation; it will help you determine whether students are focusing on whether a grain of sand will register any weight on the scale, or if students believe a grain of sand has no weight.

*How does a bucket of sand get to be so heavy when a grain of sand weighs so little?*

- There are many millions of grains of sand in a bucket, with each grain contributing a tiny bit of weight to the total weight of the bucket of sand.

*Can you think of other examples of tiny bits that seem to have no weight individually, but that can be combined together to have significant weight?*

- Grains of sugar or salt; particles of flour.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas. Include the following key ideas:

- If a large collection of grains of sand (or drops of water, etc.) have weight, then we can reason that each individual grain must have some weight, even if that weight is too small to sense or measure.
- Although individual grains of sand or drops of water may have imperceptible weight, combining millions or billions of them together can result in significant weight.

Recap the following:

- Tiny things, such as drops of water, are not heavy enough to register weight on the classroom scales.
- We've figured out how to calculate the weight of a water drop and concluded that tiny things such as single drops of water or grains of sand actually have weight.

When we think about how heavy a bucket of water feels, or a bucket of sand feels, it can make us wonder, "How many of those drops, or grains, are there in a bucket, to make it feel so heavy?"

## 1. Water, a Liquid: Investigation 5

### *What changes and what stays the same when salt dissolves in water?*

## Plan Investigation 5

Start with a single grain of typical table salt. Divide it into a billion equal-sized pieces, and then divide just one of those billion pieces into a billion equal-sized pieces. If you do this carefully, each of those smallest pieces will be the size of a single molecule of sodium chloride, the substance we call salt. Is a molecule of salt smaller than you thought? Do you think it weighs anything?

Yes, the 4-pound box of table salt has weight because each of the more than 22.5 million grains of salt in the box has weight, and each of the grains has weight because each molecule of salt has weight. This unit does not address the concept of molecules, but it does continue one important idea that students have been building over the past few sessions: very tiny things have weight.

Today we extend the idea that there is power in numbers. When students grind up kosher salt, the size of each piece decreases but the number of pieces increases; the weight *does not* change. The same thing happens when dissolving salt in water: the pieces become extremely small (too small to see), but when students weigh the container and salt before and after dissolving they discover that the weight does not change. The dissolved salt maintains its weight.

**Formative Assessment**

*Have your students collected accurate weight and volume data that they use to support a claim about what happens to salt when it dissolves in water?*

Available online at inquiryproject.terc.edu

By the end of this investigation students will understand that tracking the weight of a substance as it is transformed through crushing and dissolving can provide clues about what is happening. They will deepen their understanding that small things have weight and take up space and, that if the weight of a sample is unchanged, the amount of matter must be conserved.

### Learning Goals

- Understand that weight stays the same as a substance is dissolved
- Understand that things too small to see have weight and take up space

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Explore | Individual | 5 Mins |
| 3. Demonstrate dissolving | All Class | 5 Mins |
| 4. Dissolve salt in water | Pairs | 20 Mins |
| 5. Make meaning | Discussion | 10 Mins |

## Materials and Preparation

Preparation:

- Review *315 Dots per Page* (See Resource Quick Links)
- Measure and post the tare weight for a clear plastic 12oz cup.

For the class:

- Post the investigation question in a place where all students can see it.
- Dot Sheet 1 and Dot Sheet 2 (See Resource Quick Links)
- 1 12oz clear plastic cup approximately 1/2 full (approx. 160g) with water
- 1 12oz clear plastic cup holding 2 rounded teaspoons (approx. 20g) of kosher salt

For each group (first set of materials, for exploring salt):


- 1 12oz clear plastic cup holding approximately 1 teaspoon kosher salt
- 4 magnifiers
- 4 plastic spoons

For each group (second set of materials, for dissolving salt in water):

- 1 digital scale
- 2 12oz clear plastic cups, each approximately 1/2 full (approx. 160g) of water
- 2 12oz cups, each holding 2 rounded teaspoons (approx. 20g) of kosher salt
- 2 paper towels
- 2 short pieces of masking tape

For each group (third set of materials, for use with mini-lakes):

- 2 12oz cups, each holding 2 rounded teaspoons (approx. 20g) of kosher salt

> **Note:** Kosher salt, unlike typical table sat, contains no iodine or anti-clumping additives and so leaves water completely clear after it fully dissolves.

## 1. Ask the question

All Class 5 Mins

Students will continue to explore very tiny pieces of matter, pieces that can be smaller than most drops of water, and sometimes smaller than grains of sand. The substance they will investigate today is salt. Today's investigation also introduces *transformation*, or change, something students will continue to study throughout the curriculum, particularly transformations of water.

Today's investigation question is:

*What changes and what stays the same when salt dissolves in water?*

## 2. Explore

Individual 5 Mins

Before dissolving salt, students will spend a few minutes exploring it.

> **Note:** Allow no more than 2 minutes for each of the explorations in this section.

### Closely observe salt

Distribute the first set of materials.

Have each student take a small pinch of salt from the cup, place it on the desk, and examine the grains with a magnifier. Encourage students to look for the tiniest grains they can find in their pinch of salt.

*What do you see?*

- differences in particle size; some much smaller than others

If students have closely observed table salt, they will notice that kosher salt does not have the same cubic form as table salt.

### Transformation by crushing

Demonstrate how to crush salt with the bowl of the plastic spoon without snapping the spoon, by pressing with a finger in the bowl of the spoon.

Have students crush the salt on their desks and inspect it again using their magnifiers. Ask students to look for the smallest pieces of salt they can find.

*What changes and what stays the same when you crush salt?*

- Particle size has decreased; some are very tiny.
- The number of particles has increased.
- The tiny pieces are still salt.
- The total amount of salt remains the same.

*Do you think each grain of salt has weight? Even the tiniest pieces?*

- Yes

*How would you convince someone that a grain of salt has weight? How could you prove it?*

- *See the introduction to this session for a possible argument.*

*Do you think salt is matter? Why?*

- Salt is matter because it has weight and takes up space.

## 3. Demonstrate dissolving

All Class 5 Mins

**About Solutions**
*(background for teachers and not students)*

When one substance dissolves in another, the resulting mixture, called a *solution*, is homogeneous – the concentration of each substance is the same throughout – and gravity will not cause the two substances to separate. Solutions do not appear cloudy.

Salt dissolves in water up to a point when the solution becomes *saturated* (38 grams of salt per 100 grams of room temperature water). Beyond the saturation point, excess salt will not dissolve; it will remain visible as grains of salt.

Salt or other dissolved solids will return to their solid state as water evaporates. Dissolving is reversible because the substances (in this case, water and salt) do not combine through a chemical reaction.

Cocoa does not dissolve in water; it remains suspended in the water for a period of time but eventually will settle to the bottom.

Remind students of the investigation question:

*What changes and what stays the same when salt dissolves in water?*

Are students familiar with the term dissolve? Ask for their ideas.

Pour 20 grams of salt into a 12oz cup half filled with water and stir.

*What are your observations? Is the salt still in the water? How would you know?*

- Taste might be helpful, but can't be done in school. (Also, taste cannot indicate how much of the original salt is still in the water.)
- Evaporate the water, but that will take a long time.
- Weigh the materials prior to and after dissolving the salt.

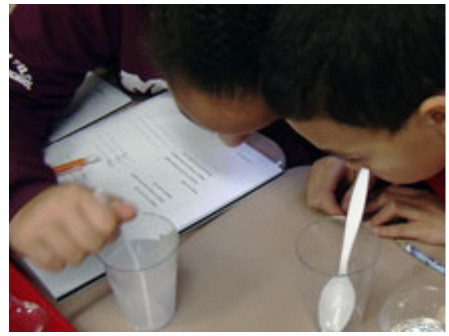
Once students understand that tracking the weights is the most reliable way to understand if dissolved salt is still in the water, they can move forward with their own exploration.

**Note:** Caution students to never to put anything in their mouths in class. Although the water, salt, and cups are probably clean and safe, do not taste.

## 4. Dissolve salt in water

Pairs 20 Mins Notebook

### Tracking dissolved salt using weight



Distribute the second set of materials to the groups.

The Science Notebook page *[What happens when salt dissolves in water?]* will guide students through the process of weighing the water, salt, and the water with the salt added, and tracking changes in the volume.

- Review the concept of tare weight. Call attention to the tare weight of the cup, which you have posted.
- Show students where to put a piece of masking tape on the water cup so they can mark the water level *before* adding the salt.
- Review the notebook page that sets out the procedure for recording the weights. The weight data will be numerical (grams); the volume data will be visual (labeled drawings).
- Students will discuss their findings after they weigh their mini-lakes.

As students finish collecting and recording the data, collect the 12oz cups of salt water and have students get their mini-lakes.

### Transforming mini-lakes to Salt Lakes

Students have probably heard about the Great Salt Lake in Utah. They'll now have the opportunity to transform their mini-lakes into Mini Salt Lakes by adding two teaspoons of salt.

Tell students they'll need to weigh their mini-lakes twice: once before adding the salt and once after adding the salt.

Distribute the third set of materials, 1 12oz cup holding approximately 20g of salt, to each pair.

Each pair:

1. Weigh mini-lake and record weight in Science Notebook.
2. Pour salt into mini-lake. **Don't stir.**
3. Re-weigh mini-lake and record weight in Science Notebook. Add a note about addition of salt.
4. Calculate the weight of the salt added to the mini-lake and record in Science Notebook.

*What weight of salt did you add to your mini-lakes?*

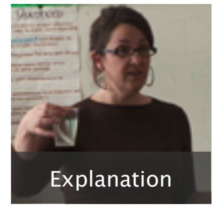
## 5. Make meaning

Discussion 10 Mins

### Purpose of the discussion

The purpose of this discussion is for students to connect the investigation question with the weight and volume data they have collected by making claims and describing the supporting evidence.

**Classroom Case**




The Role of Explanation Discussions

Available online at inquiryproject.terc.edu

*Claims and evidence:* Introduce the scientific practice of supporting claims with evidence. Whenever students make a claim, they are expected to describe the evidence that supports the claim.

> Evidence is data that supports or challenges a claim and is often in the form of a measurement or a drawing or photograph.
>
> Sometimes the only way to support a claim is by reasoning. While reasoning is important, it is not always as convincing as actual data.

*Example:* I see that the scale reads zero when I put a grain of salt on it, but I know that a full container of salt weighs more than an empty container of salt, so I reason that each grain of salt must have some weight.

Students should also start to distinguish between evidence and their own ideas or opinions.

### Engage students in the focus question

*What changed and what stayed the same when the salt dissolved in water? What evidence supports your claim?*

Possible responses include:

- The weight of the salt remains the same, even after it dissolved and the particles became too small to see. (Evidence: the combined weight of salt and water equals the sum of individual weights of the salt and the water).
- The salt continues to take up space, even after it dissolved and the particles became too small to see (Evidence: the combined volume of the salt and water is greater than the volume of just the water).
- Salt remains matter after it has dissolved and can no longer be seen. (Evidence: Dissolved salt has weight and takes up space.)
- The size of the salt grains changes, becoming too small to see. (Reasoning: The weight data lets us know that the salt is still in the water, and we know we cannot see the particles).
- The number of salt particles changes. (Reasoning: Data tell us that the weight of the salt remains the same. Since we reason that the particles have become smaller, there must be more of them.

**Note:** As students address the focus question, be sure they are referring to the data they have collected in their notebooks.

*Why do you think the salt is no longer visible? How do you explain this? (If not previously addressed)*

- The salt particles became smaller and smaller as they dissolved until they became too small and too spread out to see. Like the dots on the *315 Dots per Page* sheet, when tiny particles (or dots) are clustered they are visible but when they spread out enough, they become too hard to see.

*Note:* One might claim that the salt particles remain the same size but just become "invisible" in the water. Our sense of touch can provide evidence that the dissolved grains no longer exist at the same size.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas. Include the following key ideas:

- Remained the same: weight of salt, and the fact that the salt still takes up space (although actual volume was not measured)
- Changed: The salt is no longer visible. The grains became too small to see when they dissolved.

As you recap the investigation, be sure there is understanding of these points:

- Students' work in this investigation highlights the importance of accurate measurements.
- When students make claims, they need to support those claims with evidence or with reasoning.
- Today's investigation provided evidence that:
  - Weight stays the same as a substance dissolves.
  - Things too small to see have weight and take up space.
- The concept of matter too small to see continues as a theme throughout the rest of this unit.

# 2. Water to Vapor

This set of investigations focuses on what happens to water when it evaporates.

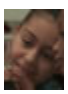
When water evaporates from a paper towel, what happens to it? Does it go somewhere else, or is it destroyed, gone forever? A closed system of two connected bottles allows students to investigate this question. The system also highlights the cycling from liquid water to water vapor and back to liquid water again (condensation). After it has become obvious that every drop of water in the lower bottle has evaporated, it reappears in a different part of the system.

At the same time students start tracking evaporation in the 2-bottle system, they uncover and keep track of changes in their mini-lakes.

### Investigations:

- Investigation 6: What happens to the water?
- Investigation 7: What happened to the water?
- Investigation 8: What is happening in the 2-bottle system?
- Investigation 9: Why do the water drops form?

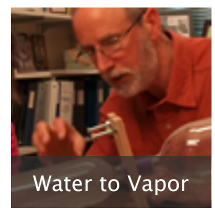
### The Child and the Scientist



**The Child:** The Challenges of Learning about Evaporation and Condensation

**The Scientist:**
What's important about evaporation and condensation?

**Scientist Case**




Watch Roger Tobin doing the Water to Vapor Investigations

Available online at inquiryproject.terc.edu

**The Child's Ideas for *2. Water to Vapor***

# The Challenges of Learning about Evaporation and Condensation

> *The idea that water vapor exists in the air as an invisible odorless gas (distinct from steam) strains their imaginations.*

Children have many experiences with evaporation and condensation in their everyday lives. The puddles that dot the street after a morning rainstorm may be gone by late afternoon. What happened to all that water? Dew appears on the grass each morning; little “beads of sweat” form on the outside of cans of soda on hot humid days; and the bathroom mirror fogs up after taking a shower. Where do the dew, sweat, and fog come from?

Explaining all these mysterious things, in ways that rigorously account for all the available evidence, is particularly challenging for children because they must use the existence of invisible entities—gases—which they do not clearly understand and may not even believe exist—to explain visible events. Further, because children know so little about gases and how they behave, it is hard for them to generate plausible mechanistic explanations.

Instead, children initially provide much shallower explanations, ones that posit a closer match between how things appear and how they are. So if the puddle disappears, then the water must be gone. Some may say that the water has “gone into the air” or even use the word “evaporated.” What they mean by that, however, isn't that the water has transformed into a water vapor gas, which is in the air, but somehow has become ethereal like the air. They no longer think it retains its identity as water.

Further evidence that they don't believe air contains a distinct water vapor gas is the much greater difficulty they have explaining condensation than evaporation. They go to great lengths to find visible sources for the dew, sweat, and fog—proposing that it rained last night or that water seeped through (or over) the glass. The idea that water vapor exists in the air as an invisible odorless gas (distinct from steam) strains their imaginations.

Clearly, explaining evaporation and condensation go hand-in-hand with each other as well as with developing an understanding of the material nature of gases and the particulate nature of matter. It is important that these ideas are all developed together, rather than treated in isolation, because they are mutually reinforcing. Without considering condensation as well as evaporation, students are not challenged to think of water vapor as an invisible gas, pre-existing in the air. Without considering the particulate model, including the idea of particles in motion, children have no mechanistic way to explain what is happening and no way to envision the invisible. Models help make the invisible more visible and real to students, facilitating using invisible entities in meaningful real-world explanations.

—Carol L. Smith

**The Scientist's Essay for *2. Water to Vapor***

# What's important about evaporation and condensation?

> *Condensation provides another clue about where the water goes, by showing, indirectly, that there really is "water" in the air, even though we can't see it.*

Evaporation really seems like magic. You leave some water in a glass, or a small puddle on a stone countertop, and when you come back later it's just disappeared. You didn't see it leave, and you can't see it anywhere now that it's gone, and it doesn't seem like you can get it back. Probably the most important thing about evaporation, then, is that in fact *nothing* has been lost, the matter *is* still around somewhere, and the process *can* be reversed. You can't see the water that used to be in the puddle, but those molecules still exist.

The evidence for these bold assertions is rather indirect, and may not be entirely convincing at the level of precision we can attain in the classroom. In a closed system — one that doesn't allow any matter to come in or go out — the water that "disappears" from one part of the system can "appear" somewhere else. We may not be able to see exactly how it got from one place to the other — in the vapor phase it was invisible to us — but we can infer that it must have been there. The weight of the system also remains constant in this process, showing that the total amount of "stuff" in the system didn't change. (Our two-bottle system isn't perfectly closed — water vapor can actually pass through the plastic at a slow but measureable rate, especially when the plastic is warm, so over the course of a few days the weight drops by a few grams. This caused us quite a bit of puzzlement until we figured out what was happening!)

Condensation provides another clue about where the water goes, by showing, indirectly, that there really is "water" in the air, even though we can't see it. Where else can the beads of water on the outside of a cold glass come from? It's interesting to think of tests, or experiences, to rule out other possibilities — for example, that it's the liquid from inside the glass that somehow appears on the outside.

These phenomena are not unique to water. Alcohol, for example, evaporates more readily than water, a phenomenon that's exploited in making distilled liquor. But everything evaporates, even solids — just the rate is usually extremely low at normal temperatures.

On the microscopic level we think of evaporation as a process in which an occasional molecule in the liquid (or solid) happens to get enough energy from random thermal motion to break its bonds to its neighbors and escape. It's not a collective phase transition, like melting, freezing, or boiling, so it happens at any temperature (just much faster at higher temperature). Condensation is the opposite — when a molecule in the vapor hits a cool surface, it can lose enough energy to reconnect with and be trapped by the neighboring molecules.

—Roger Tobin

# *What happens to the water?*

## Plan Investigation 6

Evaporation happens before our very eyes – the fog on the bathroom mirror clears, our clothing dries, the puddle on the sidewalk shrinks. What happened to the water? And *how* does evaporation happen anyway? What makes it possible?

There are some connections between evaporation and the salt that students dissolved in the previous investigation. In both processes, matter separates itself into particles that are too small to see. Also, in both processes, weight can be used to track the presence (or absence) of these particles.

Students will not arrive at definitive answers about the evaporation process today, but after they observe the evaporation of water from a paper towel and from the surface of a plastic cup, they start to propose explanations based on their observations, prior experiences, and reasoning.

By the end of this investigation students will have formulated their initial ideas through an annotated drawing about what happens to water when it evaporates.

**Formative Assessment**

*What do your students' think happens to water drops when they disappear from the outside of a cup?*

Available online at inquiryproject.terc.edu

### Learning Goals

- To express initial ideas about the process of evaporation

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Explore | Individual | 10 Mins |
| 3. Make annotated drawing | Individual | 15 Mins |
| 4. Make meaning | All Class | 10 Mins |

### Materials and Preparation

Preparation:

- Read *Annotated Drawings* (See Resource Quick Links). Create an *Annotated Drawings poster*. Save poster for reuse in later investigations.

For the class:

- Post the investigation question in a place where all students can see it.
- 1 spray mister filled with water
- 1 paper towel

For each group:

- 1 12oz cup approximately 1/4 full of water
- 1 6in strip of masking tape
- 4 1cc droppers (1cc small syringe)
- 4 paper towels
- 4 magnifiers
- 4 12oz clear plastic cups


## 1. Ask the question

All Class 10 Mins

In the previous session students investigated the transformation of salt from a solid granular material into something they could no longer see. They could infer from weight measurements that the salt was still present.

Review with students some of the important ideas from the last investigation when salt was dissolved.

- When salt dissolves in water it separates into particles too small to see.
- We can use weight as evidence that salt is still there, even if we can't see it.
- The salt particles take up space, even though they are too small to see.
- Each particle became smaller, but since the weight remained the same, the number of particles must have increased.
- Salt is matter before it is dissolved and it is still matter after it dissolves.

Connect today's investigation to the previous one. Today, the class will investigate another kind of transformation with some similarities to salt dissolving in water. Elicit students' ideas on evaporation with the following question:

> *Think about the puddles you see on the sidewalk or in a parking lot after it rains. Do these puddles stay there forever? What do you think happens to the water?*

- The puddle evaporates because the sun dried it up and it is now simply gone.
- The puddle has turned in to clouds.
- The puddle is in the air.

Explain that the class will continue to work with water, and that over the next few investigations they'll be taking a closer look at what happens when water disappears.

Introduce the investigation question:

*What happens to the water?*

Demonstrate the following for students:

- Soak one paper towel and squeeze it gently to remove any water not fully absorbed by the paper, so no drops will drip from the wet towel.
- Weigh the wet paper towel.
- Announce the weight to students.
- Drape the wet towel over something where it can remain until later in the class.

## 2. Explore

Individual | 10 Mins | Notebook

Distribute a set of materials to each group.

### Drops on a paper towel

Have each student:

- Use the droppers to put 4 drops of water (spread apart) on a paper towel.
- Tape a corner of the paper towel to the edge of the desk, so it hangs freely over the side.

### Mist on a plastic cup

Have each student hold up an empty 12oz plastic cup. With the spray mister about 12 inches away, spray the outside of each student's cup. These drops are very tiny compared with the drops students placed on the paper towels.

Have students inspect the drops carefully with their magnifiers.

*Think of these drops as very tiny puddles. Is anything changing?*

Ask students to find the *smallest drop they can see* and stare at it for a while. The drop will become smaller and should *disappear as they watch*.

Have students record their observations on *[What happens to drops of water?]* in their Science Notebooks.

## 3. Make annotated drawing

Individual | 15 Mins | Notebook

Students will now address the investigation question, *What happened to the water?*, by making a special type of drawing called an annotated drawing. Scientists use annotated drawings to explain something they have not been able to directly observe. It allows them to share their best thinking and reasoning about how something happens.

Students have observed that mist sprayed on the side of the cup disappears. They have not observed exactly what happens to the water once it has disappeared, so their explanations will have to depend on their *reasoning* about what they think happened. They develop and share their explanation by making their own annotated drawing.

Refer students to the sheet labeled *Annotated Drawings* at the back of the Science Notebook. The sheet highlights the important elements of an annotated drawing.

Review the key points of an annotated drawing with them, and then put the Annotated Drawings poster in a place where all students can see it.

On the notebook page *[What happens to drops of water?]*, students make an annotated drawing that explains what happened to the water that disappeared from the side of the plastic cup.

As students are working, circulate among them to get a sense of the range of ideas they are developing. This can help you to highlight some contrasting ideas during the discussion.

## 4. Make meaning

All Class 10 Mins

Ask students to check their paper towels.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Purpose of the discussion

The purpose of this discussion is for students to construct explanations of what happened to the drops of water, explanations that are consistent with their observations and evidence.

