- Draw and interpret a graph of the recorded temperatures as the ice melts, liquid water warms, and eventually boils.
- Discuss with your group members what the relation is between the energy flowing into the system and the temperature of the water in its various phases and phase changes. Formulate your insights into relevant central ideas.
- In the ***After*** section of the physics notebook page, report these ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the ideas and why these are important.
- Also reflect upon this exploration such as connections you can make to other experiences. How might you use what you learned in your own classroom?
- What are you still wondering?

Enter notes in Table III.1 to represent this exploration:

TABLE III.1 Central ideas about changes in states of matter

TABLE III.1 Central ideas about changes in states of matter

Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
	Draw complete Temperature versus time graph	Water occurs in three states of matter: solid (ice), liquid, and gas (water vapor).	Solid phase Liquid phase Gaseous phase
	Draw complete graph and highlight relevant section	When solid water (ice) is melting, energy enters the system but the temperature does not change.	Melting Freezing Latent heat of fusion for water (about 80 calories/gram)
	Draw complete graph and highlight relevant section	When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate.	c =specific heat in calories/(gram °C) specific heat of water = one calorie/(g °C) = energy needed to change the temperature of one gram of water by one degree Celsius.
	Draw complete graph and highlight relevant section	When liquid water is evaporating, energy enters the system but the temperature does not change.	Evaporation Heat of vaporization for water (about 533 calories/gram)

Complete documenting your exploration and writing a summary before looking at an example of student work and discussion of nuances about changes in states of matter.

1. Example of student work about changes in states of matter

Figure 3.1 shows a student's entries into a table about changes in states of matter. The student's summary of ideas about energy transfers during changes in states of matter also appears below.

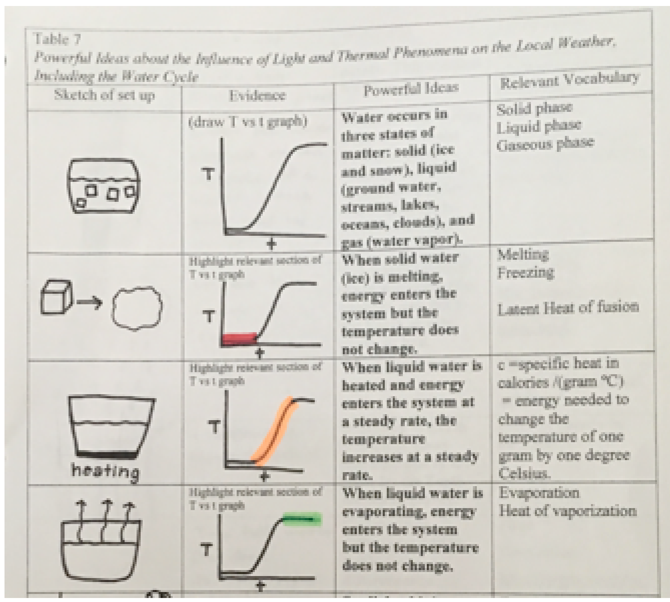


Table 7
Powerful Ideas about the Influence of Light and Thermal Phenomena on the Local Weather, Including the Water Cycle

Sketch of set up	Evidence	Powerful Ideas	Relevant Vocabulary
	(draw T vs t graph)	**Water occurs in three states of matter: solid (ice and snow), liquid (ground water, streams, lakes, oceans, clouds), and gas (water vapor).**	Solid phase Liquid phase Gaseous phase
	Highlight relevant section of T vs t graph	**When solid water (ice) is melting, energy enters the system but the temperature does not change.**	Melting Freezing Latent Heat of fusion
heating	Highlight relevant section of T vs t graph	**When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate.**	c =specific heat in calories /(gram °C) = energy needed to change the temperature of one gram by one degree Celsius.
	Highlight relevant section of T vs t graph	**When liquid water is evaporating, energy enters the system but the temperature does not change.**	Evaporation Heat of vaporization

FIG. 3.3 Example of student's Table III.1 showing changes in state graph.

Water occurs on Earth in three states of matter: solid (ice and snow), liquid (ground water, streams, oceans, clouds), and gas (water vapor). *Water occurs on Earth in three states of matter. The first state of matter in which water occurs is as a solid. This is when water is in the form of snow or ice. When the same water is heated, it can be in the state of matter of a liquid. This is when water is in the form of ground water, streams, oceans, and clouds. When the same water is boiled, it can be in the state of matter of a gas. This is when the water is in the form of water vapor.*

When solid water (ice) is melting, energy enters the system but the temperature does not change. *(Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row*

2, the relevant part of the graph is highlighted. The highlighted part shows what is happening when solid water (ice) is melting. When the ice is melting, energy is entering the system. In the graph, it is seen that the temperature does not change, even though energy enters the system.

When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate. ***(****Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row 3, the relevant part of the graph is highlighted. The highlighted part shows what is happening when liquid water is heated. When liquid water is heated, energy from the heat of the rice cooker is entering the system at a steady rate. The graph shows that the temperature is also increasing at a steady rate.*

When liquid water is evaporating, energy enters the system but the temperature does not change. ***(****Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row 4, the relevant part of the graph is highlighted. The highlighted part shows what is happening when liquid water is evaporating. When liquid water is evaporating, energy is entering the system. The graph shows that the temperature does not change, even though energy enters the system.*

Physics student, Spring 2016

This student has interpreted the flat areas of the graph as phase changes that occurred in which energy continued to flow into the system but the temperature did not change while the ice was melting and while the liquid water was evaporating.

2. Nuances about changes in states of matter

This exploration provides an example of refining understandings about the difference between heat and temperature by considering the context of application. Many students draw a straight line when predicting the graph of temperature versus time for melting ice, warming liquid water, and boiling. Such a straight line can seem reasonable given prior experiences in warming things up. A straight line is appropriate for the context of warming the liquid water. When liquid water is warming up, adding energy to the system at a steady rate increases the temperature at a steady rate and a straight inclined line on a temperature versus time graph represents that regular increase in temperature with time.

In the context of changes in state, however, <u>the temperature does not change</u> when adding energy to the system if ice is melting or liquid water is evaporating. The heater is supplying a constant flow of energy into the system of the pot of melting ice or boiling water but the temperature does not change. The temperature does not change because the energy is going into the melting process or into the evaporation process.

According to the learning progression for the structure of matter (PS1.A) articulated in the *Next Generation Science Standards* (Lead States, 2013), in the early elementary grades students are to focus upon observable properties such as whether a substance is a solid, liquid, or gas. Young students are not expected to envision what is happening to particles too small to see. By middle school, however, students are expected to understand that materials are composed of atoms and molecules, that atoms and molecules vibrate while bound together firmly in solids and loosely in liquids, and that atoms and molecules are free to move around in gases.

Changes in temperature involve changes in the *kinetic energy* of the molecules. *Kinetic energy* refers to energy associated with motion. Higher temperatures are associated with higher vibration rates among molecules in solids and liquids and with higher speeds for molecules in gases. See https://phet.colorado.edu/en/simulation/states-of-matter-basics for a simulation for the movement of water molecules in solid, liquid, and gaseous states.

During melting and evaporating, the incoming energy goes into breaking bonds between the molecules in solids and liquids rather than into increasing the rates of vibration. During freezing and condensing, energy is released as such bonds form among atoms and molecules.

The energy involved in changing states is known as *latent heat*. The adjective *latent* refers to something that is hidden or concealed. *Latent heat* refers to incoming or outgoing energy that is not detectable by a change in temperature. The energy needed to melt a gram of ice, the *latent heat of melting*, is about 80 calories. The energy released when a gram of liquid water freezes, the *latent heat of fusion*, also is about 80 calories. The energy needed to evaporate a gram of liquid water, the *latent heat of vaporization*, is about 533 calories. The energy released when a gram of water vapor condenses, the *latent heat of condensation*, is also about 533 calories.

Scientists and engineers design and use *phase change materials* to cool buildings. Microscopic pellets of phase change materials (PCM) added to insulation absorb energy as they melt during the day, for example, keeping a roof cool, and release energy as they freeze at night. See https://www.pcm-ral.org/pcm/en/pcm for a discussion of latent heat and its engineering applications such as in designing ways to manage ambient temperatures in buildings. This is an example of *Identifying situations that people want to change as a problem that can be solved through engineering*, an aspect of *engineering design* that children as young as K-2 are expected to understand according to the *Next Generation Science Standards* (NGSS, Lead States, 2013) (See NGSS Appendix I https://www.nextgenscience.org/resources/ngss-appendices .

B. Exploring phase changes in which water absorbs or releases energy

The *water cycle*, sometimes called the *hydrologic cycle*, involves water in its many phases and phase changes. The phase changes occur both when water is absorbing energy as well as when it is releasing energy. Such phenomena are the focus of the next explorations.

Question 3.3 What are some everyday examples of water absorbing energy when water changes state?

Light from the Sun can supply energy for changing the phase of water.

You can explore such changes outside on a sunny day or inside with:

- lamp
- tray
- food coloring
- source of water
- large plastic bag
- houseplant
- access to the Internet.

- In the ***Before*** section of a physics notebook page, note some examples of phase changes of water that involve absorbing energy. What are some ways to explore these?

For example:

- What happens to puddles during a sunny day?
- Pour a little liquid water onto a tray. Add a drop of food coloring to make the puddle easier to see.
- Place the tray outside in sunlight or inside near a lamp shining on the puddle. What happens after 15 minutes? An hour?

FIG. 3.4 *Evaporating puddles by 四代目火影 CC BY-SA 4.0 https://commons.wikimedia.org/wiki/File:Puddle,_Vas%C3%BAt_utca,_Zichy%C3%BAjfalu_001.jpg*

This phase change from liquid to gas is called *evaporation*. Fig. 3.4 illustrates puddles that are in the process of evaporating. How quickly a puddle evaporates depends upon the temperature and how much water is already in the air. The warmer the temperature, the more moisture the air can hold. For more information, see https://water.usgs.gov/edu/watercycleevaporation.html .

- What happens on a hot dry day when you sweat? How does sweating cool you off?
- What happens on a hot humid day? Why does sweating not cool you then?

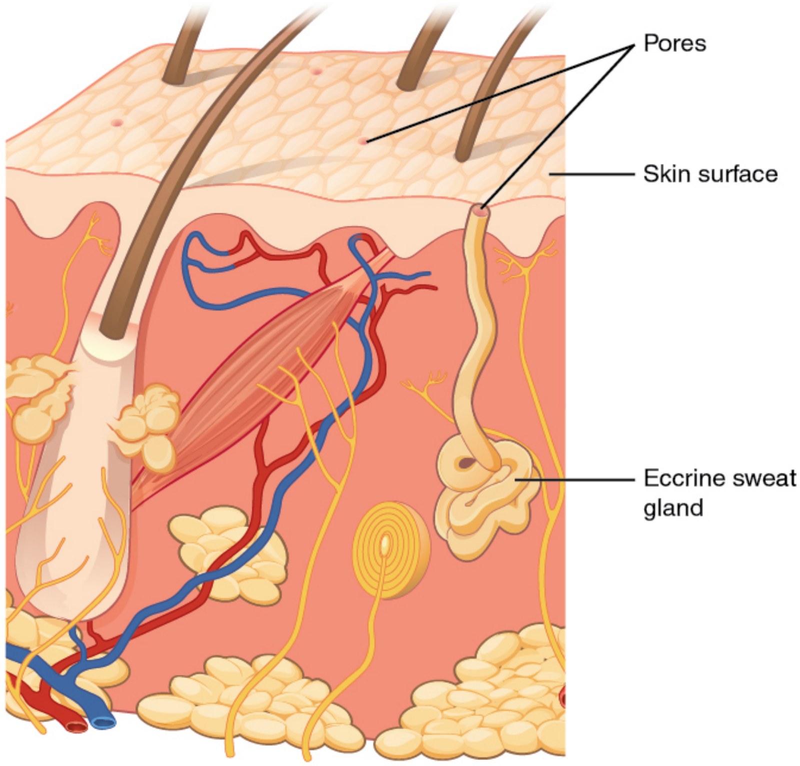


Fig. 3.5 Illustration of sweat glands that produce perspiration by OpenStax College [[CC BY 3.0](https://creativecommons.org/licenses/by/3.0)] *https://commons.wikimedia.org/wiki/File:508_Eccrine_gland.jpg*

Sweat is a form of moisture called*perspiration.* Fig. 3.5 illustrates the sweat glands in your skin. These help your body cool itself by producing perspiration that absorbs energy from your body when the moisture evaporates.
Relative humidity compares how much water vapor is in the air to how much water vapor the air can hold at a given temperature. A prediction of hot muggy weather with high relative humidity means that the air will be very humid, holding close to as much water vapor as possible. This means that very little perspiration will be able to absorb energy from your body and cool you by evaporating from your skin.

- What happens when sunlight shines on plants?
- Cover a houseplant with a plastic bag and place in sunlight outside or inside near a lamp so the lamp is shining on the plant as shown in Fig. 3.6. What happens after 15

minutes? An hour?

FIG. 3.6. Demonstration of transpiration.

This form of evaporation is called *transpiration.* The drops of water that form on the plastic bag have evaporated from the leaves and then condensed on the cooler inner surface of the bag. Plants use some energy from the Sun to grow via photosynthesis; some energy from the Sun, however, is absorbed by liquid water evaporating from the leaves. Transpiration from an acre of corn, for example, can total as much as three to four thousand gallons of water each day (see https://water.usgs.gov/edu/watercycletranspiration.html).

- What sometimes happens to ice and snow on high mountains?

FIG. 3.7 Example of sublimation on Mt. Everest. Image by [Simon Steinberger](#) *from* [Pixabay](#) https://pixabay.com/photos/mount-everest-himalayas-nepal-413/

Another form of evaporation occurs when ice or snow changes directly into a gaseous form of water without a liquid phase as shown in Fig. 3.7. This form of evaporation is called *sublimation*. See https://water.usgs.gov/edu/watercyclesublimation.html for additional information about sublimation directly from a solid to a gas.

Water also absorbs energy when changing from a solid phase to a liquid:

- What happens when ice warms?
- Place an ice cube outside in the sunlight or inside near a lamp so the lamp is shining on the ice cube as shown in Fig. 3.8. What happens after 15 minutes? An hour?

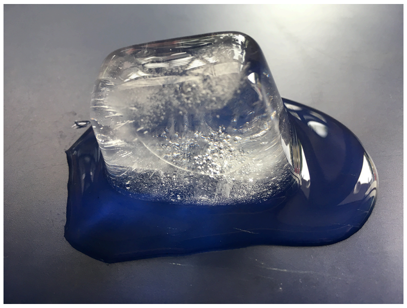


FIG. 3.8 Ice cube in a warm room.

This phase change is called *melting*. During the summer melt season in the Arctic, more sea ice has been melting than sea water has been freezing during winter in recent years. (See the National Snow and Ice Data Center Arctic Sea Ice News and Analysis at https://nsidc.org). For information about melting snow and ice, see: https://water.usgs.gov/edu/watercyclesnowmelt.html.

As shown in Fig. 3.9, melting sea ice forms fresh water *melt ponds* in depressions in the surface.

FIG. 3.9 Melting sea ice during summer in the Artic. Image by Kathryn Hansen | NASA Goddard Space Flight Center used under CC BY 2.0 https://earthobservatory.nasa.gov/images/51335/ponds-on-the-ocean

- Record your findings, including sketches, in the *During* section of the physics notebook page
- Discuss these examples of phase changes that absorb energy and formulate some central ideas that summarize your findings. Record these in the *After* section of the physics notebook page.
- Write a rationale that explains how the evidence supports the ideas and why these are important.

Phase changes also occur in the opposite direction, when phase changes of water release rather than absorb energy.

Question 3.4 What are some everyday examples of water releasing energy when water changes state?

To explore such phase changes, you can use:

- ice cold glass of water
- tray
- wide mouth jar
- hot water to fill jar about half way
- small cup that fits in opening of jar or jar lid
- ice to put in the cup or on lid

- In the ***Before*** section of a new physics notebook page, note some examples of phase changes of water that involve releasing energy. What are some ways to explore these?

For example:

- What happens if you are wearing eyeglasses when you walk inside during winter? Or get out of a hot bath and look at a mirror?
- What happens if you bring an ice-cold container of water into a warm room? For an

extra effect, use food coloring to make colored ice cubes and use those to cool the drink. What happens after 15 minutes? An hour? Are the water droplets that form on the outside of the container clear or the color of the melting ice cubes?

FIG. 3.10 Demonstration of condensation.

This phase change is called *condensation*. For more information, see https://water.usgs.gov/edu/watercyclecondensation.html. Read about the role of latent heat released from condensing water droplets in thunderclouds and hurricanes at http://climate.ncsu.edu/edu/Heat . As water vapor condenses into droplets, the heat released warms the surrounding air, causing instability in the cloud as the warm air rises.

What happens sometimes if liquid water in the atmosphere coalesces into very large droplets?

- Place a wide mouth jar on a tray. Pour some hot water into the jar, about half full. Place a cup of ice into the mouth of the jar so it just fits or simply put some ice on the upside-down lid on top of the jar. What happens after 15 minutes? An hour?

FIG. 3.11 Demonstration of precipitation.

This is called precipitation. For more information, see https://water.usgs.gov/edu/watercycleprecipitation.html . The higher the average temperature of the atmosphere, the more water evaporates; the more water in the atmosphere, the more rainfall can occur. For information about changes in heavy rainfall events in the U.S, see http://climatesmartfarming.org/changing-climate/ .

What happens if liquid water gets cold enough?

FIG. 3.12 Illustration of freezing liquid water to make ice cubes.

FIG. 3.13 Freezing winter weather. CC0 Public Domain. https://www.maxpixel.net/Leann-Snow-Coldly-Winter-Weather-Landscape-3077971

If the temperature gets cold enough, a liquid freezes into a solid form. This can occur in a controlled situation in a refrigerator or in nature during a winter storm. As liquid water freezes, energy is released. Some farmers spray crops like oranges with water to protect the crops from freezing. Why would this work? See: http://fruitgrowersnews.com/article/protecting-your-fruit-from-frost-and-freeze/

- Record findings, including sketches, in the *During* section of this physics notebook page.
- Discuss these examples of phase changes that release energy and formulate relevant central ideas. In the ***After*** section of this physics notebook page, report these ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the ideas and why these are important.
- Also reflect upon these explorations of phases changes, both those that absorb and those that release energy. What connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

C. Exploring convection phenomena

Liquids and gases are called *fluids*. Fluids can flow from one place to another. When streams of warm and cool liquid water are flowing nearby, *convection* phenomena occur. Convection also occurs with nearby streams of warm and cool air.

Question 3.5 What happens when convection occurs?

To explore convection phenomena, you can use:

- blue food coloring
- ice cube tray to make blue ice cubes in a freezer

- clear plastic rectangular container such as a shoe storage box or a clear glass loaf dish
- four paper cups and one cup that can hold almost boiling water
- source of water to fill container
- red food coloring in small bottle or eyedropper
- very hot water (close to boiling)

- In the ***Before*** section of a physics notebook page, predict what you think will happen when a stream of warm water and a stream of cold water are flowing in a clear plastic or glass container of water. Also describe a way to explore such convection currents.
- Set four paper cups upside down at four corners of a rectangle so that they can support a rectangular container such as a clear plastic shoebox or glass loaf dish.
- Fill the clear container with room temperature water and place it on the 4 cups.
- Carefully use an eyedropper or small bottle of food coloring to place a red drop on the bottom of the clear container at one end.
- Choose a cup that can hold very hot water so that you can slide it underneath the clear container.
- Fill this cup with very hot (close to boiling) water. Slide the cup of hot water under the container so that it is positioned underneath the dot of red food coloring on the bottom of the container
- What happens to the water above the red dot?
- Carefully add some blue ice cubes to the water at the other end of the container.
- What happens to the blue water melting from the ice cubes?
- What happens to the blue and red streams of water?

FIG. 3.14 Demonstration of convection currents.

- Record findings, including sketches, in the *During* section of this physics notebook page
- Discuss your findings and formulate a relevant central idea about convection currents. In the ***After*** section of the physics notebook page, report this idea and the evidence on which it is based.
- Write a rationale that explains how the evidence supports the idea and why this is important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

1. *Nuances about convection phenomena*

Convection phenomena occur when fluids differ in how dense they are. Density is a measure of how much mass a material has in a given volume. Something will sink in a fluid if it has more mass in a given volume than the fluid; something will rise in a fluid if it has less mass than the fluid in a given volume.

In this course, we measure mass in grams and volume in cubic centimeters. At standard atmospheric pressure, room temperature water (about 21°C) has a density of about 0.998 grams per cubic centimeter. Hot water close to boiling (about 93°C) has a density of about 0.963 grams per cubic centimeter, so it rises in the room temperature water. Cold water melting from an ice cube (about 4°) has a density of about 1.000 grams per cubic centimeter so it sinks in the room temperature water (see: https://water.usgs.gov/edu/density.html). These small differences in density of warm and cold water are enough to cause the convection currents observed.

Ocean currents are caused both by differences in temperature and by differences in salinity. Warm water from the tropics moves near the surface of the oceans toward the poles; cold water from the poles, being more dense, flows toward the tropics at a deeper level. Fresh water from melting glaciers reduces salinity; freezing sea ice leaves salt and other minerals behind in the ocean, increasing salinity with saltier water sinking and fresh water rising. Currents of water travel across the globe via the *Great Ocean Conveyor Belt*, which takes about 1000-1200 years for water to circulate throughout the global system (see: https://www.weather.gov/jetstream/circulation).