### Engage students in the focus question

*What happened to the drops of water you put on the paper towels, or that I sprayed on the plastic cups? Does water still exist after it disappears, or has it been destroyed?*

**Note:** If students claim that the water evaporated, ask what the term evaporated means to them. The goal is to have students move past simply using a term and to describe what they think has become of the water. Where is the water that is no longer on the cup or on the paper towel?

Provide time for students to consider their position and the reasoning to back it up. Students may offer the following:

- The water has moved into the air. (Students may suggest that the existence of clouds supports this claim.)
- The water has moved from the surface to inside the plastic or inside the paper. (What evidence can students point to to support this claim?)
- The water is gone; it no longer exists.

*If the evaporated water still exists, and where do you think it is now?*

*If the evaporated water still exists, why can't we see it?*

*Who thinks water is destroyed by evaporation and why do you think so?*

Remind students to support their position with evidence or reasoning. They should refer to their annotated drawings and notebook entries as they make their claims and provide their reasoning.

*Weigh the paper towel:* If some students think the water has moved inside the plastic or paper, weigh the paper towel saturated at the start of the investigation. Very likely it is now dry or almost dry. The weight measurement, which should be 3g to 5g less than the wet weight, provides evidence that evaporated water does not move from the surface of a material to inside of it.

*How might we test the idea that the water still exists after it evaporates, or that evaporation destroys water?*

- Make evaporation happen in a closed system, and look for evidence that the water still exists.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas. Include the following key idea:

- The only evidence we have is that evaporated water does not just move from the surface to the inside of a material. The weight of the saturated paper towel became less as water evaporated.
- There is no clear answer to the question of whether or not evaporated water has been destroyed, but the class will continue to explore that question in the science classes that follow.

As you recap the investigation, be sure there is understanding of these points:

- Today you watched as drops of water on a plastic cup became smaller; some disappeared.
- You also put drops of water on a paper towel, which also disappeared.
- This disappearance of water in the classroom matches other experiences you have had: wet clothing dries; rain puddles disappear.
- We can claim that evaporated water does not move from the surface to inside a material. The evidence for this is that the weight of the paper towel became less as water evaporated from it.

## 2. Water to Vapor: Investigation 7

# *What happened to the water?*

## Plan Investigation 7

Today students are introduced to three *closed systems*, called 2-bottle systems. These systems will allow them to investigate what happens to water once it evaporates. Does evaporation destroy water, or can students find evidence that it still exists, as they did to see if dissolved salt still exists?

One system holds fresh water and a sand-gravel-rock mix, one holds salt water, and one holds blue-tinted fresh water. Read more information about the 2-bottle system below.

By the end of this investigation students will understand how a closed system can provide evidence to help us explain a process we can't observe directly.

### Learning Goals

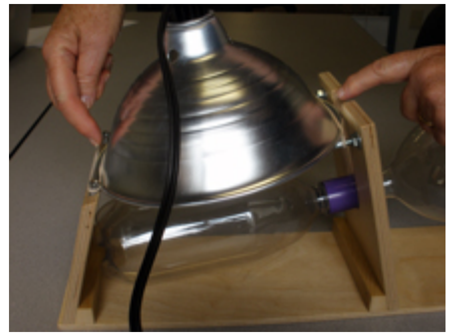
- Understand the difference between an open system and a closed system

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Uncover the mini-lakes | Pairs | 15 Mins |
| 3. Introduce the 2-bottle systems | All Class | 15 Mins |
| 4. Observe and predict | Individual | 10 Mins |

### About the 2-bottle system

The 2-bottle system is made of a 1-liter plastic bottle coupled to a 2-liter plastic bottle and held in position by a small stand. The system helps students deepen their understanding of the phase changes that are part of the water cycle, specifically the relationship between liquid water, evaporation, water vapor, and condensation. Three 2-bottle systems are used in this investigation.

Each of the lower, smaller bottles starts with 30 grams of water plus one other material (a sand-gravel mix, kosher salt, or blue food coloring). The inside of each lower bottle represents Earth's surface with an atmosphere and a body of water, and is warmed by a lamp. Each upper bottle initially contains only air. The upper bottle represents a "different place" to which water can travel in its vapor form, condense, and collect. It prevents evaporated water from just disappearing into the classroom air. Within approximately one week (if the lamps are left on continuously) *all* of the water in the warmer lower bottle will evaporate, and will condense and collect in the cooler upper bottle.

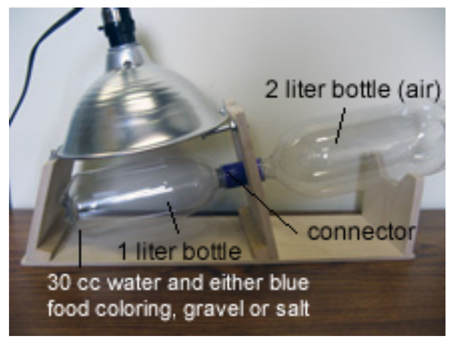


**Why use a lamp**, when evaporation can take place even at cooler temperatures? The 2-bottle system is a very tiny closed system in comparison with the system it attempts to model, which is the closed system of Earth and its atmosphere. The limited amount of air inside the bottles becomes extremely humid once evaporation starts. Such high humidity would slow and eventually stop net evaporation long before the water has completely evaporated from the lower bottle. The purpose of the lamp is to force evaporation to continue in spite of the high humidity in the closed 2-bottle system. Having all of the water in the lower bottles move to the upper bottles, leaving the sand-gravel mix, the salt, and the blue food coloring in the lower bottles, highlights the role that evaporation plays in the real world.

The bases that support the bottles also hold the lamps in the correct position. Set up as shown, and using a 100 watt bulb as specified, the lamps can safely remain on 24 hours a day. Turning the lamps off each night will dramatically extend the amount of time required to transport all of the water from the lower bottle to the upper bottle. We recommend turning the lamps off for school vacation periods.

### Materials and Preparation

Preparation:




- Assemble three empty 2-bottle systems by connecting a 1-liter bottle and a 2-liter bottle using the special connector. Place each 2-bottle system in a base. Label one base lake materials, one base salt water, and one base blue water.
- Establish locations in the classroom where you can leave the three 2-bottle systems under their lamps. As necessary, set up the extension cords for plugging in the lamps. If necessary, the bottle systems can be moved to a more accessible location when students observe them closely and make drawings, but it's better if students can observe them without the systems being moved.

For the class:

- Post the investigation question in a place where all students can see it.
- 1 funnel; conical paper cup with 1/2" snipped off the end
- 6 rubber bands
- 3 1-liter plastic bottles
- 3 2-liter plastic bottles
- 3 plastic bottle connectors
- 3 bottle system bases
- 3 assembled aluminum reflector lamps (**Use only incandescent 100 watt bulbs**)
- extension cords as needed (not included in kit)
- 1 12oz cup holding 30g of a sand-gravel mix
- 1 12oz cup holding 5g of kosher salt
- 3 12oz cups holding 30g of water
- blue food coloring

For each group:

- 2 mini-lakes (from Investigation 1)

### Concept Cartoon

The Evaporation Concept Cartoon is typically used as a formative assessment at the end of this investigation.

## 1. Ask the question

All Class 5 Mins

In the previous science class students may have taken the position that water continued to exist after evaporation, or that it was destroyed by evaporation. Their claims were supported by reasoning but not by evidence. Today they'll continue to investigate the question:

*What happened to the water?*

Using their mini-lakes and the 2-bottle systems, students will make observations they can use as evidence.

## 2. Uncover the mini-lakes

Pairs 15 Mins Notebook

Students consider the following:

> *Look in your Science Notebooks at the weight data you have collected for your mini-lakes. What has happened so far?*
>
> *What do you predict will happen to the mini-lakes during the next week if they are left uncovered?*
>
> *What evidence would need to be collected in order to test your prediction?*

Students record their prediction and explain their reasoning and describe the evidence they'll collect to test their prediction on the *[Uncovering the mini-lakes]* page in their Science Notebooks.

When they finish, students weigh the mini-lakes with the covers still on, and record that weight in the data table and on the graph. They then remove the covers. *The weight of the covers should still be included each time students weigh the mini-lakes in the future.*

## 3. Introduce the 2-bottle systems

All Class 15 Mins

Return to the investigation question:

*What happened to the water?*

Show students one of the 2-bottle systems, without the lamp.

The 2-bottle system is a *closed* system. Elements inside the system will remain there, and nothing new will be added to the system. The mini-lakes with the covers off are *open* systems. The concept of systems will be introduced in Investigation 8.

The class will have three different closed systems to observe. The lower bottle of each system represents a mini-lake or a real lake. It will hold **water** plus one other material.

The upper bottle in each system represents the air in the room, or the air that makes up Earth's atmosphere. Each upper bottle will start off holding just air.

Share with students that evaporation happens slowly when the air above the water is very humid. The lamp will be used to add heat and cause evaporation to happen more quickly in the 2-bottle system, even after the air inside the bottles becomes very humid. Show students a lamp and how it is added to the 2-bottle system.

Remind students that no extra heat was added to the paper towels or the plastic cups (in the previous investigation) while the drops of water were evaporating from them. Water can easily evaporate at cooler temperatures when it is not sealed in a closed system.

### Add materials to the 2-bottle systems or show the prepared systems

> **Note:** When adding materials to the 2-bottle systems and when moving them once they hold the materials, work carefully to keep the materials from splashing around inside the bottles. Drops of sandy, salty, or blue-colored water that are splashed around will leave deposits that may later lead students to conclude that sand, salt, or food coloring has evaporated.

As you work, describe the materials in each of the 2-bottle systems.

- Add the sand-gravel mix to a 1-liter bottle using a paper funnel. Add the 30g of water, close the system, and set it on its stand. These are the same materials used in the mini-lakes.
- Mix 5g of salt with 30g of water, add it to a 1-liter bottle, close the system, and set it on its stand.
- Dissolve 5 drops of blue food coloring in 30g of water and add it to a 1-liter bottle. Close the system and set it on its stand.

> **Note: Do not add the lamps** to the systems until after students have made their initial observations and predictions in Part 4. Evaporation and condensation will start shortly after the lamps have been turned on.

## 4. Observe and predict

Individual 10 Mins Notebook

Set up the three systems in a place where 8 students can comfortably observe each. These do not need be the same locations where the lamps are set up.

Assign one third of the class to be responsible for observing and reporting on one system, throughout the investigations. This is their "home" 2-bottle system. Students can also observe the systems for which they are not responsible.

Students annotate the line drawing of their "home" 2-bottle system on the *[2-bottle closed systems - Initial Observation]* page in their Science Notebooks. Refer students to *Annotated Drawings* at the back of their Science Notebooks for tips and reminders about making this kind of drawing.

Students use a **second** line drawing *[Predict what will happen in the 2-bottle system?]* to predict what their "home" 2-bottle system might look like in one week. The drawing will describe any changes they think might occur and explain the reasoning behind their predictions.

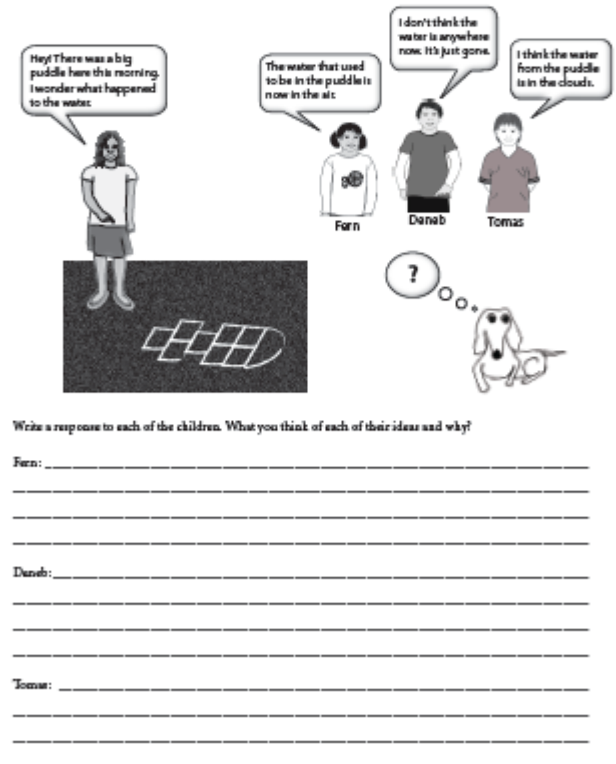
When students finish, put the lamps on the stands, secure them with rubber bands, and turn them on.

# Evaporation Concept Cartoon

This cartoon was developed to assess students' ability to:

- Explain the phenomenon called evaporation. During evaporation, water changes from the liquid to the vapor phase. Children have many experiences with evaporation in their everyday lives. However, explaining what has happened to the water is particularly challenging when they know very little about gases and how they behave.

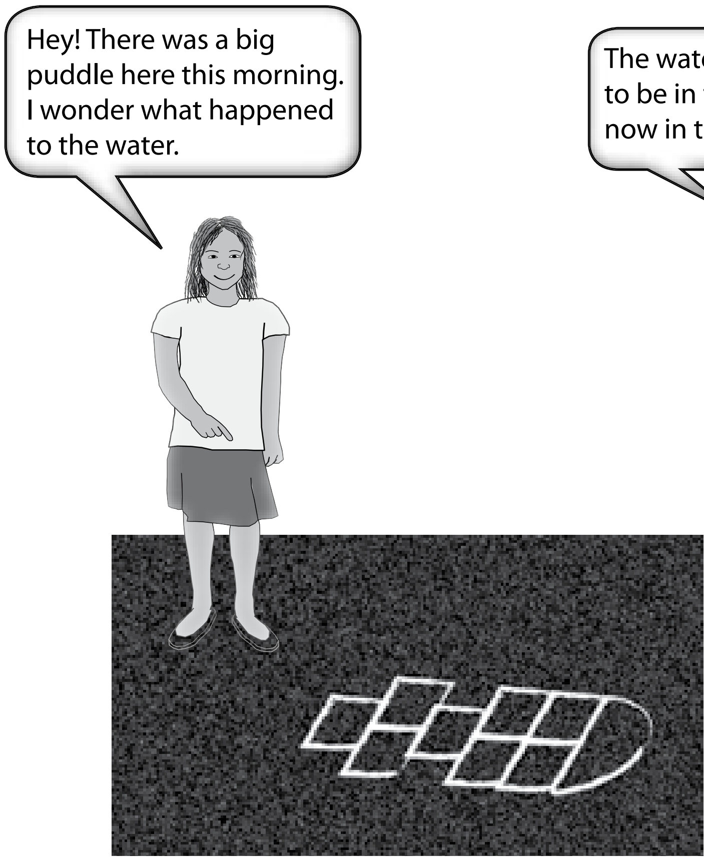
This cartoon is typically used after Investigation 7, *What happened to the water?*

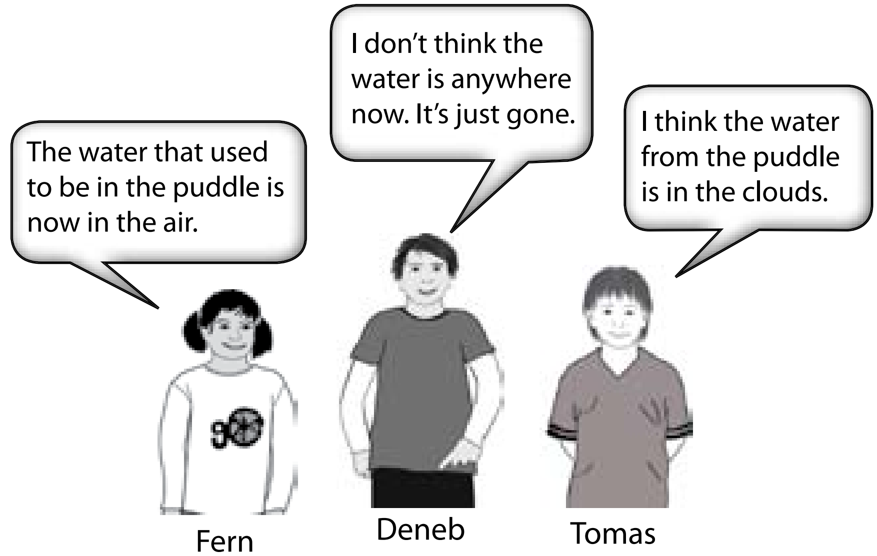


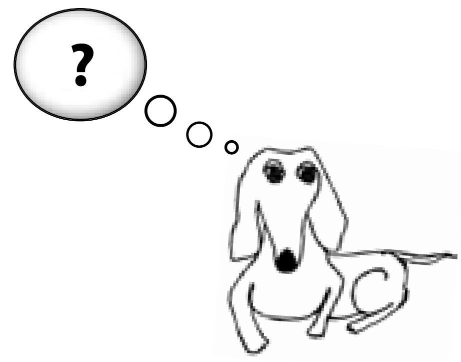

## Things to look for in student responses

Do students realize that the water from the puddle is now in the form of water vapor, a gas that is part of air?

- Some students may agree with Fern that the water in the puddle is made of particles that have escaped from the puddle, moved apart, and are now spread out in the air. The particles in water vapor are too small and too spread out to see.
- Others may agree with Deneb and think that it has "gone," meaning it is no longer water, it is not part of air, and the water in the puddle is not matter that is conserved. Those who disagree with this idea may point out that the water from the puddle still exists only it's water vapor which is invisible.
- Students may agree with Tomas that water from the puddle is in the clouds. While there may be some truth to Tomas's idea ‚Äì some water particles from the puddle may make their way to a cloud – students preference for this idea over Fern's may be a sign that they think water vapor is visible. Students may point out to Tomas that some or even most of the water from the puddle will become invisible water vapor in the air.




Write a response to each of the children. What you think of each of their ideas and why?

Fern: ______________________________

______________________________

______________________________

______________________________

Deneb: ______________________________

______________________________

______________________________

______________________________

Tomas: ______________________________

______________________________

______________________________

______________________________

## 2. Water to Vapor: Investigation 8

# *What is happening in the 2-bottle system?*

## Plan Investigation 8

What does a 2-bottle system have in common with the Solar System? While this question may at first seem like a silly riddle, it calls attention on the concept of a system. Both the solar system and the 2-bottle system have physical boundaries, and both have components that interact within those boundaries.

The components within the three 2-bottle systems increase their interaction shortly after the lights are turned on. Students will notice changes at the start of this investigation. After sharing their initial understanding of a system, they focus on the components of the closed 2-bottle system and the now open mini-lake system. They end the class by carefully observing their "home" 2-bottle system and making drawings that record the initial changes. This is the first in a series of observations that document changes in the 2-bottle systems.

By the end of this investigation, students will understand that systems have components that interact within boundaries. They'll be able to describe the components of the 2-bottle systems and their mini-lake, and start to understand the transformations of the components within the systems.

### Learning Goals

- Understand that a system has components that interact within the system boundary
- Start to understand the interaction of the components within the 2-bottle systems

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Observe the 2-bottle systems | Small Groups | 10 Mins |
| 3. Make meaning | All Class | 15 Mins |
| 4. Weigh the mini-lakes* | Pairs | 10 Mins |

** If possible, have students weigh the mini-lakes before school starts, or during a lunch period, to have additional time during this investigation.*

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- 3 2-bottle systems

For each group:

- 1 digital scale
- 2 mini-lakes

## 1. Ask the question

All Class 10 Mins

Remind students that the purpose of the 2-bottle systems is to gather data about what happens to water after it disappears. Today they will carefully study changes in their "home" system and record their observations using annotated drawings.

Today's investigation question is:

*What is happening in the 2-bottle systems?*

**What is a system?**
Introduce the term system.

> *What systems have you heard about?*
>
> - school system
> - respiratory system
> - transportation system
> - solar system

**Note:** A system is *a set of components that interact*. Some systems are extremely complex while others are quite simple.

Highlight these three essential ideas:

1. **Systems have *components*.**
   For a school system, some components include: students, teachers, classrooms, a curriculum, administrators, etc.

   For the 2-bottle systems, the components are: water; blue food coloring, or salt, or earth materials, depending on the system; the air inside the bottles; and the inside surface of the plastic bottles. Heat from the lamp is energy that comes from outside of the system and has an influence on the interactions of the components.

2. **Systems have *boundaries* (edges or limits).**
   Determining the boundary means choosing what's inside and what's outside the system.

   For the 2-bottle systems, the boundary is the plastic material that makes up the bottles. The lamp is outside the system, but the energy from the lamp is an input to the 2-bottle system.

3. **The components of a system *interact* within the boundaries.**
   In a school system, the teachers, students, the curriculum, administrators, etc. all interact.

   The interactions of the components of the 2-bottle system (such as water, air, and earth materials) are the focus of our next set of investigations.

The 2-bottle system is a *closed* system. Elements inside the system will remain there, and nothing new will be added to the system. The mini-lakes with the covers off are *open* systems.

## 2. Observe the 2-bottle systems

Small Groups | 10 Mins | Notebook

> **Note:** If the 2-bottle systems need to be moved an adult should transport them. Mishaps while moving the systems can result in water or other materials accidentally shifting from one bottle to another, upsetting the data.
>
> If the lamps need to be turned off, the lower bottle will cool and condensation will start to form there.

Remind students of today's investigation question:

*What is happening in the 2-bottle systems?*

Students will start to answer the question by observing their "home" system and recording their observations using a new line drawing on a page titled *[What is happening in the 2-bottle system?]* in their Science Notebooks.

## 3. Make meaning

All Class | 15 Mins | Notebook

The 2-bottle systems — all three of them — look different today than they did when the class first set them up. Students have evidence of this because they made drawings of the systems on the first day, and have observations from today.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Purpose of the discussion

The purpose of this discussion is for students to jointly construct explanations for the changes they observed in the two-bottle system, explanations that are consistent with their observations and evidence.

### Engage students in the focus question

*What changes in the 2-bottle system have we observed and how do we explain these changes?*

Students should refer to data in their Science Notebooks as they make claims, and provide evidence or reasoning. Possible responses include:

- Water is appearing as drops on the inside surfaces of the lower and upper bottles.
- The drops are not evenly distributed. For example, there are no drops on the surface closest to the lamp.

> **Note:**
>
> - Don't spend too much time discussing additional details (size of drops, etc).
> - If students use the terms "evaporation" or "condensation", ask them to explain these processes in their own words.
> - Wait until the Recap to introduce the term "condensation"; keep the focus on the process as opposed to the vocabulary.

*Where do you think the drops in the upper bottle came from? What makes you think that?*

- The only water in the system is in the lower bottle; water can't get into the bottles from the outside. (Reasoning)

*Did anyone see water move from the puddle in the lower bottle to the drops in both bottles?*

- No.