D. Summarizing the water cycle

A variety of physical processes underlie the phases and changes-in-phases of water known as the water cycle.

Question 3.6 What is the water cycle?

The water cycle includes the phases of solid (ice and snow), liquid (ground water, lakes, streams, rivers, ocean), and gas (water vapor), in addition to the changes-in-phases known as freezing, melting, sublimating, evaporating, transpiring, perspiring, and condensing. Briefly describe each exploration in Table III.2.

Complete documenting your explorations and writing a summary before looking at an example of student work about explorations of the water cycle.

TABLE III.2 Central ideas about the influence of light and thermal phenomena on local weather, including the water cycle

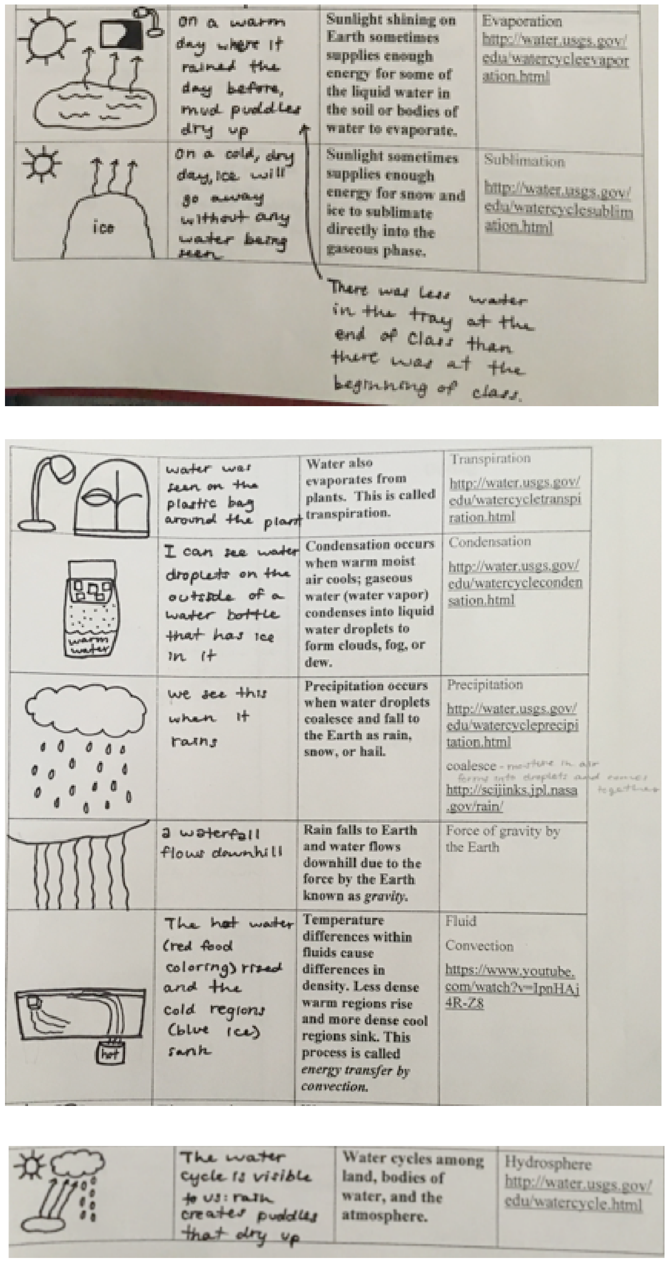
TABLE III.2 Central ideas about the influence of light and thermal phenomena on local weather, including the water cycle			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		The Sun radiates energy in all directions, some of which shines on the Earth. This process is called *energy transfer by radiation.*	Radiation https://www.windows2universe.org/sun/spectrum/multispectral_sun_overview.html
		Sunlight shining on Earth sometimes supplies enough energy for some liquid water in the soil or bodies of water to evaporate.	Evaporation http://water.usgs.gov/edu/watercycleevaporation.html
		Sunlight sometimes supplies enough energy for snow and ice to sublimate directly into the gaseous phase.	Sublimation http://water.usgs.gov/edu/watercyclesublimation.html
		Water also evaporates from plants. This is called transpiration.	Transpiration http://water.usgs.gov/edu/watercycletranspiration.html

		Water also evaporates from people. This is called perspiration.	Perspiration http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/sweat.html
		Condensation occurs when warm moist air cools; gaseous water (water vapor) condenses into liquid water droplets to form clouds, fog, or dew.	Condensation http://water.usgs.gov/edu/watercyclecondensation.html
		Precipitation occurs when water droplets coalesce and fall to the Earth as rain, snow, or hail.	Precipitation http://water.usgs.gov/edu/watercycleprecipitation.html Coalesce http://scijinks.jpl.nasa.gov/rain/
		Rain falls to Earth and water flows downhill due to the force by the Earth known as *gravity*.	Force of gravity by the Earth https://spaceplace.nasa.gov/what-is-gravity/en/
		Temperature differences within fluids cause differences in density. Less dense warm regions rise and more dense cool regions sink. This process is called *energy transfer by convection*.	Fluid Convection current https://www.youtube.com/watch?v=IpHAj4R-Z8

		Water cycles among land, bodies of water, and the atmosphere.	Hydrosphere http://water.usgs.gov/edu/watercycle.html

1. *Example of student work about explorations of the water cycle*

Figure 3.15 shows a student's entries into a table about phase changes and convection currents that occur during the water cycle.



Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
	on a warm day where it rained the day before, mud puddles dry up	Sunlight shining on Earth sometimes supplies enough energy for some of the liquid water in the soil or bodies of water to evaporate.	Evaporation http://water.usgs.gov/edu/watercycleevaporation.html
ice	on a cold, dry day, ice will go away without any water being seen	Sunlight sometimes supplies enough energy for snow and ice to sublimate directly into the gaseous phase.	Sublimation http://water.usgs.gov/edu/watercyclesublimation.html
	There was less water in the tray at the end of class than there was at the beginning of class.		
	water was seen on the plastic bag around the plant	Water also evaporates from plants. This is called transpiration.	Transpiration http://water.usgs.gov/edu/watercycletranspiration.html
warm water	I can see water droplets on the outside of a water bottle that has ice in it	Condensation occurs when warm moist air cools; gaseous water (water vapor) condenses into liquid water droplets to form clouds, fog, or dew.	Condensation http://water.usgs.gov/edu/watercyclecondensation.html
	we see this when it rains	Precipitation occurs when water droplets coalesce and fall to the Earth as rain, snow, or hail.	Precipitation http://water.usgs.gov/edu/watercycleprecipitation.html coalesce - moisture in air forms into droplets and comes together http://scijinks.jpl.nasa.gov/rain/
	a waterfall flows downhill	Rain falls to Earth and water flows downhill due to the force by the Earth known as *gravity.*	Force of gravity by the Earth
hot	The hot water (red food coloring) rised and the cold regions (blue ice) sank	Temperature differences within fluids cause differences in density. Less dense warm regions rise and more dense cool regions sink. This process is called *energy transfer by convection.*	Fluid Convection https://www.youtube.com/watch?v=IpnHAj4R-Z8
	The water cycle is visible to us: rain creates puddles that dry up	Water cycles among land, bodies of water, and the atmosphere.	Hydrosphere http://water.usgs.gov/edu/watercycle.html

FIG. 3.15 Example of a student's entries into Table III.2 about the water cycle.

In row 1, which focused upon evaporation, the student drew a picture of a sun shining on a puddle with arrows pointing upward representing evaporating water, the natural phenomenon being modeled by the equipment drawn in the upper right corner, a tray with a puddle of water on which a lamp is shining. The student wrote, O*n a warm day where it rained the day before, mud puddles dry up* and added the statement, T*here was less water in the tray at the end of class than there was at the beginning of class.*

In row 2, which focused upon sublimation, the student drew a picture of the sun shining on ice on a mountain with arrows pointing upward representing water sublimating directly from ice into water vapor. The student wrote, O*n a cold, dry day, ice will go away without any water being seen.*

In row 3, which focused upon transpiration, the student drew a picture of a lamp shining on a plant enclosed in a clear plastic bag. The student wrote, W*ater was seen on the plastic bag around the plant.*

In row 4, which focused upon condensation, the student drew a picture of a large jar filled part way with warm water, with a cup with ice cubes sitting in its opening, and droplets of water on the bottle. The student wrote, I *can see water droplets on the outside of a water bottle that has ice in it.*

In row 5, which focused upon precipitation, the student drew a picture of a rain falling from a cloud. The student wrote, W*e see this when it rains.*

In row 6, which focused upon the force of gravity by the Earth, the student drew a picture of a waterfall and wrote, A *water fall flows downhill.*

In row 7, which focused upon convection, the student drew a picture of a clear plastic container filled with water, with a blue ice cube floating at the left end with melting blue water streaming down and with a hot cup under red food color at the right end with a stream of red water floating up and over toward the ice cube. The student wrote, *The hot water (red food coloring) rised and the cold regions (blue ice) sank.*

In row 8, which focused on the water cycle, the student drew a picture of the sun, shining on a puddle with arrows, representing evaporating water, pointing up toward a cloud and with raindrops falling down. The student wrote, *The water cycle is visible to us: rain creates puddles that dry up.*

The student wrote the following rationales for the central ideas claimed in the third column of the table:

> ***Sunlight shining on Earth sometimes supplies enough energy for some of the liquid water in the soil and bodies of water to evaporate.*** *My sketch of the evaporation demonstration is seen in (row 1of the table). For this demonstration, we had a tray of water, which represents some of the liquid water in the soil and bodies of water. There was also a lamp that was shining on the water, which represents the sunlight shining on the Earth. In this demonstration, we observed the water at*

the beginning of class and at the end of class. Since there was less water in the tray at the end of class than at the beginning of class, this shows that some water was evaporated. This model is a demonstration that shows that sunlight shining on earth sometimes supplies enough energy for some of the liquid water in the soil and bodies of water to evaporate.

Sunlight shining on Earth sometimes supplies enough energy for snow and ice to sublimate directly into the gaseous phase. *Sublimation occurs if snow or ice vaporizes directly into the gaseous phases without first melting and going through the liquid phase.*

Water also evaporates from plants. This is called transpiration. *My sketch of the transpiration demonstration is seen in (row 3 of the table). For this demonstration, a plastic Ziploc bag was placed around a plant. A lamp was shining on the plant. Some water droplets were able to be seen on the bag, which demonstrates this process of water evaporating from plants, which is called transpiration.*

Condensation occurs when warm moist air cools; gaseous water (water vapor) condenses into liquid water droplets to form clouds, fog, or dew. *My sketch of the condensation experiment is seen in (row 4 of the table). For this experiment, a jar was filled with warm water. Then, a container with ice in it was placed on the top of the jar. The warm moist air that is in the jar, below the container, cools because of the ice in the container on the top of the jar. Water droplets form on the bottom of the container and on the sides of the jar, which is the gaseous water that has condensed into liquid water droplets. This process of the gaseous water condensing into liquid water droplets is how clouds form.*

Precipitation occurs when water droplets condense, coalesce, and fall to the Earth as rain, snow, or hail. Rain falls to Earth and water flows downhill due to the force by the Earth known as gravity. *My sketch of a precipitation demonstration is seen on (rows 5 and 6 of the table). First, I drew water droplets falling to the Earth as rain, which shows the process of precipitation. Then, I drew the water flowing downhill in the form of a waterfall, due to the force of gravity.*

Temperature differences within fluids cause differences in density. Less dense warm regions rise and more dense cool regions sink. This process is called energy transfer by convection. *My sketch of the convection experiment can be seen in (row 7 of the table). For this experiment, a container of room temperature water was placed on four cups. Warm water was colored red by food coloring and was warmed by very hot water that was placed directly below the food coloring. The warm water first rose up from the bottom of the container toward the top, and then it started* *moving horizontally along the top of the water toward the ice cube. Then, the blue ice cube that was placed on the top of the water was observed. The blue melted water first sank down to the bottom of the water and then it moved horizontally along the bottom of the container toward the red food coloring. These movements set up a circular current within the container. The hot water rising and the cold water sinking created convection currents. This idea of warm regions rising and cool regions sinking can also be seen in ocean currents.*

Water cycles among land, bodies of water, and the atmosphere. *Figure (3.3) shows the water cycle.*

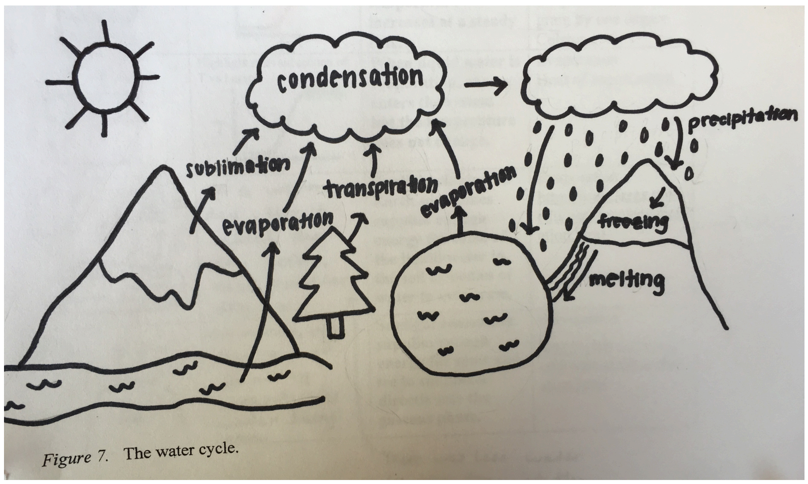


FIG 3.16 Example student's diagram of the water cycle.

The student has included labels with the phase changes of *evaporation*, *sublimation*, *transpiration*, *condensation*, *precipitation*, *freezing and melting* as well as illustrations of snow on the mountains, rain falling, clouds in the sky, and bodies of liquid water on the Earth. The student described the water cycle as follows:

First of all, the sun heats up the water and turns it into water vapor. The water vapor leaves the source and goes into the air. The water vapor comes from different forms of water on earth such as lakes and rivers through the process of evaporation, it comes from plants through the process of transpiration, and it comes straight from ice or snow without melting first through the process of sublimation. Once the water vapor rises, it goes through the process of condensation. Condensation is when the water vapor in the air becomes cold and turns back into a liquid, forming clouds. Once enough water has condensed and the clouds are full, the water falls to the ground, which is known as precipitation. Some of the water falls back into oceans, *lakes, rivers, or other water sources. Other parts of that water can be stored in ice or snow, which is known as freezing. Then, when that frozen snow or ice becomes liquid water again, this is known as melting. This process of the water cycle is continuous and will repeat itself again and again.*

Physics student, Spring 2016

The next section develops some additional central ideas useful in explaining intriguing phenomena that students may experience when enjoying a sunny day at the beach.

IV. Developing Additional Central Ideas Based on Evidence

A sunny day at the beach can be a lot of fun. Why does the sand get so hot, however, while the water is so cool when the sun has been shining on both the sand and the water in the same way for the same time? Sometimes the sky clouds over and a breeze comes up in the afternoon. Why does that happen? This section explores how light and thermal phenomena sometimes affect the local weather during a sunny day at the beach.

A. Exploring the effects of properties of materials

Question 3.7 What happens when light shines on sand and water?

Equipment: To explore the effects of various properties on what happens when light shines on sand and water, use:

- Lamp with bendable stem,
- Light probe connected to a computer with graphing software or cell phone app for reflectivity (LUX meter)
- Black paper, white paper
- Two identical clear cups
- Balance
- **Sand and water at room temperature**
- Two temperature probes, and a computer or two regular bulb and tube thermometers with a range from at least about 15°C to 35°C.

[In a remote learning situation, brown rice, split peas, or dried beans can serve as a substitute for sand if necessary. A simple balance can be made with a board (a ruler will do) and something on which to balance it like a playground teeter totter. Set this up so it is balanced and then use two identical clear cups to put about half a cup of water on one side and as much sand as you need to balance it on the other side.]

- What properties of sand and water might affect what happens when light from the Sun shines in the same way for the same time on both the sand and the water?
- In the ***Before*** section of a physics notebook page, record your ideas and predictions about the effect of properties explored in units 1 and 2: reflectivity, thermal conductivity, and specific heat. How can you explore the effects of these properties of sand and water on what happens when sunlight shines on a beach?
- To explore the property of reflectivity, move a light probe connected to a computer or a cell phone with a LUX meter app over black and white paper as well as over sand and water. Does the angle of reflection seem to matter?
- One way to explore differences in thermal conductivity and specific heat is to use equal amounts of the materials. Should one use equal amounts by mass or by volume?
- The property of specific heat is expressed in terms of the number of calories needed to change the temperature of one unit of mass by one degree Celsius so equal amounts by mass seem appropriate. Use a balance and identical clear cups to measure equal masses of sand and water at **room temperature**. Compare the volumes of the equal masses of sand and the water in the cups. What does this imply about the density of sand compared to the density of water?
- Set up a lamp with curved stem shining from the same distance away on cups with equal masses of sand and water at room temperature.
- Put both temperature probes in the same cup of water to make sure that they read the same number if put in the same container. If the probes do not read the same or close to the same number (within 0.2°C or so), calibrate them in the computer. If using regular thermometers, put both in the same cup of water and see if they read the same number; if they do not, record their temperatures and correct the final readings for this difference.
- Connect the two temperature probes to a computer and place one probe near the **top** of the cup of water and the other probe near the **top** of the cup of sand. Set the time on the computer for 900 seconds, about 15 minutes. (Or place regular thermometers near the tops of the sand and water and regularly read and record the temperatures while the lamp is shining on the cups of sand and water).
- Start the computer program (or use the regular thermometers) to record the initial

temperatures of the sand and water. If both the sand and the water have been sitting in the same room for a long time, these temperatures should be the same or close to the same (within a degree or so). If they are not the same, record the temperatures and include this difference in interpreting your results.

- Turn on the lamp. Monitor the temperatures of the sand and water, by looking at the temperature versus time graphs on the computer (or regularly record the regular thermometer readings at least every minute).
- What do you observe after at least 10 minutes?
- Move the temperature probes (or thermometers) to near the bottom of the cups. What do you observe?
- In the ***During*** section of the physics notebook page, record your findings. Draw a picture of the temperature versus time graph and indicate the parts of the graph that represent the different materials that you tested. Note any vocabulary that is new to you.

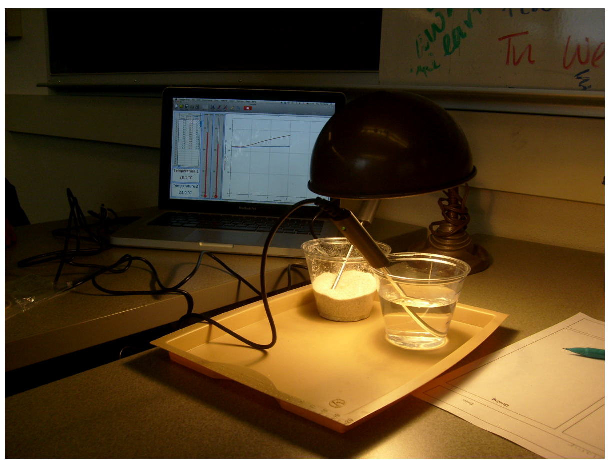


Fig 3.17 End of experiment to compare the way that energy from a lamp warms up sand and water. Line graph shows temperature versus time for sand (red) and water (blue). Note the difference in heights of the equal masses of sand and water. Which is more dense? ©Vernier Software & Technology-used with permission.

- Discuss your findings and formulate relevant central ideas. In particular, compare the slope of the graph for sand with the slope of the graph for water.
- Compare the change in temperature of the sand during ten minutes with the change

in temperature of the water during ten minutes. How is this result related to a comparison of how much the temperature changes for each unit of time (one minute)? How is this result related to a comparison of how much the temperature changes for each unit of incoming energy from the lamp?