*How do you think the water got from the puddle in the lower bottle to the drops in other places?*

- Tiny bits of water too small to see moved from the puddle into the air, the air had no place to go other than inside the bottles, and the water particles in the air (water vapor) formed water drops that collected on the inside surfaces of the bottles. (Reasoning)

*What's the difference between parts of the bottle where there are no droplets and parts where there are lots of droplets?*

- There are no droplets on the warmest part of the lower bottle.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas. Include the following key ideas:

- The change that has occurred in the two-bottle systems is that water drops have appeared on previously dry surfaces inside the bottles.
- Some claim that the drops of water come from the puddles in the lower bottles. They reason that the 2-bottle systems are closed and so there is no other source of water.
- No one saw the drops move from the puddles to the sides of the bottles. Some suggest that the water particles that moved were too small to see.

Other observations include:

- The water drops are not evenly distributed; some places remain dry.
- The sand, salt, and blue dye have not appeared anywhere else.

Introduce the term *"condensation"* and explain condensation is the reverse of evaporation: condensation involves the formation of water drops while evaporation involves the disappearance of water drops.

As you recap the investigation, be sure there is understanding of these points:

- A system is a set of components that interact within a boundary.
- The components of the 2-bottle systems include water, air, plastic bottles, and the salt, dye, or Earth materials.
- The 2-bottle systems are closed systems because matter cannot get into or out of those systems.
- The change that occurred in all three of the 2-bottle systems is that drops of water have appeared on surfaces that were originally dry.
- We reason that the drops came from puddles in the lower bottles, because the 2-bottle systems are closed systems.

The class will continue to observe and develop explanations for changes in the system.

**Note:** At this point, students are not likely to have a complete explanation for the changes that they can observe in their closed system. Complete understanding of processes that cannot be observed such as evaporation and condensation requires multiple experiences with the phenomena and opportunities for discussion and reflection. What's important is that they begin putting the pieces of the explanation into place. They will have additional time in Investigation 9 to observe the bottles and continue to formulate explanations for what is happening.

By the time students develop a full explanation, it will include three important ideas:

- Particles too small to see move out of the puddle in the lower bottle and become part of the air (evaporation).
- Because the 2-bottle system is a closed system, water in the air is trapped within the system.
- Water particles collect together on the cooler parts of the inside surface of the bottles to become visible again (temperature plays a role in the transformation called condensation).

## 4. Weigh the mini-lakes

Pairs | 10 Mins | Notebook

Have students:

- Collect and weigh their mini-lakes.
- Record the weight in the table and on the graph in their Science Notebooks.
- Record other significant observations.

Students should continue to weigh their mini-lakes daily if possible and record the data. When all of the water has evaporated, they can stop.

*How will you know when all of the water in their lake has evaporated?*

- We know how much water we put in the mini-lake so when the mini-lake loses that amount of weight, we'll know the water is gone.
- We see if there's any water left and see if the material on the lake bottom feels dry.

Point out that, as they did when they dissolved salt, students are using weight to determine *if* and *how much matter is present*.

## 2. Water to Vapor: Investigation 9

# *Why do the water drops form?*

## Plan Investigation 9

The 2-bottle systems continue to change. The inside surfaces of the bottles are covered with water droplets and intriguing patterns and gradations in the drop sizes have developed. Why does it all happen as it does? The drops actually form a map of conditions inside the system, reflecting two variables: temperature and abundance of water vapor. In the *coolest* and most humid places, the drops have grown largest. No condensation forms in the *warmest* part of the system.

Today's investigation is a continuation of the work students started in Investigation 8. Students check their home 2-bottle system. After describing *what* is happening, they rely on both observations and reasoning to again address the process: *Why* do water drops form on the inside of the bottles? The role of temperature is introduced, as well as the idea that the process of condensation is the opposite of evaporation. Finally, students measure and record the weight of their uncovered mini-lakes.

**Formative Assessment**

*How do your students explain the process of condensation?*

Available online at inquiryproject.terc.edu

By the end of this session students will connect evaporation, water vapor, particles too small to see, and condensation. They will understand that the process of condensation is the reverse of the evaporation, and they will also start to understand that temperature has an influence on the process of condensation.

### Learning Goals

- Understand that the process of evaporation involves particles of water too small to see breaking away from the surface of the water and becoming a gas.
- Understand that the process of condensation is the reverse of evaporation: water particles too small to see clump together to form visible drops.
- Understand that temperature difference is key to the process of condensation

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Explore | Small Groups | 5 Mins |
| 3. Share observations | All Class | 10 Mins |
| 4. Make meaning | Discussion | 15 Mins |
| 5. Weigh the mini-lakes* | Pairs | 10 Mins |

** If possible, have students weigh the mini-lakes before school starts, or during a lunch period, to have additional time during this investigation.*

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Dot Sheet 1, Dot Sheet 2, and Dot Sheet 3 (See Resource Quick Links)
- 3 2-bottle systems

For each group:

- 1 digital scale
- 2 mini-lakes

**Prepare for use in Investigation 10:**

- Freeze 2 trays of 1/2-inch mini ice cubes

**The processes of evaporation and condensation inside the 2-bottle system**

We do **not** suggest you present this information to your students. These ideas are presented here to help you understand some of the complexities of evaporation and condensation inside the closed, 2-bottle system.

- Condensation is related to both humidity and *temperature difference*. When air that includes water vapor is cooled to a lower temperature the particles of water vapor draw closer together. If the air is sufficiently cooled, drops of condensation will form. This is true even when that "cooled air" still seems warm, as it does inside the bottles. What matters is the temperature difference. Sufficient cooling of the humid air does not happen immediately below the lamp, but it does happen in most other parts of the system.
- Heat energy is necessary for evaporation to occur. Water can evaporate at very low temperatures, particularly when the humidity of the air is low. The heat from the lamp increases the rate of evaporation of water, but the lamp does not generate enough heat to evaporate anything else. However, even rocks would liquefy and then vaporize if the temperature were high enough.
- Net evaporation occurs when the rate of evaporation exceeds the rate of condensation. Inside the small 2-bottle closed system, humidity could quickly become high enough to stop net evaporation long before much water accumulates in the upper bottle. The added heat from the lamp forces net evaporation to continue even in a closed system with very high humidity.

### Concept Cartoon

The Condensation Concept Cartoon is typically used as a formative assessment at the end of this investigation.

## 1. Ask the question

All Class 5 Mins

The two-bottle systems have been set up and changing for a few days by now. The inside surfaces of both bottles have areas that are covered with different sized drops of water, and a puddle may have started to form in the upper bottle.

Today's investigation question is:

*Why do the water drops form?*

Before students start to answer the question they'll have another opportunity to observe the bottles.

## 2. Explore

Small Groups 5 Mins Notebook

Ask students to spend just a few minutes observing their home 2-bottle system. Students should pay special attention to:

- Places where there are water drops.
- Places where there are no water drops.

They record their observations in their Science Notebooks, on a new page titled, *[What is happening in the 2-bottle system?]*

**New drawings of the two-bottle system are not necessary.**

## 3. Share observations

All Class 10 Mins

Collect *observable* data from students about their home 2-bottle systems. As students respond, record their observations for reference during the Make meaning discussion

*Where did you see water or drops of water?*

- A larger area of the inside surface of each bottle is now covered with drops.
- A puddle may be starting to form in the upper bottle.

*Where are there no drops of water?*

- There is a large area with no drops directly under the light.
- Smaller sections of the lower and upper bottles may have no drops of water.

*What is the warmest part of the 2-bottle system?*

- The warmest part is the portion of the lower bottle that is directly under the light.

## 4. Make meaning

Discussion 15 Mins

The 2-bottle systems look very different than they did when the class first set them up. Drops of water continue to collect on the inside surfaces of both bottles, and students have agreed that the systems are closed, so the water is not coming from outside of the 2-bottle systems.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Purpose of the discussion

The purpose of this discussion is for students to jointly construct explanations for why drops of water form on the surfaces inside the 2-bottle systems.

They are encouraged to think about particles of water that are too small to see and to consider the role that temperature differences play in evaporation and condensation.

### Engage students in the focus question

*How can we explain the formation of water drops on the inside surfaces of the 2-bottle system?*

> **Note:** If students use the terms "evaporation" and "condensation", ask for details. What is the story behind the word evaporation, or condensation? What do those terms mean? Explaining what is going on is challenging as it requires students to move beyond what they can observe and to explain what can't be seen. They must move back and forth between visible evidence and inference. This discussion is an opportunity for students collectively to put pieces of the explanation into a coherent whole as if they were solving a puzzle together.
>
> Listen for explanations that include the idea that water particles too small to see leave the puddle, move into the air inside the bottles, and are now a gas called water vapor. When enough particles of water vapor cluster together on the cooler surfaces of the bottle, they form visible drops of water.

*We started with a puddle of water in the lower bottle and no water in the upper bottle. Now we see water drops on the inside surfaces of both bottles. But I didn't see any water moving from one bottle to the other. How would you explain that?*

- Particles of water too small to see break free from the surface of the puddle in the lower bottle. Those particles, that are too small and too spread apart to see, form a gas called water vapor. The water vapor travels throughout the two bottles as part of the circulating air.

*We seem to agree on how water particles behave during evaporation. But what about water vapor turning back to liquid water drops – the process we call condensation – how do these water particles behave?*

- The water particles in the air are spread far apart. When lots of those particles cluster together they become visible again, as water drops. This doesn't happen everywhere in the 2-bottle system.

*Water drops don't form in every part of the 2-bottle system. Can we figure out what's different about parts of the bottle where there are no drops and parts where are lots of them?*

- There are no drops on the surface close to the lamp where it's warmest so maybe it needs to be cool for water vapor to become liquid water drops (a process called condensation).

*Have you noticed other places where water drops form?*

- Water drops form on the sides of a can or glass that holds a cold liquid.

*Do you think it is accurate to say that evaporation and condensation are reverse processes? Explain.*

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas.

In your summary, use the three Dot Sheets to reinforce the concept that particle spacing as well as particle size has a significant influence on our ability to see the particles.

Include the following key ideas:

- Particles of water, which are too small to see individually, break free from the surface of the puddle of water and move into the air.
- These invisible particles form a gas called water vapor, which becomes part of the air and circulates inside the 2-bottle system.
- When the invisible water particles bunch together, they form visible drops on the inside surfaces of the 2-bottle system. This process is called condensation.
- Condensation is not happening on the warmest surface of any one of the three 2-bottle systems.

As you recap the investigation, be sure there is understanding of these points:

- You made new observations of the three 2-bottle systems.
- You discovered that drops of water cover most but not all of the inside surfaces of the systems.
- The warmest part of each 2-bottle system is dry.
- There is now evidence that water isn't destroyed as it evaporates. In the closed 2-bottle system, the only source of the condensation is the water vapor that originally evaporated from puddle in the lower bottle.

***Letter from the Engineer***
***The Two-Bottle System***

*The two-bottle system you have been using is an example of a design created by two engineers. They followed a design process that is highlighted below:*

- ***Define the problem***

  *The problem they faced was:*

  *"What can we build that will help answer the question?", "What happens to water when it evaporates?"*

- ***Identify the Criteria***

  *The important features of a design, the features that allow us to know if the design is a success, are called criteria. The criteria for the two-bottle system included:*

  1. *It must be a closed system (if water still exists after it evaporates, the instrument must capture it).*
  2. *It must have two separate places that can hold water, so we can tell if water moved from its original location to a new place.*
  3. *People must be able to see what is happening.*

- ***Identify the Constraints***

  *There were also some restrictions, or what engineers call constraints:*

  1. *It must be safe for use in a 5th grade science classroom.*
  2. *It must be made from simple materials, so it is not very expensive.*
  3. *It must be sturdy, not break easily.*
  4. *It must be easy to set up correctly and use.*
  5. *Whatever is going to happen needs to happen quickly, so people don,Äôt get bored waiting forever to see what might happen.*

- ***Pose solutions***

  *The engineers made lots of different sketches that they thought might work, and talked about the possible designs.*

- ***Test and Evaluate Solutions***

  *Then over the course of several weeks, they built and tested five different versions of the two-bottle system, improving it each time to better match the criteria and the constraints, before they built the version you have in your classroom.*

  *You decide:*

  1. *Did the two-bottle system allow you to answer the question, "What happens to water when it evaporates?"*
  2. *Does it meet the criteria?*
  3. *Does it comply with the constraints?*

  *What changes would you make to improve the two-bottle system so that it does a better job?*

**Continuing to observe the 2-bottle system**

Given enough time, all of the water in the lower bottle will evaporate, leaving it dry, and will condense in the upper bottle. **We recommend you leave the light on overnight and across weekends but not during school vacation periods.** If you leave the lamp on continuously this change typically takes about a week. It will take significantly longer if the lamp is on only during school hours.

If the water in the lower bottle has not evaporated and condensed in the upper bottle by the time your class completes this unit, leave the 2-bottle systems in place and encourage your students to check them once or twice a week until the process is complete.

Students will find additional line drawings for the 2-bottle systems and spaces for notes and observations in the Science Notebooks that they can use to record any further observations.

## 5. Weigh the mini-lakes

Pairs 10 Mins Notebook

Students record the date, day number, the weight, and any changes to the mini-lakes in the Data Table: Weight of mini-lake and on the Weight of mini-lake over time graph in their Science Notebooks. Remind them to include the cover in the weight.

**How long do students continue to weigh mini-lakes?**

It is critical that students continue to weigh their mini-lakes until all the water has evaporated. How will they know when all the water is gone? The most important source of evidence is the weight data: the weight stops decreasing and the line connecting the points on the graph levels off. This evidence is supported by observations that the lake looks and feels dry. If time permits, you may ask students to figure out how much the mini-lake will weigh when evaporation of water is complete. (Weight of mini-lake with salt added minus weight of water added to the mini-lake originally.)

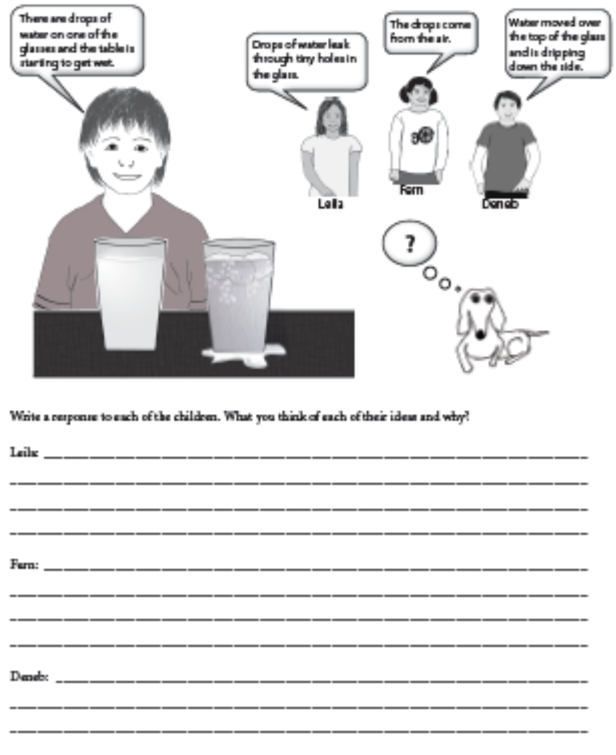
Time for weighing the mini-lakes is not built into the rest of the investigations. You will need to make a plan that works in your situation. By now students are able to weigh their mini-lakes independently. Can they weigh their lakes before school? Or before you begin science class?

# Condensation Concept Cartoon

This cartoon was developed to assess students' ability to:

- Explain the phenomenon called condensation. Condensation occurs when water vapor (water particles too small and spread out to see and always in motion) in the air comes in contact with a cool surface, slowing the motion of the particles enough to allow them to gather together and form water drops on the cool surface.

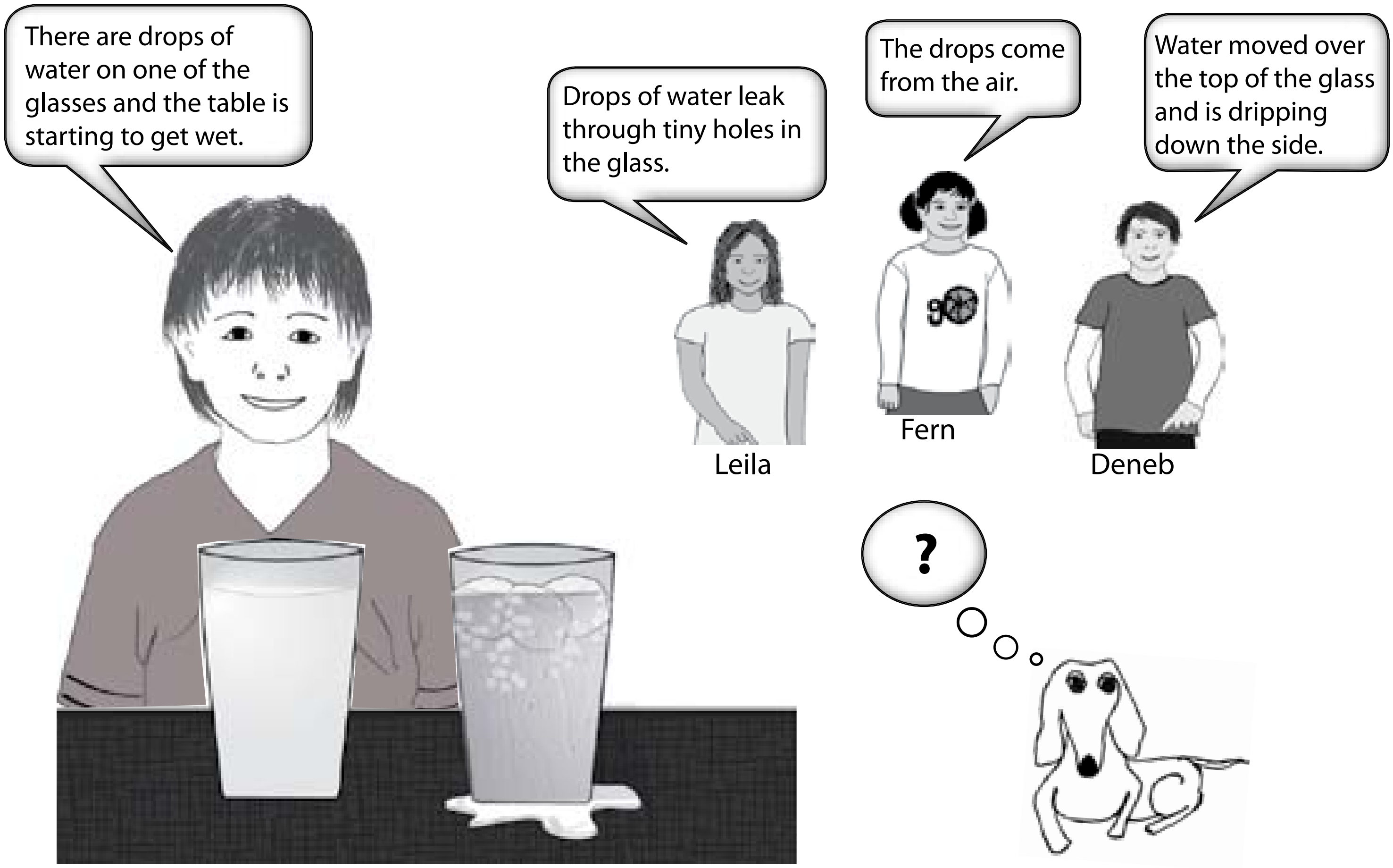
This cartoon is typically used after Investigation 9, *Why do the water drops form?*




## Things to look for in student responses

Do students realize that (a) the source of condensation on the outside of glass is water vapor in the surrounding air and that (b) for condensation to appear, water vapor must be cooled?

- Some students may agree with Leila that water has seeped through invisible pores in the glass ‚Äì this idea is commonly held by students. Students who don't agree with Leila may point out that water can't seep through the other glass because it is solid and offer another explanation.
- Others may agree with Fern and explain that the drops are only on the outside of the cold glass of water, that there are tiny particles of water in the air called water vapor, and that when water vapor comes in contact with a cool surface, the particles slow down enough so they can gather together to form drops.
- Still others, who hang onto the idea that the source of droplets is water in the glass, may erroneously agree with Deneb. Students who disagree may point out that there are no droplets near the top of the cold glass which you might expect if the water was moving from inside the glass, over the rim, to outside and offer another explanation.




Write a response to each of the children. What you think of each of their ideas and why?

Leila: ______________________________________________

______________________________________________

______________________________________________

______________________________________________

Fern: ______________________________________________

______________________________________________

______________________________________________

______________________________________________

Deneb: ______________________________________________

______________________________________________

______________________________________________

______________________________________________

# 3. Water to Ice

These investigations focus on what changes and what stays the same as water freezes and ice melts to water. Can ice and water actually be the same material when so many of their properties differ, and when the volume of a sample actually changes across transformations?

The key to answering this question is understanding the scale to which the word "material" applies. The tiniest particles of solid water (ice) are identical to the tiniest particles of liquid water; both are $H_2O$. The properties of ice and water, at the visible level, depend on the way in which those particles are arranged at the particle level. Are they rigidly bonded together to take the form of a solid, or can they slip past one another to take the form of a liquid? In Investigation 12, students are introduced to the scientific model of matter. Through the use of a computer model, they see the role that thermal energy has on the arrangement of particles, and that the individual particles remain unchanged across the solid–liquid transformations.

### Investigations:

- Investigation 10: How are ice and water the same and different?
- Investigation 11: What happens to weight and volume when water freezes?
- Investigation 12: What changes and what stays the same as ice melts?

### The Child and the Scientist

**The Child:**
The Challenges of Learning about Freezing/Melting

**The Scientist:**
What's important about freezing and melting?

**Scientist Case**


Watch Hugh Gallagher doing the Water to Ice Investigations

Available online at inquiryproject.terc.edu

**The Child's Ideas for *3. Water to Ice***

# The Challenges of Learning about Freezing/Melting

> *Children initially think that when something freezes or melts, its weight should change as well.*

Compared to the perceptual changes that occur when reshaping, crushing or grinding materials, the changes that occur with freezing and melting are much more radical. When water freezes, it goes from being something fluid, wet, and drinkable to something that is rigid hard, and chewable; when butter melts, it goes from being soft, rectangular, and yellow, to runny, formless, and clear. Further, children have limited experience with things that freeze or melt in their everyday life—water, butter, ice, and snow being their prime examples. This gives rise to a host of questions: Can you melt or freeze all materials? If so, what happens when something melts or freezes? Is it still the same kind of stuff? How do you know? What actually remains the "same" across these transformations?

Children are not always sure that it is still the same kind of material. After all, water and ice have distinct names. If being wet and fluid are central features of being water, how can ice be water? Calling ice "frozen water" suggests that there might be a deeper connection—but what exactly is that connection? How can they think about what is the same about the stuff across this transformation?