- Also discuss findings about the reflectivity of black and white paper and of sand and water. Compare your findings with those by other groups. Do they agree?
- Formulate central ideas based on the findings.
- In the ***After*** section of the physics notebook page, report these central ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the central ideas and why these are important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

Enter notes in Table III.3 representing these explorations:

TABLE III.3 Central ideas about the properties of materials

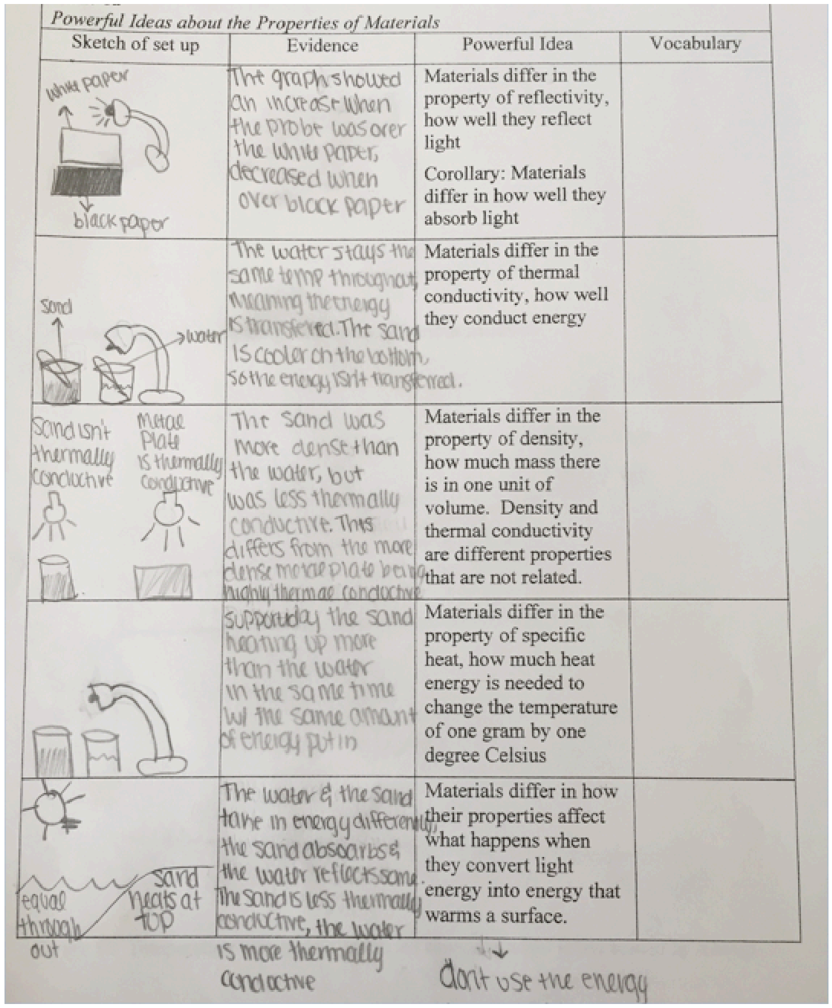
TABLE III.3 Central ideas about the properties of materials			
		Materials differ in the property of reflectivity, how well they reflect light Corollary: Materials differ in how well they absorb light	
		Materials differ in the property of thermal conductivity, how well they transfer energy	
		Materials differ in the property of density, how much mass there is in one unit of volume. Density and thermal conductivity are different properties that are not related.	

	Compare the change in temperatures, ΔT for sand and ΔT for water , during 10 minutes with the lamp shining equally on sand and on water.	Materials differ in the property of specific heat, how much energy is needed to change the temperature of one gram by one degree Celsius.	
		Materials differ in how their properties affect what happens when they convert light energy into energy that warms a surface.	

Complete documenting your exploration and writing a summary before looking at an example of student work. Also consider nuances about exploring the effect of thermal conductivity, specific heat, and reflectivity on what happens when light shines on sand and water.

1. Example of student work about what happens when light shines on sand and water

Figure 3.18 shows a student's entries into a table about ideas about properties of materials. The student's summary also appears below.



Powerful Ideas about the Properties of Materials

Sketch of set up	Evidence	Powerful Idea	Vocabulary
white paper; black paper	The graph showed an increase when the probe was over the white paper, decreased when over black paper	Materials differ in the property of reflectivity, how well they reflect light. Corollary: Materials differ in how well they absorb light	
sand; water	The water stays the same temp throughout meaning the energy is transferred. The sand is cooler on the bottom, so the energy isn't transferred.	Materials differ in the property of thermal conductivity, how well they conduct energy	
Sand isn't thermally conductive; Metal plate is thermally conductive	The sand was more dense than the water, but was less thermally conductive. This differs from the more dense metal plate being highly thermal conductive	Materials differ in the property of density, how much mass there is in one unit of volume. Density and thermal conductivity are different properties that are not related.	
	supporting the sand heating up more than the water in the same time w/ the same amount of energy put in	Materials differ in the property of specific heat, how much heat energy is needed to change the temperature of one gram by one degree Celsius	
equal throughout; sand heats at top	The water & the sand take in energy differently, the sand absorbs & the water reflects some. The sand is less thermally conductive, the water is more thermally conductive	Materials differ in how their properties affect what happens when they convert light energy into energy that warms a surface.	

don't use the energy

FIG. 3.18 Example of student's entries into Table III.3 about properties of materials.

In row 1, the student drew a picture of a light shining on white and black paper. The student wrote, *The graph showed an increase when the probe was over the white paper, decreased when over black paper.*

In row 2, the student drew a picture of a cup with sand and a cup with water, each with a temperature probe, and a light shining on the cups. (Note that the student indicated more rather than less sand than water.) The student wrote, *The water stays the same temp throughout, meaning the energy is throughout. The sand is cooler on the bottom so the energy isn't transferred.*

In row 3, the student drew a picture of a cup of sand and a metal plate, with a light shining on each, and notes *sand isn't thermally conductive* and *metal plate is thermally conductive*. The student wrote, *The sand was more dense than the water, but was less* *thermally conductive. This differs from the more dense metal plate being highly thermally conductive.*

In row 4, the student drew a picture of a light shining on a cup with sand and a cup with water. The student wrote, *Supported by the sand heating up more than the water in the same time with the same amount of energy put in*. (Note that the student again drew containers with higher rather than lower sand than water).

In row 5, the student drew a sun shining on a beach with sand and water, with labels *equal throughout* in the water and *sand heats at top* in the sand. The student wrote, *The water and the sand take in energy differently, the sand absorbs and the water reflects some. The sand is less thermally conductive, the water is more thermally conductive*. The student also drew a light and a dark arrow with the note *don't use the energy*.

The student wrote the following rationales for the ideas claimed in the third column of the table:

> ***Materials differ in the property of reflectivity, how well they reflect light. Corollary: Materials differ in how well they absorb light. …****The white paper showed an increase on the graph, because it has greater reflectivity and the black paper showed a decrease on the graph, because it has lower reflectivity. We also compared the reflectivity of the dry sand and water with a light sensor. The reflectivity of water depends upon the angle at which the light source is shining on the water. Water is highly absorbent when the Sun in high and more reflective when the sun is shining on it at an angle…*
>
> ***Materials differ in the property of thermal conductivity****. Thermal conductivity is how well a material transfers energy. The second row of (the table) shows the light source shining equally on the equal masses of water and sand. For ten minutes the light was shining over both cups with temperature probes in the cups.*
>
> *After ten minutes, the water warmed from an initial temperature of 21.6°C to 22.9°C throughout the cup of water. The temperature near the top of the sand was 31.1°C. The temperature near the bottom of the sand was the same as the initial temperature, which was 24.4°C. I would infer that the water has higher thermal conductivity because the temperature was the same throughout the substance, meaning energy was transferred from the top to the rest of the liquid.*
>
> *The same amount of light shined for the same amount of time on the same mass of water and dry sand, but the temperature of the sand was hotter on the top than the bottom. The water was the same temperature throughout, therefore the sand kept more of the energy it absorbed near the surface of the sand.*

Materials differ in the property of density, how much mass there is in one unit of volume. *The third row of (the table) describes this idea. When I was filling the cups with equal masses of sand and water I had to add some sand. I added a little bit of sand and put the cup on the scale, which showed the sand weighed much more than the water. I poured a little of the sand out and scale showed the sand cup was much lighter than the water. The little bit of the sand made a big difference, showing sand is dense. The sand was denser, so there was less sand (by volume) in the cup than water in the cup. If sand was added to water, the sand would sink to the bottom, demonstrating the sand is denser. Water is the standard, so the mass of one gram of water has a volume of one cubic centimeter at 4ºC. The density of the sand is approximately 1.6 grams for each cubic centimeter.*

The metal plate appeared denser than the Styrofoam plate that we experimented with before. The metal plate had more thermal conductivity than the Styrofoam plate, which was demonstrated by the cool feeling we experienced when touching the metal plate. When touching the Styrofoam plate there was no temperature change felt. The sand was denser than the water, but as demonstrated above, the sand had lower thermal conductivity. This is evidence that there is no relation between the properties of density and thermal conductivity.

Materials differ in the property of specific heat, how much energy in calories is needed to change the temperature of one gram by one degree Celsius*. The fourth row of (the table) represents this idea. Water is the standard, meaning one calorie is needed to change the temperature of one gram of water by one degree Celsius, at standard atmospheric pressure and 20ºC. This can be shown by* c_{water} =1 *cal/(g ºC). The specific heat of sand is smaller; sand only needs approximately 0.2 calories to change one gram of sand by one degree Celsius. This can be represented by* c_{sand} =0.2 *cal/(g ºC).*

These ideas can be used to decide which material changes temperature more. If the sand and the water have the same mass, the sand will change temperature more. Less energy is needed to change one gram of sand by one degree Celsius than is needed for water; it only takes 0.2 calories to change one gram of sand one degree Celsius while water needs one calorie to change one gram of water by one degree Celsius. One calorie of energy from the Sun will change one gram of water one degree Celsius. For sand, one calorie of energy from the Sun will change one gram of sand by five degrees Celsius. Therefore, sand will change temperature by five degrees more.

Materials differ in how their properties affect what happens when they convert

light energy into energy that warms a surface. *Two cups were filled with equal masses of water and dry sand. These cups were placed under a light where the light could shine on them equally for an equal amount of time. When light shined equally on the equal masses of the sand and water, the water heated evenly throughout the cup. The sand was warmer near the surface but remained the initial temperature near the bottom of the cup. The sixth row of (the table) shows this idea.*

Figure (3.19) shows the graph that represents our findings over ten minutes. The graph shows both water and sand increased in temperature gradually and constantly. The temperature of the sand increased more than the temperature of the water. The initial temperature of the sand was 24.4°C, which increased to 31.1°C. The initial temperature of the water was 21.6°C which increased to 22.9°C.

Water is more thermally conductive than sand. This is demonstrated by the temperature of the water being the same throughout the cup. Sand has a low thermal conductivity, demonstrated by the differences in temperature between the surface of the sand and the bottom of the sand.

The temperature of the sand (near the surface) increased more than the temperature of the water even though they were exposed to the same amount of energy for the same amount of time. This demonstrates that sand has a smaller specific heat. One gram of sand can change one degree Celsius with only 0.2 calories of energy, which means the sand needs less energy than water to change the same amount in temperature, which is shown on the graph.

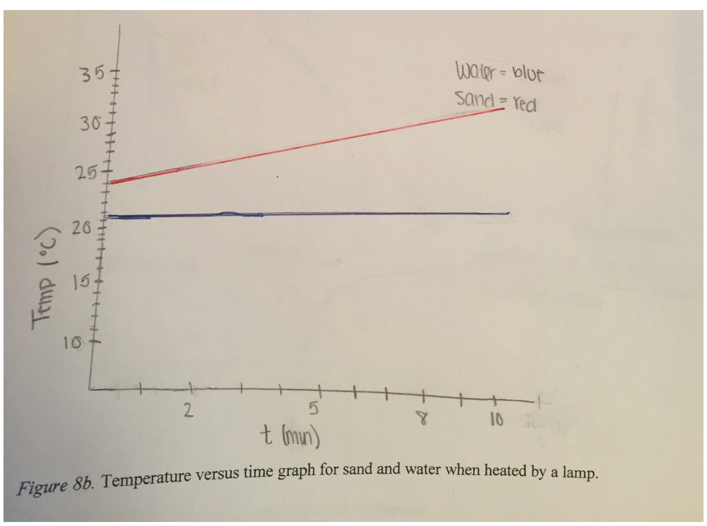


FIG. 3.19 Student's *graph of temperature changes for sand and water*

Physics student, Spring 2016

2. *Nuances about the exploration of effects of properties of materials*

(a) Noticing the lack of a relationship between the properties of thermal conductivity and density.

As this student noted clearly above, this exploration refutes the tempting inference that thermal conductivity and density are related. Although the more dense metal blocks were also more thermally conductive in the exploration in Unit 2, here the less dense water was more thermally conductive than the more dense sand.

The temperature of the sand near the bottom of the cup was lower than the temperature of the sand at the top of the cup. From this we inferred that the energy absorbed by the sand near the top of the cup stayed near the top of the cup rather that spreading throughout the sand, that sand has a low thermal conductivity. The temperature of the water near the bottom of the cup, however, was the same as the temperature of the water near the top of the cup. From this we inferred that some of the energy absorbed by the water near the top of the cup flowed throughout the water in the cup rather than staying on the surface, that water has a high thermal conductivity.

These results indicate that in this case the more dense material, sand, had a lower thermal conductivity than the less dense material, water. This is opposite to the earlier result in Unit 2 in which we inferred that the more dense materials, the 2 metals, had higher thermal conductivities than the less dense materials, wood and Styrofoam. These contradictory results indicate that there is no relation between the properties of thermal conductivity and density.

(b) Interpreting the difference in initial heights of the lines in Fig. 3.19. Visually it is clear from the graph that the temperature of the sand changed more rapidly than the temperature of the water. The lines do not start at the same height, however, as would be expected if the sand and water started at the same temperature. It is not clear whether the sand and water were at different temperatures at the start of the experiment, whether the temperature probes were not calibrated so they did not read the same temperature although the sand and water actually were at the same temperature, or whether the temperatures of the sand and water were already different at the instant in time that the computer started displaying the graph because the students turned on the light before they started the computer program recording the temperature probes. It is important to turn on the computer first, to document that the sand and water are starting out at the same temperature. Then turn on the light to start the warming process. It is clear from the graph, however, that the temperature probe in the sand increased in temperature much faster than the temperature probe in the water.

(c) Interpreting the slopes of the lines in Figs. 3.17 and 3.19. The vertical axes of the graphs shown in Fig. 3.17 and Fig. 3.19 represent the temperature of the sand (red line) and water (blue line). The horizontal axes represent the time that the lamp was shining on the sand and water. The *height* of the line at any point represents the temperature at that instant of time. The *slope* of the line represents how much the height changed during some time interval. The horizontal axis is marking off time in one-minute time intervals. For these graphs, the slope of the line represents how much the temperature was changing during one minute of time.

Because the lamp was the same distance away from the sand and water, the horizontal axis represents not only the time that the light was on but also the incoming energy shining on the sand and water. Therefore **the slopes of the lines also represent how much the temperatures of sand and water were changing for each unit of incoming energy**.

The straight lines indicate that these slopes were constant, that the temperature of the sand was changing at the same rate at the end of the ten minutes as it was changing at the beginning of the ten minutes that the light was shining on the cups of sand and water. The same was true for the water, that the rate of change of temperature for each unit of time was constant for the water.

(d) Comparing the slopes of the lines. How did the slope of the line for the sand compare to the slope of the line for the water? Clearly the slope of the red line, representing how much the temperature changed for sand for each unit of energy, was greater than the slope of the blue line, representing how much the temperature changed for water for each unit of energy absorbed.

(e) Relating the slopes of the lines to the specific heats of sand and water. How does this result for the slopes of the lines relate to a comparison of the specific heats of sand and water? As discussed in Unit 2, a material's *specific heat* is the amount of energy needed to change the temperature of a mass of one gram of the material by a temperature of one degree C. A table of specific heats (See http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html) lists the specific heat of sand as 0.19 cal/(g°C) and the specific heat of water as 1.00 cal/(g°C).

If the specific heat of sand is about 0.2 cal/ g°C, how much would the temperature of 1 gram of sand increase if it absorbed 1 calorie of energy? If a gram of sand increases in temperature by 1°C when it absorbs 0.2 cal of energy and the sand absorbs (0.2 cal + 0.2 cal + 0.2 cal +0.2 cal + 0.2 cal) of energy, how much does its temperature increase?

If the specific heat of water is 1.0cal/g°C, how much would the temperature of 1 gram of water increase if it absorbed 1 calorie of energy?

For each calorie of energy absorbed by a gram of sand, the temperature of the sand goes up about 5 degrees C compared to one degree C for each calorie of energy absorbed by a gram of water. This major difference in the properties of sand and water has major implications for what happens when light from the Sun shines on sand and water at the beach! The difference in their specific heats is the primary cause of why the sand gets hot and the water stays cool during a sunny day at the beach.

(*f*) *Considering the effect of the property of reflectivity.* In our course, students sometimes obtain different results for the property of reflectivity; some report the water reflects more than the sand and some less. It seems to depend upon the angle at which they hold the light probe. To what extent is this a problem for interpreting results?

The percent of incident light reflected is called a material's *albedo*. Water's albedo depends upon many aspects, including whether the sun is shining straight down (low albedo) or at an angle (high albedo) as shown in Fig. 3.20. The water absorbs more of the Sun's energy when the Sun is high in the sky than when the Sun is rising or setting.

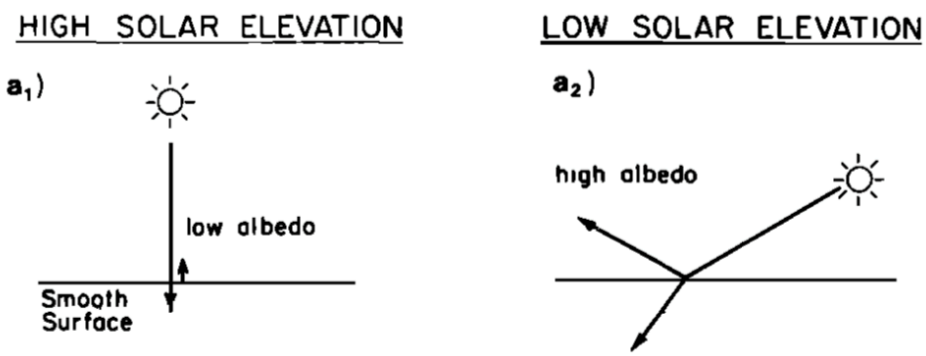


FIG. 3.20 Dependence of solar reflection upon angle of incidence. *https://atmos.washington.edu/~mcmurdie/articles/katsaros_etal_1985.pdf, p. 7314. Kristina B. Katsaros, Lynn A. McMurdie, Richard J. Lind, and John E. DeVault, "Albedo of a water surface, spectral variation, effects of atmospheric transmittance, sun angle and wind speed," Journal of Geophysical Research,* **90***(C4), 7313-7321 (July 20, 1985).*

Water's albedo also depends upon its state, whether it is liquid in the ocean, bare ice, or ice with snow. Fresh snow reflects the most, about 90%, whereas liquid water in the oceans reflects very little, about 6% as shown in Fig. 3.21. Desert sand reflects about 40% (http://www.climatedata.info/forcing/albedo/).

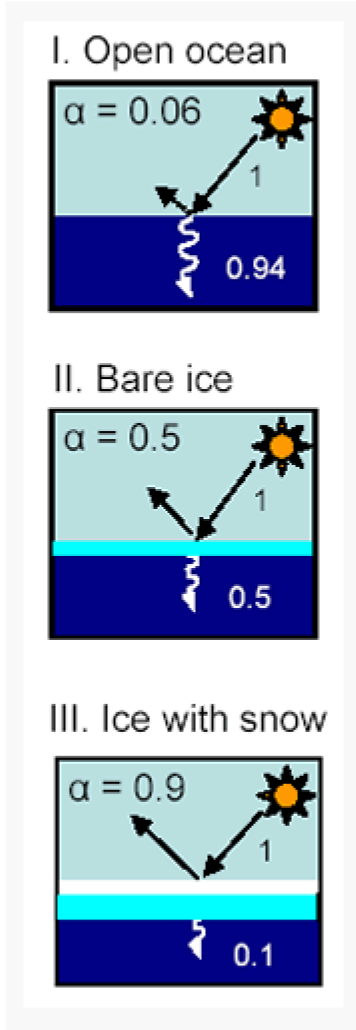


Fig. 3.21 Albedo of water in liquid and solid states. Image courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder. https://nsidc.org/cryosphere/seaice/processes/albedo.html

Is there ever a time when the water warms up more than the sand because of these differences in reflectivity? If one calorie of energy from light from the Sun falls on one gram of water and all of that energy is absorbed by the water, its temperature will go up at most 1°C because its specific heat is 1.0 cal/(g°C).

What happens when one calorie of energy from light from the Sun falls on one gram of sand? If the sand absorbs all of the energy, we saw above that its temperature goes up 5ºC because its specific heat is only 0.2 cal/(gºC).

If the sand reflects 40% of the incoming energy, however, how much does one gram of sand's temperature go up if it receives 60% of the incoming energy? If one gram of sand only needs 0.2 calories to increase in temperature by one degree Celsius and it absorbs 0.2 cal + 0.2 cal + 0.2 cal = 0.6 cal, its temperature will go up 3°C.

Even in this worst case, with the water absorbing the most it can and the sand reflecting the most it can and absorbing the least it can, the sand will increase in temperature much more than the water. This confirms that the differences in reflectivity are not very important; what matters more is the difference in specific heats.

(g) Considering the relative importance of various properties. Thinking about what properties and processes might matter during an exploration is an important part of doing science. Figuring out which matter more than others is useful so that one can focus on the causes of major effects before investing a lot of time and effort in exploring less important effects.

V. Using Central Ideas to Explain Intriguing Phenomena Involving Local Weather at the Beach

Students in our area of the country can go to the beach on sunny days. The sand is warm; brrr, the water is cold! How can that be? Later in the day, however, the sky often clouds over and a breeze comes up from over the water. Why would that happen?

A. Considering the influence of the properties of materials on thermal effects

Question 3.8 Why is the sand warm and the water cool at the beach if the Sun has been shining on both in the same way for the same time?

- Use central ideas about the properties of sand and water, such as their thermal conductivities, specific heats, and reflectivities, to explain why the sand is hot and the water cool at the beach even though the Sun has been shining on them in the same way for the same time.