Children initially think that when something freezes or melts, its weight should change as well. Generally, they expect that *harder things are heavier*, so they think that ice should be heavier than water or that solid butter would be heavier than melted butter. (Appreciating that weight stays the same across melting/freezing is thus more difficult for children than appreciating the invariance of weight across shape change.) Of course, children cannot tell whether or not the weight has changed by simply hefting, so they need to engage in careful measurement to see what is happening. Thus, there are opportunities for continued discussion about issues of weight measurement and measurement error in the context of these investigations.

Investigating freezing and melting exposes new puzzles that cry out for deeper explanation. When water freezes (unlike what happens when you pour it from one shaped container to another), its volume actually *increases* (as can be demonstrated dramatically when bottles of water "explode" when put in the freezer). How can this be, especially if its weight (and mass) remains the same?

Ultimately, satisfying answers to all these questions call for constructing a particulate model of matter. Although there are many challenges in teaching students about the particulate nature of matter —convincing them there are pre-existing particles of material of fixed size and weight, that these particles are separated by empty space and are in constant motion, that the particles are the matter itself—the (explanatory) benefits are immense. One interesting feature of this model is that it explains what exactly remains the same across freezing/melting. The individual molecules in ice and water are fundamentally the same, just in a different arrangement. Ice molecules are not hard and water molecules are not wet. Appearances can be deceiving indeed.

—Carol L. Smith

**The Scientist's Essay for *3. Water to Ice***

# What's important about freezing and melting?

Familiar as they are, freezing and melting are really quite remarkable phenomena. Over a wide range of temperatures, ice is just ice and water is just water, and their properties don't really change a whole lot. Then at one very specific temperature (32°F or 0°C) a dramatic transformation occurs — the material changes from liquid to solid (or vice versa) and its density changes noticeably. Even more remarkably, the whole process is reversible: You can take the same water from liquid to solid and back again as many times as you want, and the water at the end will be exactly the same as it was before you started.

> *In the solid the molecules are held tightly in position in a highly ordered structure, rather like the musicians in a well-trained marching band. In the liquid the same molecules are positioned at random, like the musicians hanging around after the game — they're about as densely packed, but not systematically.*

The physics of phase transitions, including

The physics of phase transitions, including freezing/melting, is pretty complicated. But there are some interesting observations to make, questions to ask, and connections to draw to other kinds of transformation, like crushing and reshaping. For example: Is water the only materials that melts and freezes, or is it a more general phenomenon? Are there properties that *don't* change when the material melts or freezes? The weight? The volume? Are the solid and the liquid different materials, or the same? (Raising the question: What do we mean by "the same material"? What kind of evidence is appropriate for answering the question?)

On a microscopic level, we ultimately understand the liquid and the solid as comprising the same molecules, but organized differently. In the solid the molecules are held tightly in position in a highly ordered structure, rather like the musicians in a well-trained marching band. In the liquid the same molecules are positioned at random, like the musicians hanging around after the game — they're about as densely packed, but not systematically. In order to move into the disordered state, the bonds holding the molecules in their array must be partially broken by the thermal energy of the molecules — that's why heat is required to melt the material, and why you can go back and forth between the two states. This is only a partial explanation. It doesn't explain why the transition occurs all at once at a specific temperature, rather than gradually as the temperature increases. But it's a start, and it has the right basic ideas.

—Roger Tobin

## 3. Water to Ice:  Investigation 10

# *How are ice and water the same and different?*

## Plan Investigation 10

There's no mistaking ice for water, but they are the very same type of matter, only in different states or phases. How can they be the same and yet so different? Even ice takes a variety of forms, such as the frozen surface of a lake, hailstones, icicles, sleet, snow, frost on the window, icebergs, and the common ice cube, to name a few.

This is the first of three sessions in which students investigate and compare ice and water, and learn more about the transformation of water to ice, or ice to water.

Today students compare the properties of ice and water. Next they record the weight and volume of a container of water before it is sent off to the freezer. There is a brief discussion about the condensation that forms on the plastic cups holding ice. Finally, students share their observations about how ice and water are the same and different.

By the end of this session students will start to identify ways in which ice and water are the same and different. This investigation will continue for two more science classes.

### Learning Goals

- Understand that liquid water and solid water (ice) have different properties

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Explore | Pairs | 20 Mins |
| 3. Discuss condensation | All Class | 5 Mins |
| 4. Share observations | All Class | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Make a class chart titled, "Comparing Ice and Water"; an example is found in Step 4.
- 2 trays of 1/2-inch mini ice cubes


For each group:

- 1 digital scale
- 1 6in strip of masking tape
- 1 fine-tip permanent marker or pen
- 2 12oz clear plastic cups 1/3 full of water
- 2 12oz clear plastic cups each holding 15 ice cubes
- 2 droppers (1cc small syringe)
- 2 8oz plastic capped water bottles, 3/4 filled with room temperature water

## 1. Ask the question

All Class 10 Mins

Review key ideas related to condensation and evaporation. Listen for and highlight the following responses:

> *What are some of the important ideas (related to evaporation and condensation) that the 2-bottle systems helped us to understand?*

- Water isn't destroyed as it evaporates; it moves somewhere else.
- During evaporation, water particles too small to see break away from the surface of a drop or puddle or lake and move into the air, becoming a gas called *water vapor*.
- The reverse of evaporation also happens: particles of water vapor clump together to form water drops large enough to see. This is called *condensation*.
- Temperature plays a role in evaporation and condensation. Warmer temperature causes evaporation to happen faster. As water vapor cools, particles clump together to form drops of condensation.

The next set of investigations explores another set of transformations: liquid water into solid water (ice), and solid water to liquid water. Explain that transformations of water (water vapor to liquid water; liquid water to solid water; solid water to liquid water) are called "changes of state" or "phase changes."

Introduce today's investigation question:

*How are ice and water the same and different?*

Students will continue to discover similarities and differences during the next two investigations.

> **Note:** If you need to review the concept of material properties, here are some examples:
>
> - *Glass* is transparent, hard, smooth, and brittle.
> - *Wood* is opaque, and will not conduct electricity.
> - *Oil* is sticky and flows slowly (viscous).
>
> Material properties are independent of the size of the sample.

## 2. Explore

Pairs 20 Mins Notebook

### Properties of ice and water

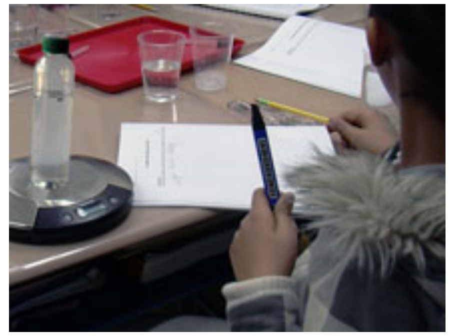
Distribute materials. To address the investigation question, students compare and contrast the properties of ice and water and record their observations on the page *[Comparing ice and water]* in their Science Notebooks.

### Prepare for the next investigation

Students collect data in preparation for the next investigation: *What happens to the weight and volume of water when it freezes?* Show students a plastic bottle 3/4 filled with room temperature water:

> *If we keep this water bottle closed, and we don't change it in any way except to freeze it, do you predict its weight will increase, stay the same, or decrease? What makes you think this?*
>
> *What do you predict will happen to the volume? What makes you think this?*

Give students a few minutes to record their predictions and explain their reasoning on the page *[Predictions about freezing water]* in their Science Notebooks.



Distribute the remaining materials to each group. Each pair of students will prepare their water bottles for freezing, following the procedure described in their Science Notebooks and here:

- Place a strip of masking tape vertically on the outside of water bottle.
- Mark the water level on the tape. If necessary, adjust the water level to align with the mark, using the pipette.
- Write team members' initials on the tape.
- Weigh the bottle and water and record the data in the table on the page *[What happens to weight and volume when water freezes and ice melts?]*, in their Science Notebooks. For this investigation students will always weigh the water and the water bottle together, so there is no need to determine and subtract tare weight.

## 3. Discuss condensation

All Class 5 Mins

One goal of this brief conversation is for students to pay attention to another instance of condensation. Note that the amount of condensation that forms on the ice-filled plastic cups will depend on the amount of water vapor in the classroom air.

*Do you notice any condensation forming on the outside of your cups holding the ice? Where?*

- Next to the ice cubes or ice water, on the coolest parts of the cup just as condensation formed on the coolest surfaces of the 2-bottle system.

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

*Where are the droplets coming from? Why do you think they are forming?*

*Do you think that water vapor in the air and water forming on the outside of the cold cup are the same kind of matter?*

**Note:** A common misconception is that the condensation is water that leaks through the plastic. If someone suggests this, show the class the bottle holding room temperature water and point out that no water is leaking through that plastic.

## 4. Share observations

All Class 10 Mins

Return to the investigation question:

*How are ice and water the same and different?*

Post a T-chart, or Venn Diagram, "Comparing Ice and Water" with the headings Same and Different. Start by asking students to identify differences between ice and water. As students share the observations they recorded in their Science Notebooks, add them to the class list. Some likely observations are shown below.

**Comparing Ice and Water**

<table>
<tr><th colspan="2">Same</th></tr>
<tr><td colspan="2">have weight<br>take up space<br>are matter<br>feel wet<br>can change temperature</td></tr>
<tr><th colspan="2">Different</th></tr>
<tr><th>Ice</th><th>Water</th></tr>
<tr><td>solid<br>holds a shape<br>hard<br>cold<br>transparent in some parts but not always</td><td>liquid<br>takes the shape of its container<br>soft<br>can be warm or cold<br>transparent</td></tr>
</table>

Save the list of observations. Students will continue to investigate water-ice transformations and will add more observations to the list in Investigation 12.

### Recap the investigation

The transformations of water from a liquid to a gas and the reverse are evaporation and condensation. The transformations of water, from a liquid to a solid and the reverse are freezing and melting.

One question for students to think about, and one they will discuss in a future class, is:

> *Your bottles of water are going in the freezer. Is water still the same material after it is frozen?*

## 3. Water to Ice: Investigation 11

# *What happens to weight and volume when water freezes?*

## Plan Investigation 11

How much can something change and still remain the same? When water freezes, the changes seem dramatic, and yet the kind of matter remains the same – it's still water. While liquid water and frozen water have different names and some different properties, the kind of matter remains the same, and for a specific sample of water, the weight does not change. The volume of a sample is not conserved across a phase change. Freeze water and its volume will increase. Evaporate that same sample of water and its volume will increase even more, but its weight will be conserved.

**Formative Assessment**

*What happens to weight when water freezes?*

Available online at inquiryproject.terc.edu

In this session, students follow up on an investigation they launched in the previous class. They discover that the volume of their samples increased as the water froze, but they may have mixed results when they report on the weight. The question of weight can be complicated by inaccurate scales, condensation that forms on the outside of the bottles, and a tendency to believe that if the volume of a sample increases, so must the weight. While the topic of condensation is not related to the investigation question, its appearance on the frozen containers affords an opportunity to discuss this process, which is so common and yet still mysterious to many.

By the end of this session students will have evidence that the volume of their water samples increased and weight stayed the same across the phase change from liquid to solid.

### Learning Goals

- Understand that across phase change, while the volume changes, the weight of a sample stays the same
- Understand that *weight* is the reliable measure of the amount of matter

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Collect data | Small Groups | 10 Mins |
| 3. Share findings | All Class | 15 Mins |
| 4. Make meaning | Discussion | 15 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Make a class chart titled, "Transforming Water to Ice and Ice to Water"; an example is found in Step 3.
- Recover the bottles from the freezer as close as possible to start of class. **Insulate** the bottles as necessary to keep them frozen until students get them.


For each group:

- 1 digital scale
- 2 plastic bottles prepared in the last class that are now frozen
- 4 paper towels

## 1. Ask the question

All Class | 5 Mins

Remind students that they are continuing to investigate transformations of water and ice. Today's investigation question is:

*What happens to weight and volume when water freezes?*

Students will collect weight and volume data for their now-frozen bottles. They will compare that data with the weight and volume data they collected before the bottles were frozen.

## 2. Collect data

Pairs | 10 Mins | Notebook

Distribute the materials.

Do students notice condensation on the outside of the frozen water bottles? Remind them that the condensation is coming from water vapor in the classroom air, and that condensation is the reverse of evaporation. Water vapor in the air is cooling against the cold surface and condensing on it. They'll need to dry the condensation from the bottles before they weigh them, so they'll get an accurate weight for just the bottle and the ice inside of it. Students record their findings in the data table on the page *[What happens to weight and volume when water freezes and ice melts?]* in their Science Notebooks.

1. Dry condensation from the container.
2. Measure and record the weight.
3. Observe and record the volume by checking the level of the ice. Did it stay the same, increase, or decrease?
4. Complete *[What happens to weight and volume when water freezes?]* reflections in the Science Notebooks.

## 3. Share findings

All Class 15 Mins

Have students contribute data to the class table: weight before freezing, the weight after freezing, and the volume after freezing (same, increased or decreased).

**Transforming Water to Ice and Ice to Water**

| Pair | Weight before Freezing (grams) | Weight after Freezing (grams) | Volume after Freezing (Notes) | Weight after Melting (grams) | Volume after Melting (Notes) |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| etc. | | | | | |

**Why does the water expand when it freezes?:**

In simplest terms, the tiny water particles rearrange themselves to form crystals when they freeze. In their new arrangement, the particles are not as tightly packed together as they are in liquid form and they take up more space.

## 4. Make meaning

Discussion 15 Mins

The class table now holds weight and volume data for (12) bottles. That data includes: weight before freezing; weight after freezing; and information about volume.

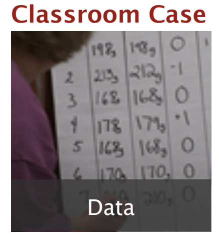
### Purpose of the discussion

The purpose of this discussion is for students to connect the investigation question with the weight and volume data they have collected by making claims and describing the supporting evidence.

### Engage students in the focus question

*Based on the data we have collected, what can we claim about weight and volume when water freezes? Let's start with volume.*

**Classroom Case**




The Role of Data Discussions

Available online at inquiryproject.terc.edu

**Volume**

Class data will very likely justify a claim that volume increases when water freezes.

*What can we claim about volume? What evidence supports this claim?*

*How do your predictions compare with the classroom data?*

*Have you noticed other situations in which the volume of water expands when it freezes?*

- water bulging over the top of the ice cube tray
- hoses expanding or bursting when left outside in freezing weather

**Weight**

> *What can we claim about weight? What evidence supports this claim?*
>
> *How do your predictions compare with the classroom data?*

If every pair reports no weight change, you can skip the question below.

> *Some people found the weight stayed the same, while for others the weight increased/decreased. How can we account for these contradictions?*

**Note:** Although the actual weight of the water in the bottles does not change during freezing, it's unlikely that the weight *measurement* will remain the same for every pair in the classroom, due to the limitations of the scales or other sources of error. Students may think that since the volume of water has increased, the weight must also increase.

- The scales round to the nearest gram and are not the most accurate scales. A one-gram difference might be explained by a scale giving different readings, so we can assume the weight stayed the same.
- No matter was added to or removed from the inside of the container once it was covered, so the amount of matter inside the container has not changed.
- Condensation adds new matter to the *outside* of the container, so if someone did not completely remove the condensation, this might explain a small increase in the weight, but the weight of water inside stayed the same.

Save the frozen containers. Students will weigh and measure them again in the next class, after the ice has completely melted. Since the containers are sealed, evaporation will not influence the results.

### Summarize the discussion and recap the investigation

Using the same language students have used, summarize their main ideas.

Include the following key ideas:

- The volume of a sample of water increases when it is frozen.
- The weight of a sample of water remains the same when it is frozen.
- (Include if appropriate) Reasoning tells us that small changes in the weight of a sample are due to an error of some type. (rounding or reading error.)
- Highlight the idea that weight is the measure of the amount of matter, the amount of stuff, so when there is no change in the amount of matter–no one added more water to the bottle or removed water from the bottle–then we should expect no change in the weight.
- Remind students that when they dissolved salt in water and the salt was no longer visible, it was weight that convinced us that the salt was still there.

As you recap the investigation, be sure there is understanding of these points:

- The class collected and shared weight and volume data for the samples of frozen water.
- The data allowed the class to answer the investigation question, What happens to weight and volume when water freezes?
- We learned that the weight of a water sample remains the same even when volume increases.
- Since reasoning,Äîas well as most of the data,Äîtells us that the weight of water does not change when no water is added or removed, we conclude that a small change in the weight of a sample is due to rounding or possibly a recording error.

## 3. Water to Ice:  Investigation 12

# *What changes and what stays the same as ice melts?*

## Plan Investigation 12

Today students complete their investigation of ice. They start by checking the bottles to answer whether weight and volume change as ice melts. At this point students should have substantial evidence for answering the question, *What changes and what stays the same as ice melts?* at the visible level. To learn about what is happening at a very much smaller scale, the particle level, students observe the Particle Magnifier, a computer model that introduces scientists' understanding that all matter is made of tiny particles (atoms or molecules). As the ice is warmed, students see the motion of individual particles increase to the point where the bonds holding the particles locked in position in the solid begin to break and reform. This allows the particles to slide past and collide with one another as the ice is transformed to water.

By the end of this session students will understand that, as ice melts, the weight of a sample remains the same, the volume decreases, and the kind of matter – water – remains the same. They will have been introduced to the *particle model of matter* and considered how the model helps to explain the transformation of a solid to a liquid.

### Learning Goals

- Understand that liquid water and ice are the same kind of matter
- Become familiar with the particle model of matter to explain transformations of water

| Sequence of experiences | | |
|---|---|---|
| 1. Explore bottles | Pairs | 10 Mins |
| 2. Use data | All Class | 5 Mins |
| 3. Introduce Particle Magnifier (Water) | All Class | 15 Mins |
| 4. Make meaning | All Class | 15 Mins |

### Materials and Preparation

Preparation:

- Read *The Particle Magnifier* (See Resource Quick Links)
- Explore the Particle Magnifier (Water)

For the class:

- Post the investigation question in a place where all students can see it.
- Post the class chart, "Comparing Ice and Water"; created in Investigation 10.
- Post the class table, "Transforming Water to Ice and Ice to Water"; created in Investigation 11.
- The Particle Magnifier (Water), using a classroom computer and projector or Smart Board.

For each group:

- 1 digital scale
- 2 plastic bottles of water, from the last investigation

## 1. Explore bottles

Pairs | 10 Mins | Notebook

The class will finish their investigations of ice today. After they check the weight and volume of the melted ice, they will return to the investigation question:

*What changes and what stays the same as ice melts?*

Distribute materials. Give each group the *same scale* it has been using to weigh the water and ice in the previous classes.

Point out that there is no condensation on the containers. This should reinforce the fact that water does not seep through the plastic, and that temperature plays a role in condensation. Students:

1. Measure and record the weight on the page *[What happens to weight and volume when water freezes and ice melts?]* in the Science Notebooks.
2. Check the volume by observing the level of the water and record the observation (did the volume increase, decrease, or stay the same?) on the same page.
3. Respond to the questions on the page *[What changes and what stays the same as ice melts?]* in their Science Notebooks.
4. Enter the weight and volume data in the last two columns of the class data table.

**Transforming Water to Ice and Ice to Water**

| Pair | Weight before Freezing (grams) | Weight after Freezing (grams) | Volume after Freezing (Notes) | Weight after Melting (grams) | Volume after Melting (Notes) |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| etc. | | | | | |

## 2. Share data

All Class | 5 Mins

Use the data from the class chart, Comparing Ice and Water and/or the class data table, Transforming Water to Ice and Ice to Water to address the following:

> *Some of the properties of ice and water are the same and some are different. Do you think ice and water are the same or different kinds of matter?*

Some possible student arguments:

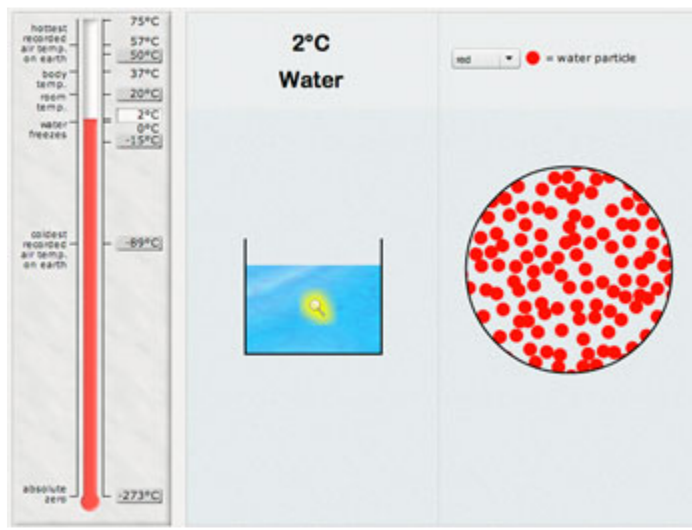
**Transforming Water to Ice and Ice to Water**

| Yes, ice and water are the same kind of matter | No, ice and water are not the same kind of matter |
|---|---|
| • The container had water in it when it was first sealed, and it has water in it now, so it had to be water when it was frozen.<br>• If you put a piece of ice in a glass of water and it melts, the type of material is all water.<br>• The weight of a sample doesn't change when water freezes to ice and ice melts to water. | • Ice is translucent and water is clear (transparent).<br>• Ice is a solid and water is a liquid.<br>• The volume of a sample of ice decreases when it melts to water. |

Explain that you are going to introduce a scientific model that may help them think in a new way about the matter that makes up ice and water.

## 3. Introduce Particle Magnifier (Water)

All Class 15 Mins




Explain that scientists believe **all** matter, including ice and water, is made of very tiny particles. Single particles of matter are much too small to see even with the most powerful microscopes available. Once enough of the particles clump together, we see them with our eyes as water, or ice, or salt, or other materials. The Particle Magnifier (Water) represents what scientists imagine they might see if they could see individual particles of ice or water at various temperatures.

Start by selecting Absolute zero on the thermometer of the Particle Magnifier (Water) and show the ice/water at increasing temperatures. At each temperature, provide a few words of context (see Notes, below) and ask:

*What are the particles doing now? What has changed? What stays the same?*

| Temp | Notes | Likely student observations |
|---|---|---|
| Absolute zero | No heat energy is present. | • The particles are arranged in a pattern.<br>• The particles are not moving.<br>• All of the particles are the same size and shape. |
| −89°C | The ice is still extremely cold, but heat energy is causing the particles to vibrate. | • The particles are still arranged in a pattern.<br>• The particles are jiggling, or vibrating.<br>• The size of the particles is the same. |
| −15°C | The ice is warmer, but is still quite frozen. | • The particles are vibrating at a greater speed than at −89°C.<br>• They are still arranged in a pattern. |
| 2°C | Enough heat energy has been added to transform ice to water. | • The particles are no longer arranged in a pattern; they are sliding past and colliding with one another.<br>• The water particles look the same as the ice particles. |
| 20°C | The water is at room temperature. | • The particles are moving faster, still sliding past and colliding with one another.<br>• The water particles look the same as the ice particles. |

*What do you predict will happen if I increase the temperature of the water even more?*

| Temp | Notes | Likely student observations |
|---|---|---|
| 50°C | The water is now too hot to touch, but it is not boiling. | • The particles are moving faster, still sliding past and colliding with one another.<br>• The water particles still look the same as the ice particles. |

*How does the Particle Magnifier explain some of the differences between solids and liquids?*

- Solid materials have a shape because the particles are locked together.
- Liquids flow because the particles have more heat energy, have broken away from one another, and can slide past and/or bump one another.