1. Example of student work explaining about hot sand and cool water at the beach

At a sunny day at the beach, the top of the sand is warm. The radiation from the Sun heats up the surface of the sand, but sand has a low thermal conductivity, so this energy stays at the surface of the sand. When you dig your feet into the sand it is cool below because the energy from the Sun was not transferred below the surface of the sand.

Water has a higher thermal conductivity, meaning the energy from the Sun is quickly transferred throughout the water, a big area. This means the heat will be *even throughout the water, taking a lot more energy than is supplied to finally heat up the entire ocean. The water also feels cool because water has a bigger specific heat than sand. Despite the water receiving the same amount of energy for the same amount of time as the sand, the water needs more energy to change one gram of the water one degree Celsius. It takes 1 calorie of energy from the Sun to change one gram of the water one degree Celsius, while sand only needs 0.2 calories of energy from the Sun to change the same amount. This means it will take longer for the water to increase in temperature because water needs more energy to do so.*

Another factor contributing to water temperature is the angle of the Sun. If the Sun is shining on the water from an angle, some of the light is reflected. When the light is reflected the energy is not being absorbed, so the temperature is not increasing as much. When the Sun is high in the sky above the water, the energy will be absorbed because the light is not being reflected.

Physics student, Spring 2016

B. Considering the influence of light and thermal effects on weather at the beach

A wonderful sunny day at the beach can turn cloudy and somewhat chilly with a breeze coming off the water late in the afternoon. What causes this shift in the weather?

Question 3.9 Why do clouds and sea breezes often form in the afternoon after a sunny day at the beach?

- Draw a diagram that illustrates why sand is warm, water cool, clouds often form in the sky, and breezes blow in from the sea in the afternoon after a sunny day at the beach.
- Explain these aspects of local weather at the beach in terms of transfer of energy processes such as radiation from the Sun, reflection, absorption, conduction, evaporation, condensation, and convection.
- To explain a complex sequence of physical processes, start with radiation from the Sun and discuss each step with your group members. What is the influence of differences in thermal conductivity and specific heat between sand and water? What roles do conduction, evaporation, condensation, and convection play in setting up a circulation of air above the sand and water?
- Monitoring what one is doing can be helpful when developing complicated explanations. Every so often, step back and consider: What are we doing? Why are we doing this? How is doing this helping us?

Complete your explanations before looking at an example of student work. Next consider nuances about the influence of light and thermal phenomena on local weather at the beach. Then enjoy reading about how three young children learned to interpret a sea breeze diagram like the one below.

1. Example of student work explaining about cloudy skies and sea breezes forming in the afternoon after a sunny day at the beach

This student created a clear diagram of the convection cycle underlying sea breezes:

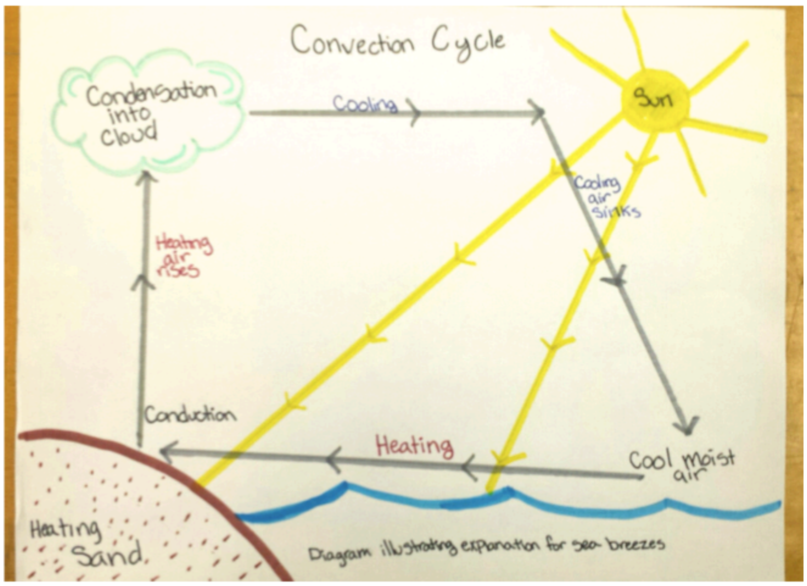


FIG. 3.22. Student's diagram explaining why clouds and sea breezes often appear in the afternoon after a sunny day at the beach.

The diagram is labeled *Convection Cycle* and as a *diagram illustrating explanation for sea breezes*. The student drew and labeled a *Sun* whose rays shine on both the land and sea, *heating* the *sand* and water. The warm sand warms the air above by *conduction*, and the *heating air rises*, represented by the gray upward arrow. Some water evaporates forming *cool moist air* above the water, which blows toward the shore forming a sea breeze, represented by the gray arrow toward land. A cloud forms in which *Condensation into cloud* occurs as moisture in the warm moist air condenses in the cooler upper atmosphere.

The *cooling air sinks*, represented by the gray arrows to become *cool moist air* over the water, which then blows toward shore, represented by the gray arrow toward the land.

The student interpreted the diagram as follows:

> *As we have learned in the past few weeks, light leaves a source such as the Sun and travels in all directions, (including) to the sand and to the water. Sand is a poor conductor of heat so when the Sun warms the sand, the heat is not distributed evenly, making the surface hot. Also the specific heat of sand is lower than that of water so when both are exposed to the same amount of light, the sand at the surface will have a higher change in temperature.*
>
> *Water is a good conductor of heat so the heat from the sunlight is evenly distributed throughout the water. Also water has a higher specific heat than sand so it will not warm as much when exposed to the same light.*
>
> *Over the water, some of the light energy is used to change the state of some water, evaporating it into a gas state. This makes the air over the water cooler moist air.*
>
> *The air above the sand continues to heat, because the sand heats at a higher rate than the water. As the air (above the sand) warms, it rises. The cool moist air above the water begins to move toward the sand, (forming the sea breeze).*
>
> *The hot sand heats the cool moist air in a process called conduction, causing the air to rise, (cool), and the gaseous water to form a cloud through condensation. As the air cools, it sinks back toward the water. As the warm and cool air moves, it is called "convection."*

Physics Student Fall 2015

2. Nuances about explaining changes in the weather during a sunny day at the beach

There are many sea breeze diagrams available on the Internet. Some are quite detailed, such as http://www.yachtingmonthly.com/sailing-skills/understand-sea-breeze-49027). This is intended for people interested in sailing in coastal waters. Some diagrams show land breezes that occur at night as well as sea breezes that occur during the day, such as http://climate.ncsu.edu/edu/Breezes . This website refers to differences in air pressure that are related to changes in the density of air. As the land warms by energy radiated from the Sun, the air immediately above it also warms by *conduction*; as the warm air expands, it become less dense than the cool air above it and the warm air rises. This forms a low pressure region over the land. The cool moist air over the water is more dense. This forms a high-pressure region over the water. The cool moist air then flows toward the land, which forms the sea breeze. As this moist air warms over the warm land by conduction, it also expands and rises. This sets up a *convection* current of warm moist air rising and cool air flowing from the ocean over the land up into the upper atmosphere and back down to the water. The upper atmosphere is cool and as the rising warm moist air cools, the moisture *condenses* into tiny droplets of water, forming clouds. This complex cycle is an example of the interactions of several of Earth's systems, the geosphere (rock, soil, and sediments including sand), hydrosphere (water in the ocean and atmosphere), and atmosphere (air over both land and sea).

3. Example of learning and teaching about sea breezes with friends and/or family members

Question 3.10 What happens when teaching friends or family members about the physical phenomena underlying changes in the weather at the beach?

The student who drew the diagram in Fig. 3.22 chose to discuss sea breezes with three children for whom she baby sat: Lucie-7, Ava-4 and Ruby-4:

> *I did this project with some of the children I babysit, Lucie, Ava, and Ruby. I asked the girls if they had ever heard about sea breezes and what they think when they hear that phrase.*
>
> *Lucie, said: "um is that like breezes from off of the sea?" Ava and Ruby asked: "is that like when you can see the wind moving leaves and stuff?" I then showed the girls a diagram of sea breezes and asked them their initial thoughts.*
>
> *Mind you the girls are 4 and 7 so the answers I got are interesting.*
>
> *Me: Which do you think is warmer when you go to the beach, the water or the sand?*
>
> *R: "The sand!"*
>
> *A: "The water….. I mean the sand!"*
>
> *L: " the sand, cause sometimes the sand is super hot and burn-y and you have to dig down to where it isn't as hot."*
>
> *Me: Okay so do you think the air above the water is warmer or colder than the air above the sand?*

L: "The air above the sand is probably warmer, cause it is being warmed up by the sand."

Me: Okay good. Does warm air sink or rise do you know?

A:" Um, I think warm air rises."

Me: Why?

A: " Well cause in our room during the summer it was always way hotter on my top bunk than it was on Ruby's bottom bunk. And it was way hotter at the top of the house than in the downstairs and dad said its cause hot air likes to go up."

Me: That's really good thinking Ava. So do you think that the warm air at the beach warms and rises too?

A: "Well yeah probably."

Me: Okay so say there is wind that comes and blows the air above the sea over to the sand, what would happen?

L: "well the air would get warmer, cause it would be with the warm sand. Then it would rise up like the hot air in the house does."

Me: Ruby can you show me on the diagram where you think this is happening?

Ruby pointed to where the arrow points up on the diagram and goes towards the cloud.

R: Right here is where it is happening. It goes up and into a cloud.

Me: Good job Ruby. Okay so when the hot air goes up something called condensation happens, which is like when you have a cold water bottle and the water drops collect on the outside of the bottle. This is because the water inside the bottle is colder than the water in the air outside the bottle. This is also how clouds form. The different air temperatures mix and the water drops form into a cloud because a cloud is actually a mist and a lot of water drops. Now on the diagram what looks like it happens to the cloud?

L: The cloud goes back out to the ocean.

Me: Okay and as the air goes back to the ocean it gets colder, what happens to colder air?

R: Colder air goes down!

Me: Good job Ruby, Ava can you point to where the colder air is going down?

Ava pointed to the arrow of cold air descending back to the top of the water.

Me: Okay now what do you think will happen to the air when it gets back above the water?

L: I think it will keep going in this circle like the diagram says. Cause it will get pushed by sea breezes; then it will get all hot again over the sand. And that will make *it rise up into the air and be a cloud. Then it will get pushed back out to sea and sink again when it gets cold. And start again and again.*

One thing that I think Lucie in particular learned about was patterns, which described by the article are: "Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them." Lucie was able to say that she thought that the air would continue in a cycle and would follow the sea breeze cycle in a pattern that the cold air would always sink and the hot air would always rise.

I also think that the girls participated in engaging in argument from evidence. When Ava explained to me why she thought that the hot air would rise she used evidence she had from her own life to explain what she thought would be true. She was engaged in forming an argument, and backing it up with what she already knew.

Also the girls worked on asking question and on finding a good way to answer the questions that I proposed to them, to think about what the other girls had said, and to make a guess or to answer with that in mind.