**Optional:** The Science Notebook page *[Particle Magnifier ice and water particles]* is there for you to assign if time permits.

## 4. Make meaning

All Class 15 Mins

### Purpose of the discussion

The purpose of the discussion is for students to clarify their understanding of transformation of solid ice to liquid water at the particle level. Focus the discussion on the investigation question: What changes and what stays the same as ice melts?

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Engage students in the focus question

*Imagine a tray of ice cubes. Imagine those cubes melting. If we could zoom in and see the ice melt at the particle level – like we did with the Particle Magnifier – what do you think would change and what would stay the same as ice melts?*

- The individual particles stay the same when ice melts.
- For both ice and water, the warmer the temperature, the more the particles move.
- In ice, the particles are arranged in a pattern, even when they are warmed up and vibrating (jiggling but still in place).
- In water, individual particles slide around and collide, and are not arranged in a pattern.

### Revisit the Particle Magnifier (Water)

*What connections do you notice between the visible evidence and changes at the microscopic level?*

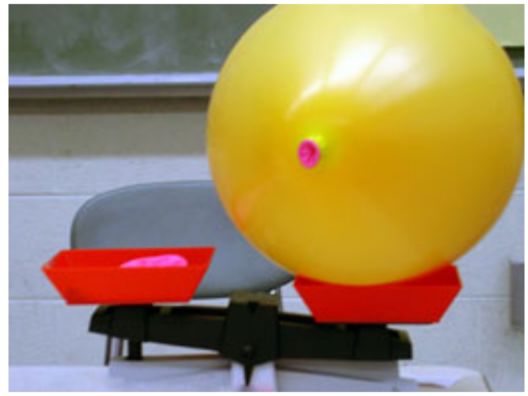
| Visible Level | Particle Level |
|---|---|
| Solid water (ice) keeps its shape and liquid water doesn't. | Particles in ice are held in a shape. Particles in water aren't locked in place. They slide past and collide with one another. |
| At the visible level, reasoning tells us that water remains the same – ice is formed from water and returns to water when it melts. | Particles in the model remain the same. Particle motion and arrangement change. |

### Summarize the discussion and recap the investigation

When a sample of water is transformed to ice and back to water, the weight does not change. When water freezes, the volume increases but returns to the original volume when the ice melts. The particle model of matter explains these transformations of water.

**Note:** Materials typically contract when they cool and change from liquid to solid. Water is an exception: it expands when it freezes and transforms to ice.

# 4. Air, a Gas



Our first breath is of air – we've lived with it all our lives, yet few people think about air as a gaseous form of matter that has weight and volume. Gases are another form of matter, just like liquids and solids. They have weight, take up space, and have properties that students can explore.

Students discover that gases are highly compressible: a sample of gas can be squished down to a significantly smaller size. Liquids and solids are essentially incompressible. Students observe that a sample of gas visibly expands when heated and contracts when cooled. What can account for this? While the individual particles that make up each type of gas (e.g., oxygen, nitrogen) are unique, one thing all gases have in common is the arrangement of those individual particles. Compared with solids and liquids, gas particles are on average significantly spread out. They are in constant motion, continuously colliding with one another and taking up much more space than the volume of the individual particles. Again, students see a computer model that demonstrates how a gas responds to increasing or decreasing amounts of thermal energy.

### Investigations:

- Investigation 13: Is air matter?
- Investigation 14: What are some properties of air? (1)
- Investigation 15: What are some properties of air? (2)
- Investigation 16: What are some properties of air? (3)

### The Child and the Scientist

**The Child:**
The Challenges of Learning About Air and Other Gases

**The Scientist:**
What's important about air and gases?

**Scientist Case**


Watch Lindley Winslow doing the Air, A Gas Investigations

Available online at inquiryproject.terc.edu

The Child's Ideas for *4. Air, a Gas*

# The Challenges of Learning About Air and Other Gases

> *when children are asked to put together the things that are alike in that "they are matter or made of some physical stuff," they almost never group air with solids or liquids*

Many children from a very early age have heard about air and know that it is very important. For example, I remember my 3-year-old daughter was shocked to learn that during pregnancy, she was entirely inside me—that her head wasn't somehow sticking out of my tummy—as she exclaimed (with worry), "But how did I *breathe*?" She knew, even then, that air exists and that it is very important—that she needed air to breathe.

The challenge in teaching children about air (and other gases) then is not simply making them aware of its existence or importance, but giving them a deeper appreciation for *what type of thing it really is*. To come to see air (or other gases) as a form of matter requires not only developing a general concept of matter, but also reconceptualizing matter as something that occupies space and has weight, and learning that air and other gases share these properties.

Children, of course, know much more about the world of everyday objects—toys, animals, vehicles, clothing, furniture, food—and liquids, especially those that they drink—water, milk, and juice. But these objects and liquids seem to be fundamentally different from air given their appearances and how they behave. Consider: Objects are things that you can see, feel, touch, and hold in your hand. They have heft; they take effort to hold and move. When you let go of them, they drop to the floor. Objects also take up space. In contrast, air is different. Air is invisible and odorless—something that you cannot see, feel, touch, or hold in your hand. Air doesn't have heft or appear to take up any space.

Thus, it is not surprising that when children are asked to put together the things that are alike in that "they are matter or made of some physical stuff," they almost never group air with solids or liquids. Indeed, when I asked my daughter that question when she was six, she laughed and said "Of course not—you can't see air or feel it or touch it." For her, air was prototypically *non-material*, something she grouped with other immaterial things like heat, light, shadows, dreams, and ideas. (Heat and light actually gave her more pause than air because you could *feel* heat and *see* light; she ultimately concluded these were not matter too because what was critical was to have a confluence of perceptual cues—seeing, feeling, AND touching in order to be matter.) These ways of responding are typical for elementary school (and many middle-school) students.

We can't simply tell children "matter comes in three phases—solid, liquid, and gas" and expect them to understand. And we can't "simply wait until they are old enough to understand," as children don't magically become ready to accept air is matter at a certain age. Rather, the solution is to realize that we need to prepare the ground in indirect ways for their learning that air is matter: by helping them elaborate on their ideas about solid and liquid materials and their properties, including that they have weight and take up space. This is exactly what the learning progressions approach of the Inquiry Project aims to do.

—Carol L. Smith

**The Scientist's Essay for *4. Air, a Gas***

# What's important about air and gases?

By far the most important thing about gases is simply that they exist. They are not nothing, but are another form of "stuff" (matter) just like solids and liquids. They have mass and are comprised of molecules.

> *The molecules are not in the gas, they are the gas. There isn't anything else. The vast majority of the volume of a gas actually is literally nothing.*

The main reason gases seem so insubstantial is that they're typically *much* less dense — about a thousand times less — than solids and liquids. That low density means that the molecules in a gas are much farther apart than in solids and liquids — about ten times farther apart on the average — which means they're not attached to each other, and in fact are pretty much non-interacting, except when they bounce off each other. The lack of interaction, in turn, makes gases actually much easier to understand at a fundamental level than solids or liquids. That's why there's an "ideal gas law" but no "ideal solid law" or "ideal liquid law".

If the molecules are that far apart, then what's in between them? Nothing. Really. The molecules are not *in* the gas, they *are* the gas. There isn't anything else. The vast majority of the volume of a gas actually *is* literally nothing. All the mass is in the molecules, but at any given moment they take up only about one thousandth of the volume. But keep in mind that "far apart" here is only relative to solids and liquids. The average distance between molecules in air is about one ten-millionth of an inch — it's not like you can walk between the molecules. Also the molecules are in constant, rapid motion — a typical molecular speed in air is several hundred miles per hour. So even though at any given instant the molecules occupy a small fraction of the volume, the "empty" spaces have molecules passing through them all the time.

Under the right conditions — low enough temperature and/or high enough pressure — any gas can condense into a liquid. We see this with water vapor when it condenses on a cold surface. But even air itself can be liquified; it just requires *very* low temperatures, far below anything that occurs even in the coldest places on earth. Still, with the right equipment it's not that hard to do. Liquid nitrogen is cheaper than milk.

Finally, air is not the only gas. The bubbles in boiling water, for example, contain essentially pure water vapor. Air itself is a mixture of gases (about 4/5 nitrogen and 1/5 oxygen, with much smaller amounts of argon, water vapor, carbon dioxide and other stuff), though this isn't something we're emphasizing in the present curriculum.

—Roger Tobin

## 4. Air, a Gas: Investigation 13

# *Is air matter?*

## Plan Investigation 13

Air is our most familiar example of the state of matter we call gas. We live immersed in it and depend on it to stay alive. It's also invisible, not particularly tangible, and can be challenging to investigate. But, like solids and liquids, air is matter. It has weight (more than we might imagine), it takes up space, and it is composed of particles too small and too spread apart to see. Air, a mixture of gases, shares properties with water vapor, the gaseous form of water that is part of air. Understanding air helps us understand water vapor.

This investigation is the first in a sequence of four in which students investigate the properties of air. In spite of our being able to move freely through air, students establish that air takes up space as they manipulate a system of coupled syringes. Through a convincing balloon demonstration, it is also established that air has weight.

**Formative Assessment**

*Can your students use data to reason that air is matter?*

Available online at inquiryproject.terc.edu

By the end of this investigation students will have evidence that air takes up space, has weight, and, therefore, is matter. Students will be introduced to the idea that air is composed of particles too small and too spread apart to see.

### Learning Goals

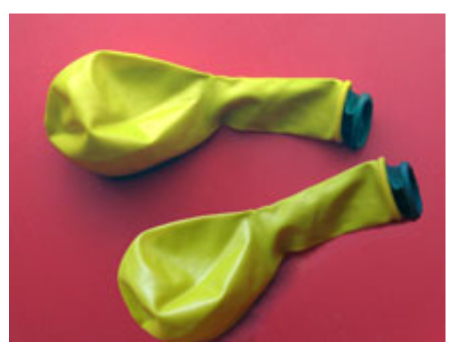
- Understand that air takes up space, has weight, and is matter composed of particles too small and too spread apart to see

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Explore air in a closed system | Pairs | 10 Mins |
| 3. Weigh balloons | All Class | 15 Mins |
| 4. Make meaning | All Class | 10 Mins |

### Materials and Preparation

Preparation:

- Cut twelve 16in long pieces from the coil of clear plastic 1/4-inch tubing
- Assemble two sets of 16in double balloons. A double balloon is a set of two balloons, with one balloon inserted into the other balloon. Sliding the balloons over the eraser end of a pencil will help insert one balloon inside the other.
- Press a rubber stopper firmly onto the tip of the balloon pump (See photo).



- Practice using the balloon pump to inflate and tie off a double balloon. Only the inner balloon needs to be tied. Use one hand to squeeze the balloons against the rubber stopper. With the other hand, use rapid, continuous motion of the pump handle to inflate the double balloon to near-maximum size.
- Perfectly balance a double pan balance that has an uninflated double balloon in each pan.

For the class:

- Post the investigation question in a place where all students can see it.
- Dot Sheet 2 (See Resource Quick Links)
- 1 double pan balance, perfectly balanced with an uninflated double balloon in each pan
- 1 balloon pump with rubber stopper inserted onto the tip
- 2 sets of 16in double balloons

For each group:

- 2 16in lengths of clear plastic 1/4-inch tubing
- 4 12cc syringes

### Concept Cartoon

The Air Has Weight Concept Cartoon is typically used as a formative assessment at the end of this investigation.

## 1. Ask the question

All Class 10 Mins

### Review

Review some of the important ideas about ice, water, and particles.

- When a container of water freezes, or a container of ice melts, the *weight remains the same*.
- We use weight to measure and track the amount of matter.
- When water freezes, its volume increases.
- When ice melts, its volume decreases.
- When water freezes or ice melts, the properties change but the material does not.
- Ice and water are different states of the same material.
- Condensation forms from water vapor in the air.
- Condensation is the reverse of the process of evaporation.
- Scientists believe all matter is made of particles too small to see.
- In ice, particles are locked together, even when they vibrate, and hold their shape.
- In water, particles slide past and collide with one another, and take the shape of its container.

Ask students if they would like to make any additions or changes.

### Launch the new strand

Explain that students are about to spend four science classes investigating air. When particles are clumped together, we can see the matter and use our classroom tools to measure the weight and volume. When the tiny particles are spread apart, we cannot see them. Water vapor is an example of a material whose tiny particles are spread apart so we can't see them. Air is another example. Air is actually a mixture and water vapor is part of air.

Today's investigation question is:

*Is air matter?*

Students have measured the weight and volume of both solid and liquid materials, and have established they are matter. Today students use some new tools as they look for evidence to determine whether or not air is matter.

## 2. Explore air in a closed system

Pairs 10 Mins Notebook

Before you distribute the tubing and syringes, remind students that if air is matter, it has to take up space. A question is:

*Does air take up space?*

What positions do students take? Be sure to hear from students with positions on each side of the question. Ask students to make a claim and to provide the evidence or reasoning on which their claim is based.

Give each pair of students two syringes and a 16-inch length of clear plastic tubing, to set up the following system:

- Set the plunger of each syringe at the middle of its barrel (the 6 cc line).
- Push one end of the clear plastic tubing onto the tip of each syringe.

Describe this set-up as a *system*.

*What are the components of this system?*

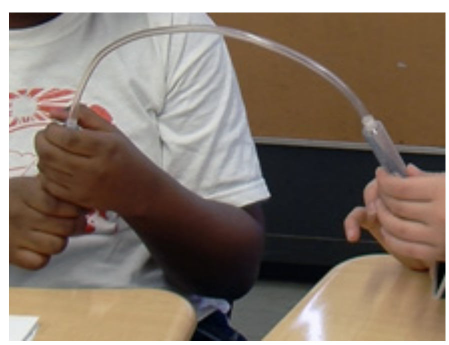
- The 2 syringes, tube, and air.

*Do you think this is an open or closed system?*

- Like the 2-bottle system, the connected syringes form a closed system. Nothing can get in or out once the system has been set up.

*How do we describe the boundary (outside edges) of this system?*

- The outside of the tubing and syringes.



Have students explore the system. *It takes no more than a minute or two* for students to explore how the system works. The point is to let them experience a situation in which air clearly takes up space.

*What happens when you push one plunger very slowly while not touching the other plunger?*

*What happens when you push one plunger very quickly while not touching the other plunger?*

*Do you find evidence that air takes up space?*

Collect the syringes while students write a response to the *[Does air takes up space?]* page in their Science Notebooks.

## 3. Weigh balloons

All Class 15 Mins Notebook

**The Weight of Air**

If you scoop a cup of water out of a large pot you can feel its weight. If you pour that water back into the pot, you would not expect that weight to cause the water to sink to the bottom of the pot and stay there, as if it were a rock. The water from the cup will mix in with and drift through the rest of the water as if it were weightless, because it has the same density as the water in the pot.

For the same reason, any specific quantity of air in the atmosphere appears to be weightless. However, air does have weight. Air pressure, which we hear about in weather reports, results from air's weight. Since we live with air pressure all around us, and even inside of us (e.g., lungs) we do not sense it. Even scales do not sense the weight of air, because they are completely surrounded by air pressure.

One way to demonstrate that a sample of air has weight is to make it denser than the surrounding air. It that case, the sample will sink in the atmosphere. Cold air is denser than warm air; more particles are packed into each cubic centimeter. Open the freezer door and you'll feel the cold air spilling down towards the floor. Compressed air is denser than uncompressed air, with more particles packed into each cubic centimeter.

*Why a double balloon?*
A balloon resists being stretched, so as it is inflated it compresses air particles closer together, making that air more dense than the uncompressed air in the room. A double balloon offers even more resistance to being inflated, and compresses the air particles even closer together, making the enclosed air dense enough for a balloon-sized quantity to tip the pan balance.

Students may not need this much information. The demonstration speaks for itself.

Remind students that if air is matter, it must have weight. A question is:

*Does air have weight?*

- No, you can't feel air and it doesn't register on a scale.
- Yes, because my soccer ball feels heavier after I pump it up with air.

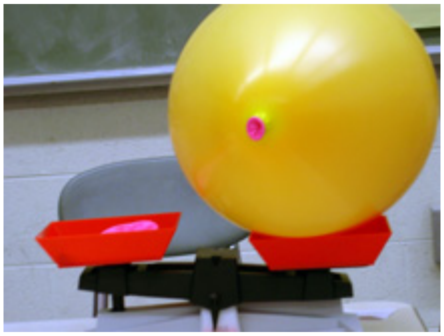
What positions do students take? Be sure to hear from students with positions on each side of the question. Ask students to make a claim and to provide the evidence or reasoning on which their claim is based.

Show students the uninflated double balloons placed on each side of the double pan balance. Point out that the two sides balance and so there are equal weights on both sides. Next, ask students to imagine that the balloons on one side of the balance are inflated.

*What will we observe if air doesn't weigh anything?*

*What will we observe if air does have weight?*

Use the balloon pump (with the rubber stopper) to inflate one set of doubled balloons to its full size. Using a balloon pump to inflate a balloon avoids adding moisture from your lungs into the balloon, which in turn helps to establish the fact that "dry" air has weight.



Tie off the opening of the inner balloon and return the inflated double balloon to the double pan balance. The pan with the inflated double balloon will move down.

*Do we have evidence that air has weight?*

Students record their responses on the *[Does air have weight?]* page in their Science Notebooks.

## 4. Make meaning

All Class 10 Mins

**Note:** Students may claim that air has weight and takes up space *only when it is in a container*. Does it make sense that weight and volume disappear once the closed system is open? Weight and volume of air are easier to *perceive* and *measure* when it is in a closed system and that is why we used the balloons in this investigation.

### Purpose of discussion

The purpose of this discussion is to help students make sense of the results of today's experiences, which provide evidence that air has weight and takes up space. Students may feel that today's results are in conflict with other experiences they have had with air. Focus the discussion on the investigation question: Is air matter?

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Engage students in the focus question?

*Is air matter or not?*

*Does air take up space? What is your evidence?*

*Does air have weight? What is your evidence?*

**Claim or position:** Air takes up space:

- When I take a really big breath of air, my chest expands.
- An inflated balloon takes up more space than an uninflated balloon.

**Claim or position:** Air doesn't take up space:

- I can walk right through air. (We can also walk through water, but we agree that water takes up space.)
- When a classroom is "filled" with air, how can there be room for students to come into it? (Unlike the syringes, the classroom is an *open system*; when students come in, they push some of the air out.)

**Claim or position:** Air has weight:

- When we put air in one set of balloons the balance went down on the side with the inflated balloon.

**Claim or position:** Air doesn't have weight:

- Scales don't register the weight of air.
- We can't feel weight even if there's a lot of it on top of us.

### Summarize the discussion and recap the investigation

Summarize the arguments for each position. See if there is consensus for the argument that air takes up space and has weight, and therefore, is matter.

Thinking of air as matter, which puts it in the same category as the sand, gravel, and water in the mini-lakes, can require an adjustment in our thinking.

Remind students of the dissolved salt. It's easy to think of salt as matter, but even after the salt particles became too small and too spread apart to see, the salt maintained its weight and it still took up space: it maintained its classification as matter. This may be the strongest connection students can make between air and another substance they accept as matter.

Reiterate the concept that air has weight and takes up space, and thus is matter. The reason we can't see air is because the particles are tiny on a scale that's hard to imagine and are spread far apart. On a windy day, we have an easier time sensing the presence of air.

# Air Has Weight Concept Cartoon

This cartoon was developed to assess students' ability to:

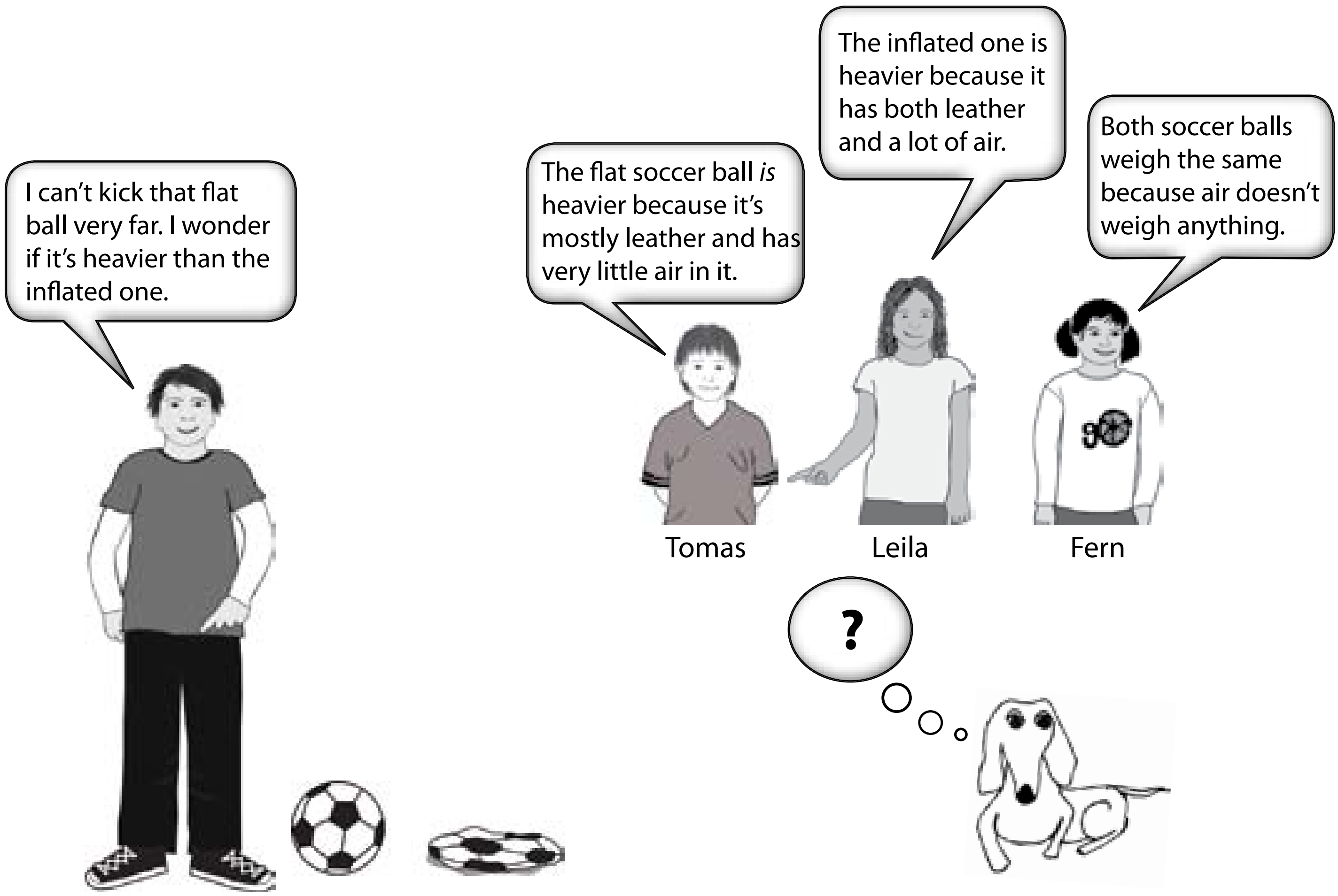
- Explain that air has weight and is matter and, therefore, makes the ball heavier; this requires that they distinguish the objective weight of materials from their felt weight (air weighs something because it is matter from air weighs nothing at all because I don't feel it in my hand) and the absolute weight of a object from its density or heaviness for size.

This cartoon is typically used after Investigation 13, *Is air matter?*


## Things to look for in student responses

Do students realize that an object's weight increases when air is added?

- Some students may agree erroneously with Tomas that air may make objects feel lighter because they are less dense or less heavy for size or because air has intrinsic lightness (i.e., adding air makes things lighter). These students may be confusing weight with density. Those who disagree may point out that air is matter, matter has weight, so if you add air, you are adding weight to the deflated ball.
- Others may agree with Leila, who points out that if you add air to the leather the weight will increase, because air is matter and all matter has weight. Students who have observed that when air is added to a balloon the weight increases (albeit slightly because air has a very low density) may use this as further evidence for agreeing with Leila. These students are giving evidence of moving away from thinking of weight as felt weight to weight as linked to amount of matter and measured on a balance scale.
- It's not unusual for students to think that air doesn't weigh anything and so agree with Fern. These students may say that they can't feel air in their hand, giving evidence that they are thinking about felt weight rather than objective weight. Students who have observed that when air is added to a balloon the weight increases (albeit slightly because air has a very low density) may use this evidence to disagree with Fern.




Write a response to each of the children. What you think of each of their ideas and why?

Tomas: ________________________________________

Leila: ________________________________________

Fern: ________________________________________

## 4. Air, a Gas: Investigation 14

# *What are some properties of air? (1)*

## Plan Investigation 14

If you have added air to the tires of a car or a bicycle, you have had some experience with compressed air. It takes some effort, but it's possible to squeeze a large volume of air into a significantly smaller space. This is not true for liquids or solids, which are essentially incompressible. What is it about air, and gases in general, that allows it to be compressed? In comparison with solids and liquids, the individual particles (atoms or molecules) of any gas are quite far apart from one another, with nothing but a vacuum in between them. Therefore, when pressure is applied to a gas, the particles can be squeezed closer together.

Today students continue to explore the properties of air. Students compare the compressibility of air and water and then develop an annotated drawing that responds to the question, "How do you explain the difference in the compressibility of air and water?"

By the end of this investigation students will understand that, in contrast with liquids and solids, air is observably compressible.

**Formative Assessment**
*Can students envision what might happen at the microscopic level to explain why air is more compressible than water?*

Available online at inquiryproject.terc.edu

### Learning Goals

- Understand that air is compressible

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Explore compressibility | Individual | 15 Mins |
| 3. Create an annotated drawing | Individual | 20 Mins |

### Materials and Preparation

Preparation:

- Fill 4 12cc syringes with water, eliminate air bubbles, and install caps to the open ends using finger pressure. Do not use a lot of force to tighten the caps.
- Fill 4 12cc syringes with air and install caps to the open ends using finger pressure.

For the class:

- Post the investigation question in a place where all students can see it.
- Annotated Drawing Poster (See Resource Quick Links, also used in Investigation 6)
- Make a class chart titled, "Properties of Air"; an example is found in Step 1.
- 2 1gal buckets
- 4 12cc syringes filled with water, with caps
- 4 12cc syringes filled with air, with caps


For each group:

- 4 12cc syringes without caps

**Prepare for use in Investigation 15:**

- 12 copies of each of the two annotated drawings you select from today's class

## 1. Ask the question

All Class 10 Mins

Now that air has been established as matter, students begin a list of air's properties. Introduce the investigation question:

*What are some properties of air?*

Record properties of air that students can identify. As they mention a property ask for evidence or reasoning that supports their claim.

**Properties of Air**

| Properties | Evidence or Reasoning |
|---|---|
| Air is invisible. | I can see through it. |
| Air has weight. | I saw the filled balloons tip the balance in the last science class. |
| Air takes up space. | Air made the plunger of the syringe move. |
| Clear air has no odor or taste. | Personal observations. |

Save the list of properties; students will add properties as they continue their investigation of air.

Introduce the term compressible – able to be squeezed or pressed into a smaller size or volume. One property of a rock is that it is not visibly compressible. One property of a sponge is that it is visibly compressible. Explain to students they'll be exploring the compressibility of air and how it compares with the compressibility of water.

## 2. Explore compressibility

Individual 15 Mins Notebook

### Predict

*Do you think that air and water are compressible?*

Have students predict and explain their reasoning in their Science Notebooks, *[Predicting the compressibility of water and air]*.

### Air in a single syringe

Distribute a 12cc syringe to each student. Direct students to:

1. Pull the plunger back to the 12cc mark.
2. Cover the small opening in the syringe barrel with the palm of one hand.
3. Push the plunger.
4. Consider these questions:

   Does the plunger move?
   What happens when you release the plunger?

Students only need a minute or two to explore the compressibility of air with the syringes. Collect the syringes when they are finished.

> **Note:** As students explore the compressibility of air, they may become interested in whether or not the syringe plunger returns to the exact same spot once it has been released. It may not, due to friction between the rubber seal and the plastic barrel of the syringe, or because a tiny bit of air leaked out between the syringe and the palm of the hand. Neither of these possibilities should distract from the big idea that air can be squeezed into a smaller space, and will expand again once the plunger of the syringe is released.

### Water and air in a syringe

*How does the compressibility of water compare with the compressibility of air?*

Move from group to group with two plastic buckets each holding two capped water-filled syringes and two capped air-filled syringes. Under your supervision, give four students at a time an opportunity to compress water and air in syringes. Be sure students point the capped ends of their syringes into one of the plastic buckets before they apply pressure to the plungers. In the unlikely event that the pressure causes a cap to release, the water and cap will end up in the plastic bucket.

Provide a few minutes for students to record observations on the *[Observing the compressibility of water and air]* page in their Science Notebooks.

*Is there another property of air we can now add to the list?*

- Air can be squeezed into a smaller space; it is compressible.

> **Note:** Liquids and solids are compressible, but only to a tiny degree in comparison with air or gases in general.

*Does this compressibility change our finding that air takes up space?*

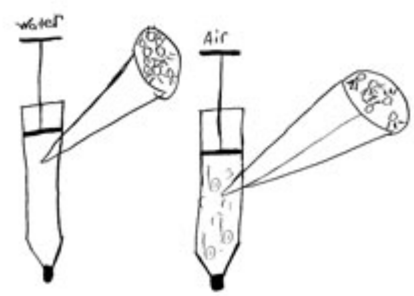
- No. Air still takes up space, but the amount of space it takes up can change when it is squeezed or compressed in a closed system. (Sealing the opening of the syringe changes it temporarily into a small closed system.) Air can't be squeezed so much that it takes up no room at all.

> ***Letter from the Engineer***
> *When you compressed air in the syringe, maybe you noticed that it pushed back with a little bounce. Air acts somewhat like a spring. You can compress it, or squeeze it into a smaller volume. When you push on the plunger you can feel the air pushing back. When you stop pushing, the air inside the syringe will return to its original size.*
>
> *There are different ways to compress air. One way is to squeeze a certain volume of air into a smaller space. That's what you did with the syringe. Another way is to use a pump, like a bicycle pump, to squeeze extra air into something that is already full of air. That's what you do when you pump air into a basketball, soccer ball, or bicycle tire. Why is it possible to add more air to something that is already full of air? Only because air is easily compressible — the particles can be squeezed closer together. (Remember how different it felt when you tried to compress water in the syringe?)*
>
> *The bouncy feeling you notice when you compress air can be very useful. When you dribble a basketball, the part of the ball that hits the floor gets pressed into the ball a little bit. It's a little like pushing the handle of the syringe or squeezing a spring. The air inside the ball gets squeezed, and it springs back, just like the handle of the syringe did. This "springing back" makes the ball bounces back up to you. Maybe you have tried to dribble a basketball or kick a soccer ball that did not have much air in it. If you have, you know the ball does not have the same kind of springiness or bounce.*

## 3. Create an annotated drawing

Individual | 20 Mins | Notebook

Use the Annotated Drawing poster to review the purpose and important characteristics of an annotated drawing. Students may want to review the Annotated Drawings at the back of the Science Notebook. They should make their drawings on the page *[Explaining the compressibility of water and air]* in their Science Notebooks. Their drawings should answer the questions below.




*How do you explain the difference in the compressibility of air and water?*

*What would you see at the particle level to explain what is going on?*

> **Note:** You will need to select two drawings that offer different explanations for students to review in the next investigation. Try to find a drawing that portrays water as made of particles that are packed together (making it visible) and air as made of particles that are spread apart (making air invisible) and select it for the class to review. Select a second drawing that portrays an alternate explanation of the composition of water and air. Alternately, you can choose to use the Sample Annotated Drawings found in the References.

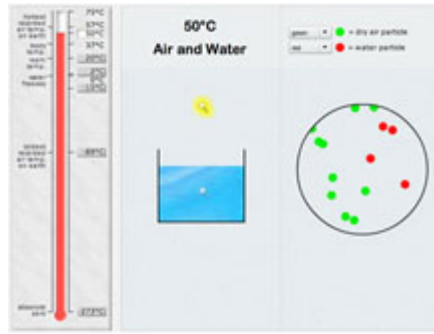
### Recap the investigation

Explain that you are going to select two annotated drawings based on different ideas about why air is compressible and water is not. The class will discuss those drawings at the start of the next investigation.

## 4. Air, a Gas: Investigation 15

# *What are some properties of air? (2)*

## Plan Investigation 15




At the macroscopic scale, air is common and familiar. At the particle scale, it remains such a mystery. In the seemingly still air of a room, countless particles (molecules) of nitrogen, oxygen, water vapor and other gases move faster than the speed of sound, constantly colliding with one another.

In today's investigation, students discuss two annotated drawings that explain the difference in compressibility between air and water. They use their experience with the Particle Magnifier to reason why water is not compressible. In discussion, they generate ideas about a particle explanation for the compressibility of air. This sets the stage using the Particle Magnifier to look at the particle model of air, a gas.

By the end of this investigation, students will understand that air is composed of particles too small and spread out to see. They will understand that because the particles are spread out, there is space for them to move closer together when air is compressed. Students will also know that air is a mixture of gases.

### Learning Goals

- Understand that air is made of particles too small and spread apart to see
- Understand that air is a mixture of different gases, including water vapor
- Understand that the relative compressibility of air and water can be explained in terms of the configuration of their particles

| Sequence of experiences | | |
|---|---|---|
| 1. Discuss annotated drawings | Discussion | 20 Mins |
| 2. Show the Particle Magnifier | All Class | 15 Mins |
| 3. Add to Properties of Air chart | All Class | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Annotated Drawing Poster (See Resource Quick Links, also used in Investigation 6)
- 12 copies of each of the two annotated drawings you selected from the previous investigation or Sample Annotated Drawings (See Resource Quick Links)
- Dot Sheet 1 and Dot Sheet 2 (See Resource Quick Links)
- The Particle Magnifier (Water-Air), using a classroom computer and projector or Smart Board
- Properties of Air chart with the addition column: Particle Explanation; an example is found in Step 2.

**Prepare for use in Investigation 16:**

- Create bubble mix with the following ingredients. Mix these liquids, cover, and let sit for at least 12 hours prior to Investigation 16.
    - 80cc water
    - 40cc Joy dishwashing liquid
    - 10cc glycerin

## 1. Discussion: comparing annotated drawings

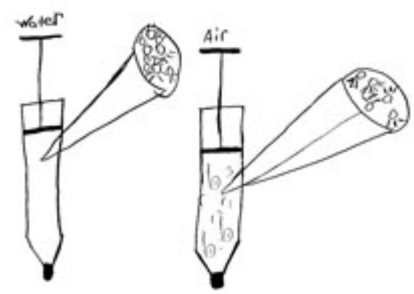
Discussion 20 Mins

### Purpose of the discussion

The purpose of this discussion is for students to develop more refined explanations for the differences they have observed in the compressibility of air and water. The discussion also generates a need for thinking about air on the particle scale. The discussion focuses on the question: *Are air and water compressible?*

### Prepare for all class discussion

Distribute two annotated drawings you selected from Investigation 14 for students to discuss in pairs. Have student pairs briefly review and discuss the two drawings (5 minutes).




Students should use the discussion questions on the Annotated Drawings poster that you have displayed (these are also found on the Annotated Drawings resource at the back of the Science Notebooks).

- What are these drawings trying to explain? (FYI: the reason why air is compressible and water is not)
- Do you see anything in the drawing that you don't understand or would like clarified?
- If you compare the two annotated drawings, how are the explanations the same? How are they different?

Begin the all-class discussion by noting that water is not compressible. Remind students that they used the Particle Magnifier to look at the arrangement of particles in water. You may want to show the class Dot Sheets 1 and 2.

### Engage students in the focus question

*Why do you think air could be compressed and water could not?*

*Why do you think the water could not be compressed?*

- Water is visible so this means the particles are close together. (Dot Sheet 1 ,Äì liquid water)
- Water cannot be visibly compressed because the particles are already close together and can't get any closer.

Next, build on students' ideas about why water can't be compressed to think about why air is compressible. Keep the focus on particles in these explanations.

*Why do you think air* ***can*** *be compressed?*

- Air is invisible so this means the particles are more spread out than particles of water. (Dot Sheet 2 – air)
- There are wider spaces between the particles of air.
- Air is visibly compressible because there is a lot of space for the particles to be squeezed closer together. This is not true for water, or for any liquid or solid.

### Summarize the discussion

Students may not reach a scientifically accurate explanation of compressibility. This presents the need for a model of what is happening at a scale too small to see. The scientist's model of the structure of air in the Particle Magnifier is introduced.

## 2. Show the Particle Magnifier

All Class 15 Mins

**Note:** The full version of the Particle Magnifier (Water-Air) allows users to view air and water vapor in addition to the ice / water inside the container. There is no magnifier in the air at -273°C. Nitrogen, oxygen, and all of the elements that compose our atmosphere would be solids before the temperature reached absolute zero.

Unlike the ice-water transformation, there is no emphasis on gradual change in air with temperature change. The key point to highlight is the contrast between air and water.

Remind students that this is an animation that shows what scientists think happens. At each temperature, ask students:

*What are the particles doing now? What has changed?*

| Temp | Notes | Likely student observations |
|---|---|---|
| +2°C | Show water. This is a reminder to help highlight the difference between water and air. | • This is liquid water. The particles are not "locked" in a grid. They are sliding around and bumping into one another. |
| +2°C | Show air. | • The particles of air are much more spread apart than the particles of liquid water.<br>• The particles are the same size.<br>• There is some water vapor (the gas form of water) in with the air. |

This is the first time students have seen air represented as distinct particles. Remind them of these key points:

- Students have evidence that air has weight, and takes up space, and is therefore matter.
- Scientists have learned that all matter is made of tiny particles too small to see.
- When tiny particles are clumped together, as they are in water, we can see the matter. (Dot Sheet 1)
- When those particles are spread apart, as they are in air, or in salt that has been dissolved in water, we cannot see the matter. (Dot Sheet 2)

Move back and forth between water and air, at different temperatures, highlighting the difference in the distance between particles.

*What are your ideas now about why air is compressible and water isn't?*

- There is more space between the air particles so there's room for them to move together when air is compressed (squeezed).

## 3. Add to Properties of Air chart

All Class 10 Mins

Refer to the chart. Add air is compressible to the properties list. Point out that there is now a third column in the chart called Particle Explanation.

> *How can we explain each property in terms of particles that make up air and the spaces between them?*

Model a response by completing the first row yourself.

***The first property is air is invisible. A particle explanation would be air particles are too tiny and too spread out to see. We used Dot Sheet 1 to help us understand this.***

Complete the Particle Explanation column for the properties listed so far.

**Properties of Air**

| Properties | Evidence or Reasoning | Particle Explanation |
|---|---|---|
| Air is invisible. | I can see through it. | Air particles are too tiny and too spread apart to see. |
| Air has weight. | I saw the filled balloons tip the balance in the last science class. | Air is matter and each air particle has a tiny bit of weight. |
| Air takes up space. | Air made the plunger of the syringe move. | Air is matter and each air particle takes up a tiny bit of space |
| Air has no odor or taste. | Personal observations. | |
| Air is compressible. | I squeezed the syringes from 12ml to 6ml and when I stopped squeezing, the plunger returned to 12ml. | Air particles have a lot a space between them so they can be squeezed together. |

### What's in air?

Explain that although all of the air particles looked the same in the Particle Magnifier, air is actually a mixture of different gases.

Just two gases, nitrogen and oxygen, make up more than 99% of the volume of dry air at ground level. Water vapor in the air varies from a trace to 4%. The amount of water vapor is limited by the temperature of Earth's atmosphere. More than a dozen gases exist in air in tiny amounts, (these are called trace gases) including neon, helium, methane, hydrogen, ozone, carbon monoxide, and sulfur dioxide.

### Recap the investigation

Review the key ideas of the investigation:

- Like water, air is made of unimaginably tiny particles.
- Air particles are too small and too spread apart to see.
- The greater space between air particles explains why air is compressible while water is not.
- Air is a mixture of different gases, including water vapor.

## 4. Air, a Gas: Investigation 16

# *What are some properties of air? (3)*

## Plan Investigation 16

If you had a high-speed camera that could capture a photograph of the billions of billions of speeding molecules in a cubic centimeter of air, there would not be much to see. The actual air molecules take up only one tenth of one percent of the space they occupy. At room temperature, most of that cubic centimeter of air, 99.9%, is actually vacuum. Heat up that one cubic centimeter of air and the percent that is vacuum would increase.

Today students observe the effects of heating and cooling 1,000 cubic centimeters of air. They make annotated drawings that explain these effects in terms of heating and cooling air at the particle level. They complete the list of properties of air they began in Investigation 13.

By the end of this session students will understand that air expands when it is warmed and contracts when it is cooled and these phenomena can be explained in terms of the motion of particles.

### Learning Goals

- Understand that air expands when it is warmed and contracts when it is cooled and these phenomena can be explained in terms of the particles that make up gases
- Understand the connection between change in temperature and change in particle speed

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 5 Mins |
| 2. Use the Particle Magnifier | All Class | 5 Mins |
| 3. Make annotated drawings | All Class | 10 Mins |
| 4. Discuss annotated drawings | All Class | 15 Mins |
| 5. Add properties | All Class | 10 Mins |

### Materials and Preparation

For the class:

- Post the investigation question in a place where all students can see it.
- Properties of Air chart (from Investigations 14 and 15)
- Annotated Drawing Poster (See Resource Quick Links, also used in Investigation 6)
- The Particle Magnifier (Water-Air), using a classroom computer and projector or Smart Board
- Bubble mix (prepared earlier)
- 1 12oz plastic cup
- 1 1-liter plastic bottle
- 2 1gal buckets 1/2 filled with hot and cold water

## 1. Ask the question

All Class 5 Mins

Today students will investigate another property of air that scientists call thermal expansion. Later the class will complete their list of properties in answer to the investigation question:

*What are some properties of air?*

The temperature of air can change. We've all felt the difference between warm summer air and colder winter air. Explain that students are about to collect some evidence to answer the question *What happens to the volume of air as it's warmed or cooled?*

### Demonstrate warming and cooling air

**Note:** The following teacher - led demonstration works well as long as the water in one bucket is noticeably warmer than room temperature, and the water in the other bucket is noticeably cooler than room temperature.

Show students the 1L bottle of room temperature air. Ask them to predict and explain their reasoning.

*What do you predict will happen to the volume of air in this bottle if we warm it? Will it stay the same, become larger, or become smaller?*

*What if we cool it?*

Provide a few minutes for students to gather their ideas. Then ask for a few people to share their ideas with the class. Check for students' understanding of "volume" - the amount of space the air in the bottle takes up. If the volume of the air becomes larger, it will need more space than the inside of the bottle - where is there additional space for it to move to?

Introduce a way to test students' predictions by putting a flexible material -- a thin soap film -- over the top of the air-filled bottle, changing it from an open to a closed system, and do the following demonstration.

Narrate your procedure as you move through the steps.

- Half-fill two plastic buckets, one with hot water and one with cold water.
- Dip the opening of a 1L bottle into the bubble mix to create a soap film that seals the room temperature air in the bottle. This turns the bottle into a closed system.
- Turn the bottle upright and place the lower half of the bottle into the hot water to warm the air.
- Place the lower half of the bottle into the cold water to cool the air.
- Repeat the process.

**Note:** It's important that students have an opportunity to share their ideas about why the bubble formed, but it's not important that they develop a scientifically accurate explanation at this moment. Soon they will see what happens when air is warmed and cooled in the Particle Magnifier.

Provide a few minutes for students to gather ideas about what's happening to the air to make the bubble form.

*What did you observe?*

- When the air was warmed, a bubble formed.
- When the air was cooled, the bubble disappeared and the soap film slid down into the bottle.

*Why do you think the bubble formed?*

- The warmed air expanded.
- Air entered the bottle.
- Warm air rises.

If students claim that the bubble formed because warm air *rises*, turn the bottle so that the bubble is lower than the bottom of the bottle. The warmed air will not rise to the now elevated bottom of the bottle, and the bubble will not deflate.

**Note:** The temperature increased meaning the air particles inside the bottle were moving faster, colliding more forcefully so the air expanded, pushed on the soap film, and caused a bubble to form. When the bottle of air was cooled, the particle motion decreased, so the air contracted and the soap film moved down inside the bottle.

## 2. Use the Particle Magnifier

All Class 5 Mins

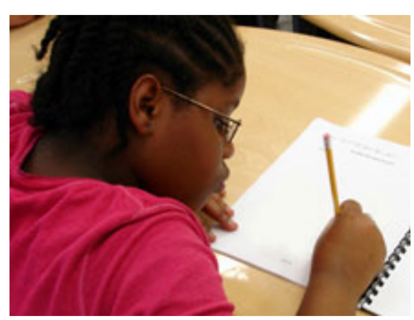
Remind students that air is made of particles too small and too spread out to see. Show the Particle Magnifier once again, asking students to look for the changes that occur at the particle level when air temperature is increased or decreased. Draw attention to the connection between increased temperature and increased particle speed.

| Temp | Notes | Likely student observations |
|---|---|---|
| +50°C | Show air. | • The particles of air are spread farther apart.<br>• The particles are moving faster.<br>• There is more water vapor in with the air. |
| +2°C | Show air. | • The particles of air are closer together.<br>• The particles are moving more slowly.<br>• There is less water vapor in with the air. |

**Optional:** The Science Notebook page *[Particle Magnifier air particles]* is available for you to assign if time permits.

## 3. Make annotated drawings

All Class 10 Mins Notebook



Use the Annotated Drawing poster to review the key points about annotated drawing.

Ask students to make an annotated drawing in their Science Notebooks on the page *[Heating and cooling air]*. These drawings should:

- **Show** what happened when the bottle of air was placed in warm water and **explain** why it happened.
- **Show** what happened when the bottle of air was placed in cold water and **explain** why it happened.

## 4. Discuss annotated drawings

All Class 15 Mins

### Purpose of the discussion

The purpose of the discussion is for students will understand that air expands when it is warmed and contracts when it is cooled and these phenomena can be explained in terms of the motion of particles.

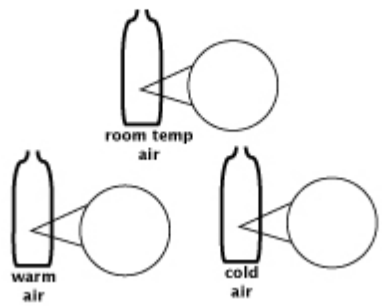
Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

### Engage students in the focus question

*How do warm air, cool air, and room temperature air differ?*

Make a large sketch similar to the one in the Science Notebooks.




- Ask students how you should draw the soap film in all three bottles.
- Draw particles of room temperature air in the magnifier circle.
- Ask students to recommend how you should draw the particles in the magnifier circle for warmer air. Encourage them to refer to their own ideas that they represented in their drawings.

  *What is the same about the particles in room temperature and warmed air?*

  - They are the same size — the particles stay the same.

  *What is different about the particles?*

  - They are farther apart (are more spread out, there is more space between them).

  *Why did the bubble form?*

  - When the temperature is higher, the particles move faster and they bump into each other more often and move farther apart making the air take up more space.
  - ==> The only space the air could move to was outside the bottle so the air pushed up on the soap film.

Draw the particles in the magnifier circle for the cooler air.

*Why did the soap film move down into the bottle when the air was cooled?*

- When the air is cooler, the particles move more slowly and they moved closer together. When there was less space between the particles, the air in the closed system took up less space in the bottle so the soap film moved down.

*If you put a magnifier on air near the top of the bottle and one on the air that's near the bottom, how do you think the particles and spaces between them would compare?*

- They would look the same in both places because air particles are evenly distributed in the bottle.

It is not unusual for students to think that "hot air rises" so there will be more air particles near or in the bubble and few or none at the bottom of the bottle. You may want to explain that if we were able to see the particles, we would find they are quite evenly distributed throughout the bottle.

- There will be many more air particles near the top than at the bottom of the bottle (a frequently held but incorrect idea)

**Summarize the discussion and recap the investigation**
To summarize the discussion, complete the properties of air chart and review the key ideas for today

## 5. Complete the Properties of Air chart

All Class 10 Mins

*What additional properties of air can we add to the list?*

**Properties of Air**

| Properties | Evidence or Reasoning | Particle Explanation |
|---|---|---|
| Air is invisible. | I can see through it. | Air particles are too tiny and too spread apart to see. |
| Air has weight. | I saw the filled balloons tip the balance in the last science class. | Air is matter and each air particle has a tiny bit of weight. |
| Air takes up space. | Air made the plunger of the syringe move. | Air is matter and each air particle takes up a tiny bit of space |
| Air has no odor or taste. | Personal observations. | |
| Air is compressible. | I squeezed the syringes from 12ml to 6ml and when I stopped squeezing, the plunger returned to 12ml. | Air particles have a lot a space between them so they can be squeezed together. |
| Air expands when it is warmed. | I saw the bubble form when the bottle was placed in warm water, even when the plastic bottle was held upside down. | When temperature increased, air particles move faster, collide harder, spread apart, so the air takes up more space. |
| Air contracts when it is cooled. | I saw the bubble shrink when the plastic bottle was placed in cool water. | When temperature decreased, particles slow down, get closer together, and the air takes up less space. |

Review these key ideas from today's investigation:

- Air particle size does not change with a change in temperature.
- Air particle spacing increases as temperature increases and decreases when air is cooled.
- Air particles are quite evenly distributed inside the bottle.

# 5. Two Scales (Wrap Up)

To close this unit, students apply their new understandings as they annotate their graphs documenting mini-lake weight change across time. Their first annotations describe the sources of the weight and the observable changes across time (e.g., added salt; salt dissolved; removed cover; water evaporated) Their second round of annotations explain the mini-lake transformations at the particle level (e.g., particles of salt in the water became too small to see; particles of water moved from the surface into the air to become water vapor). Next students read the *Why are these ships in a field? The Story of the Aral Sea* to learn how the rivers that once fed the lake balanced the evaporation from the lakes surface, and how the sea has almost disappeared since that balance has been disrupted. Finally, students reflect on how their understandings of water transformations and matter have evolved as a result of their experiences with five specific elements of the unit: the mini-lake; the spray mister; the 2-bottle system; the Particle magnifier; and the syringe.

### Investigations:

- Investigation 17: What's the story behind the graph?
- Investigation 18: How have our understandings changed?

# What's the story behind the graph?

## Plan Investigation 17

Students have kept track of their mini-lakes throughout this unit. They measured the contents, speculated on the changes that might occur over time, added salt, and tracked weight changes across time as the water evaporated. Today they tell the story of the mini-lakes by annotating their graphs. The annotations should allow someone unfamiliar with their work to understand the transformations of the mini-lakes at two different scales: the macroscopic or visible scale, and the microscopic or particle scale. Students then combine their annotations on a class graph. That sharing should result in a robust story that helps everyone strengthen their understanding of the mini-lake transformations.

Next students return to the mystery of the ship in the field. They read the story of the transformation of the Aral Sea, which has some interesting connections with the transformation of the mini-lakes: in both cases, the water that evaporated was not replenished. In both cases, sand, salt, and other solid earth materials were left behind.

**Formative Assessment**

*Can students annotate their change over time graphs to explain changes in their mini-lakes?*

Available online at inquiryproject.terc.edu

By the end of this session students will have a deeper understanding of how the scientists' model of matter (matter made up of particles too small to see ) can explain familiar, everyday transformations such as evaporation, freezing, melting, condensation, and even the disappearance of water from a huge lake!

### Learning Goals

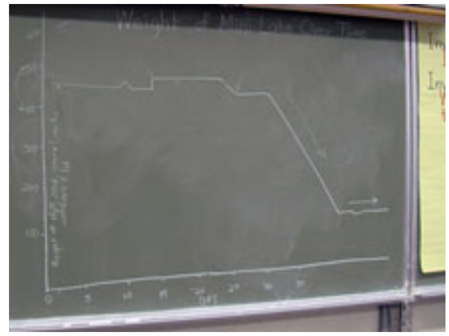
- Understand that the particle model explains transformations of water at the visible level

| Sequence of experiences | | |
|---|---|---|
| 1. Ask the question | All Class | 10 Mins |
| 2. Annotate the graphs | Pairs | 10 Mins |
| 3. Share and discuss | Discussion | 15 Mins |
| 4. Connect mini-lakes and real lakes | All Class | 10 Mins |

## Materials and Preparation

Preparation:

- Read the student resource *Why are these ships in a field? The Story of the Aral Sea* (Available in the Resource Quick Links)



For the class:

- Post the investigation question in a place where all students can see it.
- Create an unlabeled reproduction of the mini-lake weight-over-time graph. This does not need to be scaled accurately.
- Set of images of ships in a field" or notebook pages.
- Computer and a system for projecting the images if using electronic presentation.

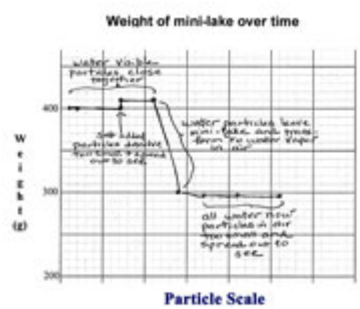
For each student:

- 1 copy of *Why are these ships in a field? The Story of the Aral Sea* (See Resources Quick Links)

## 1. Ask the question

All Class | 10 Mins | Notebook

Ask students to open their Science Notebooks to the graph they have created that records the weight of the mini-lake across time.




Today's investigation question is:

*What is the story behind the graph?*

Students will answer that question by annotating their graph, writing short notes directly on the graph and in the margins around it. These notes should tell the story of the mini-lake to *someone who is not familiar with* the work students have done over the past several weeks.

> **Note:** The story of change in the mini-lakes can be told at different scales. At the visible scale, the terms dissolving and evaporation can describe most of the changes. However, students have started to learn what happens at the particle scale as these transformations occur. Emphasize that as students annotate their graphs, they should describe what is happening at both the visible level (salt dissolved, water evaporated, etc.) and at the particle level.

The graph shows changes in weight across time. Student notes should explain:

- Where the weight comes from?
- What changed and what stayed the same across time?
- Why the changes happened?
- Any other information students think will be helpful.

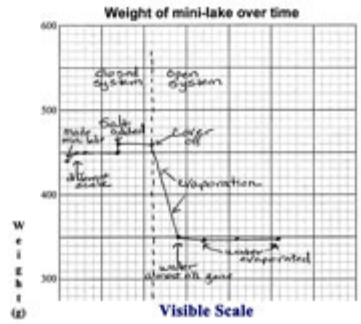
Students' notes should tell the story at **two scales**: at the **visible scale** (what we can see) and at the **particle scale** (things we can't see, but have learned about during the past few weeks.) You may choose to have students annotate events at the visible scale individually or in pairs and describe what happened at the particle level on the class graph in Step 3.

Students should make use of any notes they entered in their data table.

## 2. Annotate the graphs

Pairs 10 Mins

Mini-lake pairs should discuss the data and contribute ideas for annotating the graphs, but each student should annotate his or her own graph. It's not essential that everyone complete the annotations. The class will combine their notes on the large class drawing of a graph and students can continue to add notes to their own graphs at that same time.




Enlarge Sample

Ask students to annotate observable changes such as the created of mini-lake, added salt, took off cover, water evaporated. They can also note explanations for the "shape" of the line. For example a horizontal line means the weight didn't change (no matter was added or taken away from the mini-lake), a line that slopes upwards shows that the weight increased (due to the addition of salt), a line that slopes downward indicates a loss of weight (due to evaporation of water).

## 3. Make Meaning

All Class 15 Mins

### Purpose of the discussion

Students combine their notes on the classroom graph to explain the story behind the graph.

### Engage students in the focus question

*What's the story behind the graph?*

Start with Day 1 and work across the data points in chronological order. As students contribute notes to the class graph, ask if others agree or if there are different explanations. Be sure students address the following questions in the annotations:

*Where does the weight come from?*

*What changed and what stayed the same across time?*

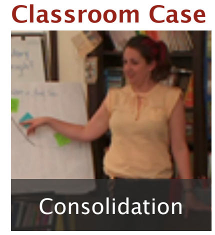
*Why did the changes happen?*

When you have recorded the observable events in the life of the mini-lake, add notes that describe what was happening at the particle level.

*How would we tell this "story" in terms of particles?*

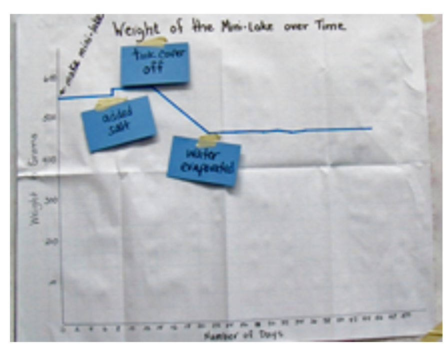
- Particles of water were tiny but close enough together so we could see the water.
- When salt dissolved, the particles became too small to see in the water.
- Some water particles left the mini-lake through evaporation and became water vapor that was part of the air.
- All of the original water particles are now water vapor - these particles are too small and spread apart to see.

**Classroom Case**




The Role of Consolidation Discussions

Available online at inquiryproject.terc.edu



Point to the slope on the classroom graph that reflects evaporation from the mini-lakes:

> *This slope shows that a mini-lake lost approximately 150 grams over the course of about one week - or about 20 grams per day. What happened to this water?*
>
> - It became a gas called water vapor and moved into the air.

Point out that over the course of about one week, the collection of mini-lakes added more than 1500g of water — more than 1 1/2 liters of water — to the classroom air.

> *Can students imagine how much water moves into the air from a real lake each week?*

**Summarize the discussion**
Ask a student to tell the story of the graph from beginning to end.

## 4. Connect mini-lakes and real lakes

All Class   10 Mins

Show students the images of the Aral Sea ships, and highlight the similarities and differences between the mini-lakes and real lakes:

- The evaporation process is the same for both, with particles of water too small to see moving into the air to become water vapor.
- In most real lakes, the water that leaves through evaporation or streams is replaced by water from streams and by rain and snow.
- The mini-lakes lost water through evaporation but none of that water was replaced.

Give each student a copy of *Why are these ships in a field? The Story of the Aral Sea*, and then read the story as they follow along. Next, read the *Letter from the Engineer*, "Engineering and the Aral Sea".

***Letter from the Engineer***
***Engineering and the Aral Sea***

*When people decided to use water from the Amu and Syr Rivers for watering cotton fields, they turned to engineers with the question: How can we move water from the rivers away from the Aral Sea and toward land that will be used to grow cotton? The engineers understood the problem they were asked to solve, and they designed canals — very long ditches — that would carry water from the two rivers to the future cotton fields. Their solution worked very well for the cotton farmers. Lots of water from the rivers went into the new canals and to the cotton fields, and much less water went into the Aral Sea. Farmers were now able to grow cotton in places that had always been much too dry (not enough rain) to grow crops.*

*But the canals also created problems. As the water in the Aral Sea evaporated, it was no longer replaced by river water. Furthermore, the salt did not evaporate. So the sea became more and more salty and eventually the fish died. For the fishermen, the new canals were not a solution, they actually created a new problem. And when so much water evaporated that most of the old sea dried up, the winds blew dust and salt from the old sea bottom into the air. Many people who lived nearby inhaled salt and dust into their lungs and became ill, so the new canals were not a solution for them either.*

*Did the people who decided to send water to the cotton fields think the Aral Sea would just stay the same? Did they forget about evaporation?*

*Engineering projects can often make peoples' lives better in some ways, but they can also cause new problems if people are not careful to think about everything that will change as a result of a new project. Can you think of some things that have been designed to make life easier in some way but that also created problems?*

(Possible responses include disposable items such as plastic water bottles; cars; leaf blowers.)

## 5. Two Scales:  Investigation 18

# *How have our understandings changed?*

## Plan Investigation 18

In this final session, students reflect on how their understandings have grown and changed during the curriculum unit, and how they can apply their new understandings to water, air, and transformations of matter in the real world.

This opportunity for reflection is structured by having students focus on five models or investigations from the curriculum: the mini-lake, the spray mister, the 2-bottle system, the Particle Magnifier, and a syringe.

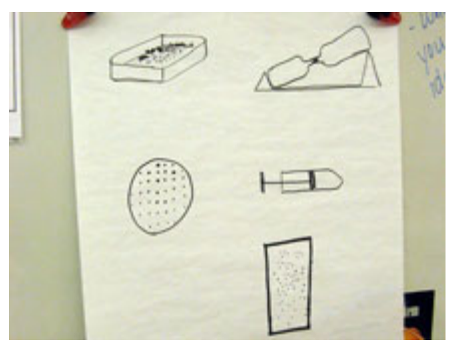
By the end of this investigation students will have had an opportunity to apply the new understandings they have developed about water, air, and the transformation of matter to real world situations.

### Learning Goals

- Understand that models help to explain scientific phenomena

| Sequence of experiences | | |
|---|---|---|
| 1. Introduction | All Class | 5 Mins |
| 2. Reflection | Small Groups / Individual | 20 Mins |
| 3. Discussion and wrap up | All Class | 20 Mins |

### Materials and Preparation



For the class:

- Prepare a classroom poster with copies of the five simple sketches found in the Science Notebooks: the mini-lake, the spray mister, the 2-bottle system, the Particle magnifier, and a syringe.

## 1. Introduction

All Class | 5 Mins

This is the final session of this curriculum unit. Since students first set up their mini-lakes in Investigation 1, they have explored water, ice, and gases including water vapor. They have considered how water is transformed, from a solid to a liquid, and from a liquid to a gas (water vapor), and what changed and what remained the same across these transformations. Their notebooks are filled with data, ideas, questions, predictions, and explanations.

Today students reflect on what new understandings they have as a result of this work. How have their ideas changed? What questions do they still have?

## 2. Reflection

Small Groups | 20 Mins | Notebook

On the *[New Ideas]* page in their Science Notebooks, students will find 5 images: the mini-lake, the spray mister, the 2-bottle system, the Particle Magnifier, and a syringe. Each image represents one or more investigations of transformations of water.

> *In the real world, water is constantly transformed from liquid to vapor (gas) or solid and back again. What did you learn from your work with the mini-lake, the spray mister, the 2-bottle system, the Particle Magnifier, and the syringes to help you understand the transformation of water?*

Ask students to look through their Science notebooks and discuss the question in their group. They should then turn to the *[New Ideas]* page and write their responses next to each of the five images. They should write any questions they still have, or things they find confusing.

## 3. Discussion and wrap up

All Class | 20 Mins

### Purpose of the discussion

The purpose of this discussion is to bring ideas together and connect them to real world phenomena.

### Engage students in the focus question

*In the real world, water is constantly transformed from liquid to vapor (gas) or solid and back again. What did you learn from your work with the mini-lake, the spray mister, the 2-bottle system, the Particle Magnifier, and the syringes to help you understand the transformation of water?*

Talk Moves

Use this checklist to plan and reflect.

Available online at inquiryproject.terc.edu

Refer to the poster with the five drawings and repeat the question that is the focus of this discussion:

- Focus the discussion on just one image at a time.
- Encourage students to use their notebook entries.
- Remind students that, as they make claims about new understandings, they should describe the evidence that supports their claim.

As time permits, ask students if they are thinking differently now about any of these questions:

*Why does a puddle disappear?*

*Why do we often see water drops on the outside of a glass of water in the summer?*

*Why do we see dew on the grass in the early morning and it's gone by noon?*

*If the water level in a lake stays the same, does that mean that no water is evaporating?*

### Summarize the discussion and recap the investigation

This investigation provided students with an opportunity to bring together all of their experiences and learning about transformations of water, and to reflect on the ways their ideas and understanding have grown and changed. The last set of questions — about puddles, lakes, water drops on cold glass of water on a summer's day, and early morning dew — is a reminder that they now have a far deeper understanding of science phenomena that they experience every single day.

# Curriculum Kit

## How to Obtain a Kit

Information on how to obtain a materials kit is available on the Inquiry Project website (inquiryproject.terc.edu) in the Grade 5 Curriculum.

## Curriculum Kit Materials

Materials are listed for a classoom of 24 students split into 6 groups of 4. Your classroom may require modifications of this list.

- 1 spray mister
- 1 pitcher
- 1 double pan balance
- 1 balloon pump

- 1 rubber stopper
- 1 bottle glycerin
- 1 bottle Joy dishwashing liquid
- 1 bottle blue food coloring

- 1 lb kosher salt
- 2.5 liters sand

- 2.5 liters gravel
- 1/2 liter small rocks

- 2 1/2-inch mini ice cube trays
- 2 1-gallon buckets
- 6 digital scales
- 6 trays
- 12 16-inch balloons
- 24 conical paper cups
- 24 magnifiers
- 24 plastic spoons

- 20 feet of clear plastic 1/4 inch tubing
- 200 centimeter cubes
- 12 100ml graduated cylinders
- 12 8oz plastic capped water bottles
- 14 sandwich boxes with covers
- 24 1ml small syringes
- 32 10cc syringes (10 with caps)
- 48 185ml capped vials
- 60 12oz clear plastic cups

- 3 aluminum reflector lamps
- 3 100 watt incandescent bulbs
- 3 2-liter plastic bottles

- 4 1-liter plastic bottles
- 3 bottle system bases
- 3 plastic bottle connectors (opening enlarged to 7/8 inch diameter)

### Classroom supplies:

- 12 index cards
- paper towels
- masking tape

- 6 rubber bands
- fine-tip permanent markers or pens
- extension cords as needed

- access to a freezer, copier, hot/cold water source, interactive whiteboard or flip chart, and a computer with projector or interactive whiteboard

## Refill/Replacement Kit

- 1 lb. kosher salt
- 12 16in. balloons
- 2.5 liters fine sand
- 2.5 liters gravel

- 1/2-liter small rocks
- 60 12oz clear plastic cups
- 24 4oz conical paper cups

# Aral Sea

**Investigations 1, 17**

## Why are these ships in a field?

The images of ships in a "field' – actually a dry inland seabed – pose a mystery for the students, and as importantly, they highlight the extraordinary scale at which evaporation occurs. Over 70,000 cubic kilometers of water evaporate from Earth's land surfaces each year. Usually that water is replaced by rain and snow, and distributed by the rivers that keep lakes and other inland bodies of water replenished. This replenishment typically hides the effect of evaporation. But what happens if rivers are diverted, so that they no longer replace the water that evaporates? When evaporation removes more water than comes into a body of water, the water level will drop until over time until the body of water disappears. This is the story behind ships in a field.

The mystery of the ships is presented to students in Investigation 1, in the form of a set of images. We recommend leaving both the location and the full story behind the disappearance of the water a mystery until after students have had their own set of experiences with evaporation and condensation. The curriculum returns to the images in Investigation 17, when we suggest you share the story behind the images; that is, the story of the Aral Sea in central Asia.

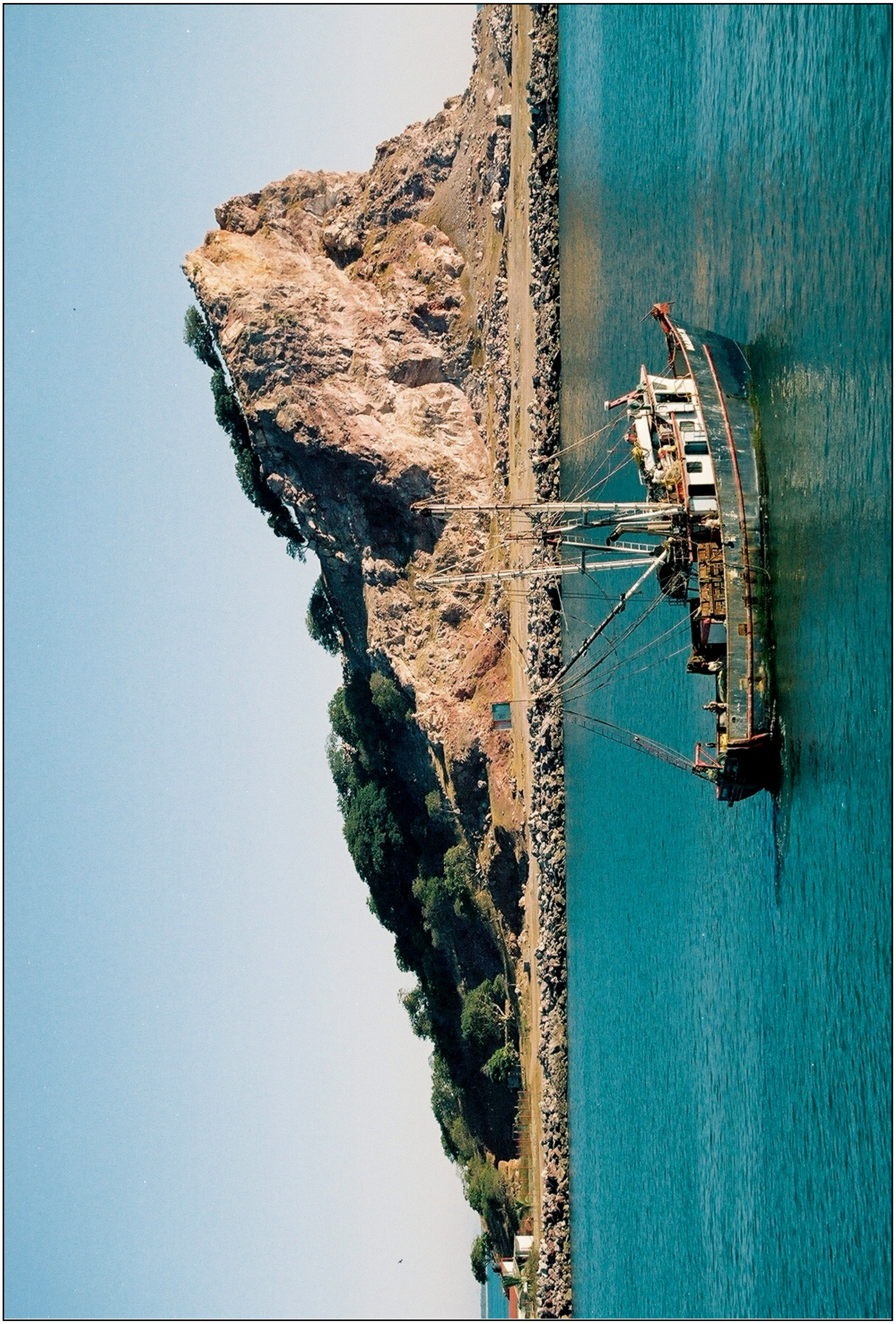
In 1960, the Aral Sea was the world's 4th largest inland body of water. Its surface area exceeded 67,000 square kilometers, greater than the surface area of Lake Huron. It supported a substantial fishing industry. In the 1960's, vast amounts of water from the two rivers that feed into the lake started being diverted to provide irrigation for cotton fields. By the 2007 the level of the lake had dropped so much that 90% of its former area was dry land. The water that remains – in the deepest parts of the original lake – is now separated into smaller bodies of water that are so salty that fish can no longer survive. The countries that border the former sea are considering plans for reversing this decline, but so far no significant actions have been taken.

### Student questions

When students see the images, they will wonder what happened to the water, but their questions are likely to go beyond that.

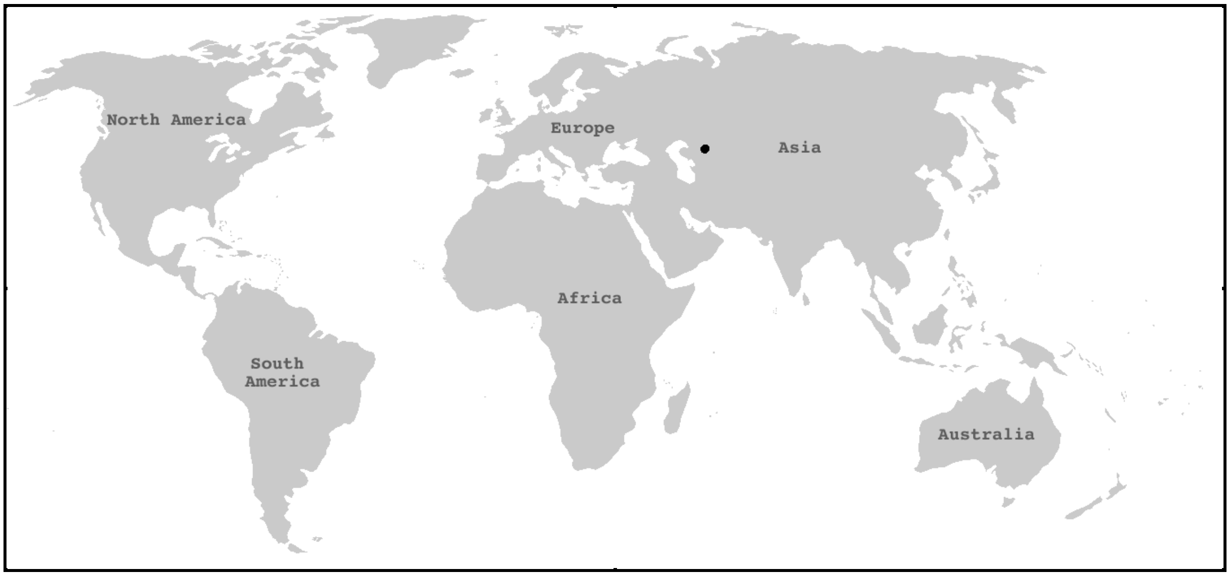
- They may ask if the water sank into the ground.
  *The land below the sea would remain saturated, and would not be able to absorb additional water until after the sea had evaporated. The land did not absorb the sea. The water evaporated.*
- They may wonder why the ships were just abandoned, rather than being moved to somewhere else.
  *Unlike recreational boats, commercial ships are usually built on the shoreline of the body of water in which they will sail. They are too large to move across land. They can't really go anywhere. In addition, once the fishing industry collapsed, most of the ships were of no use, even if they could have moved to the parts of the lake that remain.*
- They may wonder what happened to the people on the ships. *The evaporation of water from the lake occurred across decades. It was not a sudden event. No one was caught stranded on a ship that suddenly found itself on dry ground. People probably left the ships while they were still tied up beside a pier, and long before the ships ended up on dry ground.*

Remember to highlight the fact that this is a story about the evaporation of water, the enormous scale at which it happens, and what happens when water that evaporates is not replaced. It's the same story – at a different scale – as the story of a puddle after the rain stops.



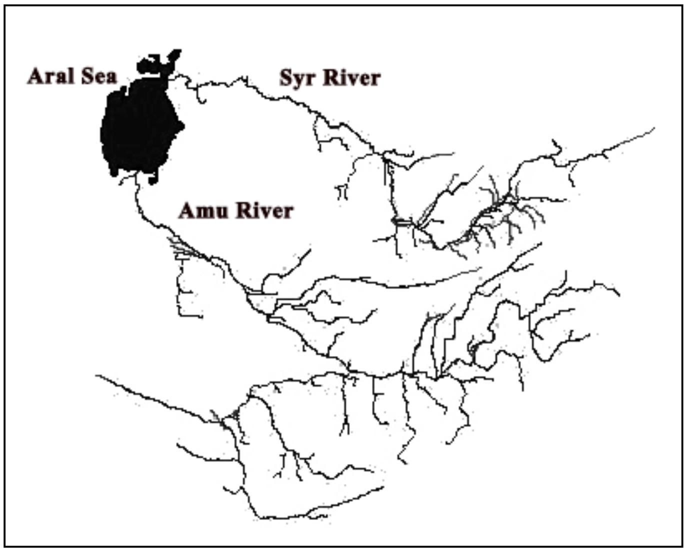
## *Why are these ships in a field?*
## The Story of the Aral Sea

**Where is the Aral Sea?** Look for the black dot on the map below. It is in a part of the world called Central Asia.




Here is a map that shows the countries of Central Asia. The Aral Sea is inside the circle. At one time, the Aral Sea was the 4th largest *inland* body of water in the world. An inland body of water is one that is completely surrounded by land. Most inland bodies of water are called lakes or ponds, but some of the largest ones are called seas. Large ships carried cargo across the sea, and thousands of fishermen worked on the Aral Sea's fleet of fishing boats.

**Where did the Aral Sea get its water?** From rain. Some rain fell directly into the lake. Most of the water came from rain that fell on the land surrounding the sea. Rain that fell on parts of seven different countries formed streams, which formed rivers, which flowed into the Aral Sea. The map below shows the two large rivers - the Syr River and the Amu River - that flowed into the Aral Sea. It also shows the many smaller rivers and streams that provide the water for those two rivers.




http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/aral3.htm
Sandra Akmansoy and **Daene C. McKinney, PhD**
**Center for Research in Water** Resources
University of Texas at Austin

**With all that rainwater, why didn't the Aral Sea just keep growing?** It did grow, but the bigger it became, the more water it lost by evaporation. It stopped growing when the amount of water that evaporated each day was the same amount as the water that flowed into it each day.

**Why did the Aral Sea get smaller?** More than 50 years ago, some people decided to create very large cotton farms in Central Asia. They needed lots of water for the cotton farms, so they dug canals to redirect water from the Syr and Amu Rivers to the cotton fields. The amount of water that came into the Aral Sea was then much less than the amount of water that evaporated. Each year the Aral Sea became smaller and smaller. (With no water being added to your mini-lakes, they too became smaller and smaller until all of the water had disappeared.)

**Why are boats and ships still there?** Very large boats and ships are too heavy to move across land. They can only travel on water. Once there was not enough water for them to float, they became trapped. Many of them have been taken apart and the materials have been recycled, but some of them are still there. It's a strange sight to see large ships resting on dry ground.

NASA astronauts took this photograph in 2009. The black line shows the size of the Aral Sea before the canals were completed. Today, only small parts of the Aral Sea remain.

# 315 Dots per Page

Each of the three pages that follow has been printed with the exact same amount of ink; each has 315 black dots that are all the exact same size. When those 315 dots are spread equally across the page, they are very difficult to see beyond a distance of a few feet. When those same 315 dots are clumped together, their visibility increases dramatically.

Although the Dot Sheets are not labeled in any way, they are referred to in the curriculum by their order:

- Dot Sheet 1 shows the dots equally spaced but clustered closely together.
- Dot Sheet 2 shows the dots equally spaced but spread across the sheet.
- Dot Sheet 3 is identical to Dot Sheet 1; there are times when showing all three sheets in order called for in the curriculum.

These pages can help students understand why we can see salt in its solid form but not after it has been dissolved; or water in its liquid form but not when it is a gas. It's not the amount of salt or water that changes; what changes is the distance between the tiny particles that make up the salt or the water.

Point out to students that the dots on these sheets are billions of times larger than the particles that make up salt, or water, or any type of matter. The same general idea applies: spreading them apart makes them difficult or impossible to see.

# Annotated Drawings

Annotated drawings include a combination of notes and labeled drawings that provide an explanation about a scientific process. They are used in this curriculum to answer specific scientific questions. In contrast with an *observational drawing*, which represents all elements of an object or scene in great detail, an annotated drawing has a specific area of focus. Some elements of the drawing may be represented by the simplest of outlines and need no elaboration while other elements require carefully detailed drawing and explanations.

Annotated drawings are not considered finished products. They represent one's best explanation of a process *at a point in time*; they are works in progress. They provide a way for communicating one's thinking with others.

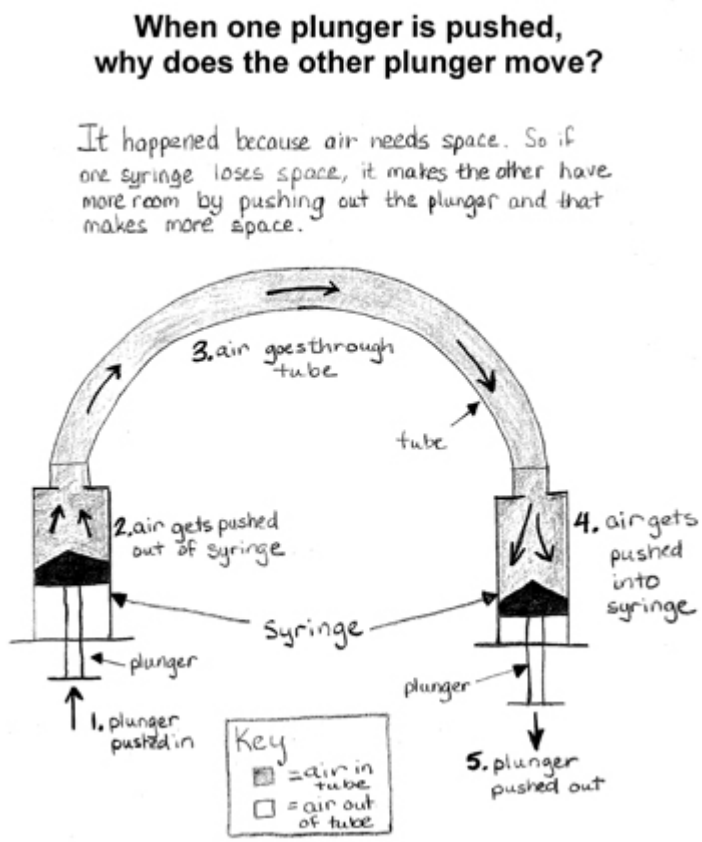


Figure 1: Annotated drawing sample

Figure 1 is an example of an initial annotated drawing by a 5th grade student. It was produced immediately after students explored a small system composed of two syringes connected by a plastic tube (See Investigation 13). The purpose of the exploration is to help students realize that air is matter and takes up space.

The question the annotated drawing must address is, "When one plunger (of one syringe) is pushed, why does the other plunger (of the second syringe) move?" The annotated drawing in Figure 1 highlights the air inside the system, by use of a *color key*. It uses *arrows* and *notes* to indicate the direction of movement of the air and both plungers, and addresses the question with the explanation, "*It happened because air needs space so if one syringe loses space it makes the other have more room by pushing out the plunger and that makes more space.*"

Another set of notes, augmented with arrows, describes the sequence: (moving clockwise from lower left)
*"Plunger pushing in.*
*Air gets pushed out of syringe.*
*Air goes through the tube.*
*Air getting pushed into syringe.*
*Plunger pushed out."*

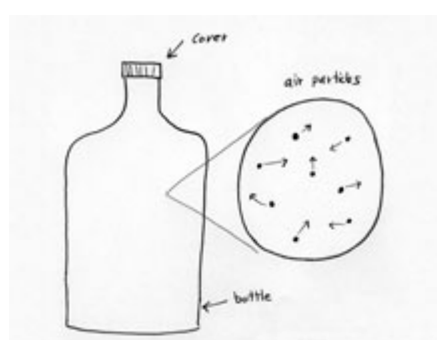


Figure 2: Annotated drawing sample with magnifier

### How do students represent matter or a process that's invisible?

Whenever the focus of an annotated drawing is something students cannot actually see, such as the tiny particles that compose all matter, ask students to use the technique illustrated in Figure 2, which includes drawing an imaginary "magnifying lens" to zoom in and make visible something that is invisible to the human eye.

## Reviewing annotated drawings

- While annotated drawings initially represent the thinking of an individual student, understanding and refining them is an important group effort.
- The goals of the review process are to:
    - help students develop the ability to think critically about scientific processes
    - learn how to communicate their ideas through annotated drawings
    - use the all class review process to refine these ideas

### A suggested review process

1. After the class in which students create the annotated drawings:

    Select two annotated drawings, ideally ones that are representative of different explanations for the scientific process.

    Make enough copies to give a set to each pair of students and have one for the class.

2. In the following science class:

    Explain the goal of the review: to deepen our understanding of the science by looking closely different ways people chose to explain our observations and explanations.

    Remind students of the scientific process that is the focus of the drawings:

    *What observation or process do these drawings try to explain?*

    Provide time for pairs of students to look at the drawings through 3 lenses:

        *Is there anything you don't understand and would like clarified?*
        (Example: Your key shows that air is colored gray but nothing outside of the system is colored gray. Do you think there is air outside the system as well)?

        *How are the explanations in both drawings the same? How are they different?*
        (Example: Both drawings show a closed system with air completely filling the space in the syringes and tubing.)

        *Do the annotated drawings explain your observations?*
        (Example: When I pushed the first plunger, the second plunger did not move right away; it moved a tiny bit later. The annotated drawing doesn't explain why this happened.)

    Repeat the pair review with the whole class.

    Highlight aspects of the observational drawings that support clear communication (e.g., arrows, keys, notes)

    Summarize aspects of the explanation that are scientifically accurate.

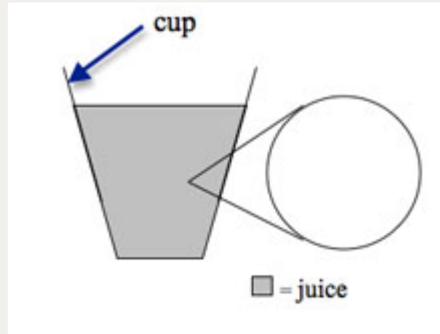
    Provide a few minutes for students to revise their own drawings in light of what they learned in the class review.

## Model for an Annotated Drawing Poster

### Annotated Drawings

1. Provide an explanation.
2. Use simple outline drawings.
3. Use a magnifier to show things too small to see.
4. Use labels, arrows, and a color key.
5. Add notes to explain important ideas.

You can change your annotated drawing as your understanding and your explanation changes.



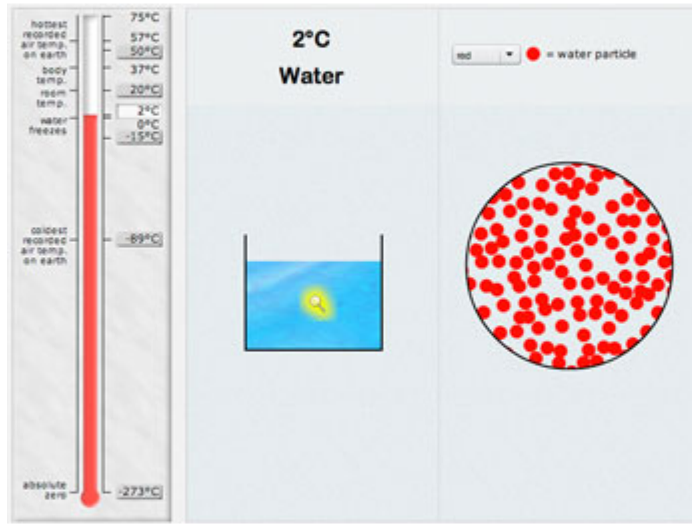
# Particle Magnifier

Investigation 12

- Particle Magnifer (Water)

Investigation 16

- Particle Magnifer (Water-Air)




The Particle Magnifier (Water) showing water at 2°C

At different points in this curriculum unit students have explained a process (e.g., salt dissolving in water; water evaporating) by making reference to particles too small to see. This explanation corresponds with scientists' understanding that all matter is composed of individual particles (atoms or molecules) too small to see. How small are these particles? It would take trillions of water molecules to form a drop of water with a diameter the same as the period at the end of this sentence.

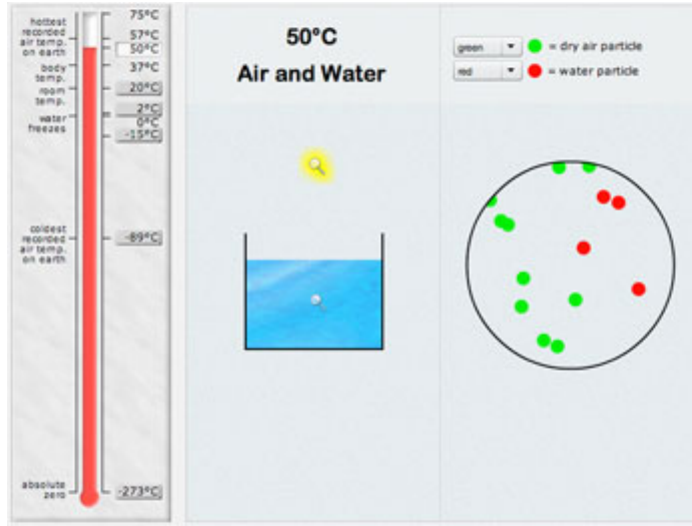
The Particle Magnifier allows students to observe the arrangement and motion of water particles in their solid, liquid, and gaseous states, and supports the concept that, regardless of state, the particles themselves remain the same. A user can select one of six different temperatures on the thermometer to observe how particles respond to different amounts of heat energy.

Although the specific focus of the model is water, it's important to let students know that the following 5 key ideas, which the model highlights, are true for matter in general:

- matter is composed of tiny individual particles
- particles of matter are in motion whenever heat energy is present (temperatures above absolute zero)
- particle motion increases with temperature (amount of heat energy)
- particles of matter attract one another – somewhat the way magnets do – and are "locked" together (solids) unless the motion caused by heat energy becomes strong enough to cause particles to break loose from one another (melt) and sliding past and/or bump one another
- when enough heat energy is added, particles of matter can fly off the surface of a liquid or solid and into the air, something that changes the form of matter (to a gas) but not the matter itself

## Two Versions of the Particle Magnifier

The **Water** version of the Particle Magnifier, which is used in Investigation 12, provides a microscopic view of the ice and water inside the container, and extends students' explorations of the water-ice transformations in Investigations 10-12. It does **not** include a magnified view of the air above the container since students will not start to explore the properties of air until Investigation 14.




Particle Magnifier (Water-Air) showing air at 50°C

The Water-Air (full version) of the Particle Magnifier is introduced in Investigation 16. Users can elect to view water particles in the container as well as in the air above the container. The full version of the Particle Magnifier extends students' explorations of air in Investigations 13-16, and extends their understanding of evaporation, which they explored earlier in the curriculum unit.

There is no option to view air particles at -273°C, since at this temperature there would be no gaseous form of matter. Nitrogen, oxygen, and all of the elements that usually compose our atmosphere would be solids before the temperature reached absolute zero.

Color selection of the particles in the model is arbitrary, and can be changed using the dropdown menus.