I also learned that I am not completely comfortable explaining this phenomena, mostly because I am not sure that I fully understand how this cycle is taking place yet so I was not sure how to phrase questions. I also didn't do the best job of having the girls try and figure out the diagram on their own. This is something for me to work on in the future when I work with other students.

Physics student, Fall 2015

VI. Using Mathematical Representations to Estimate a Quantity of Interest

In our area, going to the beach involves being aware of and prepared for the possibility of a tsunami occurring. A tsunami is a large wall of water that may flood a beach and surrounding areas because of an earthquake. Geologists have used mathematics and knowledge of physical phenomena to build complex computer models for predicting earthquakes and tsunamis.

A. Exploring computer models designed to predict earthquakes and tsunamis

A major 9.0 earthquake may occur, for example, off the coast of northern California, Oregon, Washington and British Columbia. This region is called the Cascadia Subduction Zone (see http://www.oregon.gov/oem/hazardsprep/Pages/Cascadia-Subduction-Zone.aspx). This fault line is about 600 miles long and lies under the Pacific Ocean about 70 to 100 miles beyond the shoreline. If there is a major earthquake along this fault line, a tsunami wave that comes ashore is predicted to be up to 100 feet high.

Question 3.11 How do geologists predict earthquakes and tsunamis?

The Earth's surface is broken up into *tectonic plates*, (*https://www.geolsoc.org.uk/Plate-Tectonics/Chap2-What-is-a-Plate*). A *subduction* zone is a region in which one plate moves underneath another. The cause of multiple earthquakes in the Pacific Northwest region is attributed to movement of the Juan de Fuca oceanic plate under the North American plate as shown in Fig. 3.23.

FIG. 3.23 Model of Juan de Fuca Plate subsiding under the North American Plate. CC0
http://www.oregon.gov/oem/hazardsprep/Pages/Cascadia-Subduction-Zone.aspx

When one tectonic plate presses against another, pressure builds up until motion occurs; the earthquake releases energy that travels outward through the Earth as *seismic waves* (http://www.geo.mtu.edu/UPSeis/waves.html). The primary waves, known as p-waves, are compression waves that travel quickly through the Earth as shown in Fig. 3.24. P-waves move the earth back and forth in the direction of motion. Secondary waves, known as s-waves, are like water waves, they move the earth up and down, or side to side, as shown in Fig. 3.24. https://en.wikibooks.org/wiki/Historical_Geology/Seismic_waves

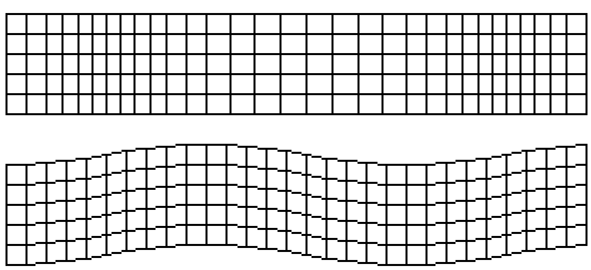


FIG 3.24. *Top: p-waves; Bottom: s-waves.* Actualist [CC BY-SA 3.0]
https://en.wikibooks.org/wiki/Historical_Geology/Seismic_waves

- For each pair of students to model what happens during an earthquake: Use a Slinky® .
- To model p- waves, each pair holds the end of a Slinky® with the Slinky® stretched out along the floor. One gives the Slinky® a hard push toward the other.
- Next model s-waves. One person gives the Slinky® a quick jerk side to side. If the pair are standing up, jerk the Slinky® up and down.

If such an earthquake happens off the Pacific Northwest coast, a series of large ocean waves, up to 100 feet high, may quickly flood coastal areas in 15 to 20 minutes (see: http://www.oregongeology.org/tsuclearinghouse/). These huge waves are called tsunamis. Tsunamis might also originate in distant earthquakes occurring under the ocean elsewhere, with perhaps several hours warning. Signs in tsunami zones alert residents and visitors with a visual display of the danger as shown in Fig. 3.25.

FIG. 3.25 Tsunami danger alert sign. http://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf

Residents of these areas and visitors to the beaches and coastal towns need to be aware of where high ground is and how to get there. For links to evacuation maps for many Oregon locations see, for example: http://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm . Details are available at http://www.oregongeology.org/pubs/fs/TIM-maps-factsheet.pdf. Before leaving home, visitors should locate where they will be and review evacuation routes and what to do in case of a tsunami (see http://nvs.nanoos.org/TsunamiEvac and Fig. 3.26 and Fig. 3.27.)

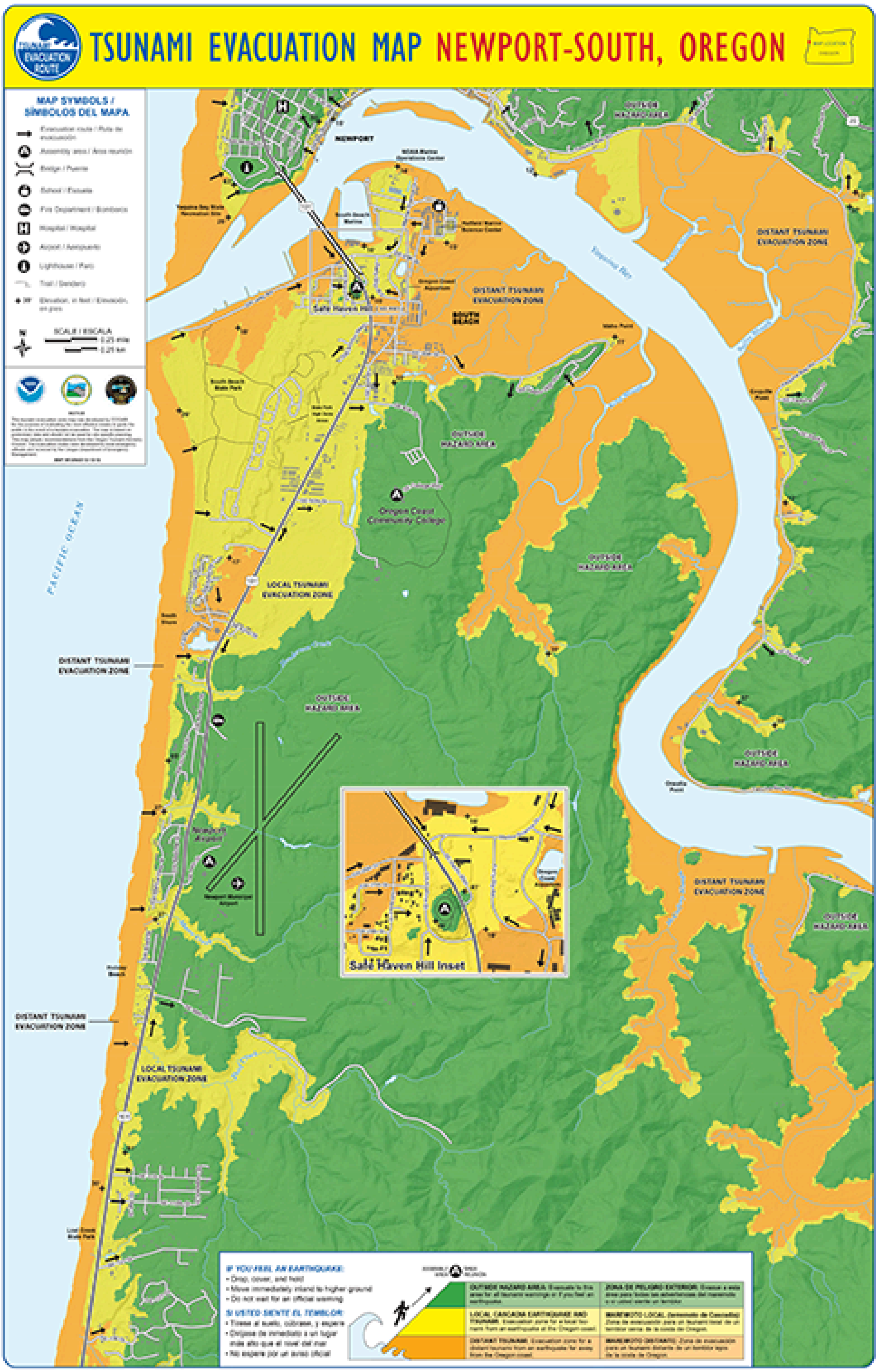


FIG. 3.26 Tsunami evacuation map for South Newport, OR: [*https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf*](https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf)

The instructions at the top of the map state:

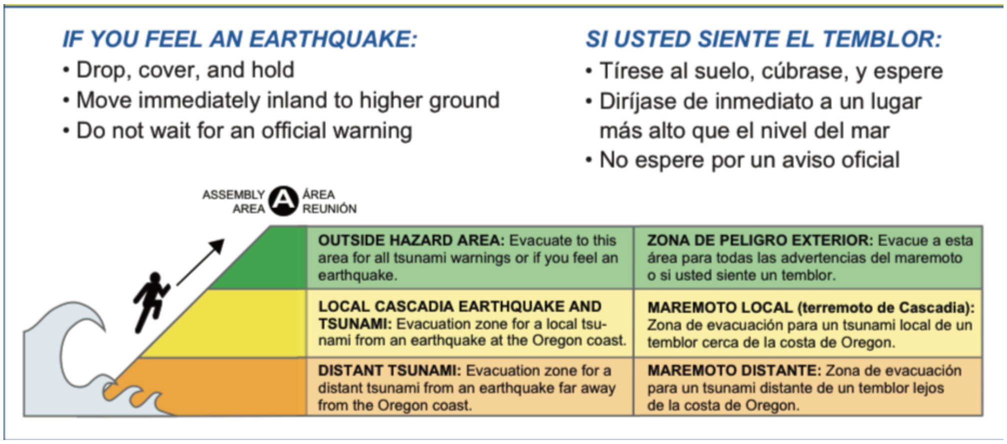


FIG. 3.27 *Instructions if you feel an earthquake.* *https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf*

The predicted safe areas are green, the areas likely to be inundated by a local tsunami are yellow, and those likely to be inundated not only by a local tsunami but also by a distant tsunami from an earthquake far away from the Oregon coast are orange. An A on the green area of the map indicates a designated assembly area in the event of an evacuation.

Steps to be prepared include making a disaster plan, preparing supplies in case of a disaster, protecting yourself during an earthquake, evacuating if necessary, and following your plan (see: http://www.oregongeology.org/tsuclearinghouse/steps-visitors.htm#prepare). Although an enticing very low shore may occur just before and after a large wave, it is important to head immediately away from the beach as more very large waves may follow.

Preparation includes assembling a 'Go-Bag' to keep in your car in case of a disaster (see, for example, the suggested list for a 3-day emergency kit at the end of https://www.oregongeology.org/pubs/tsubrochures/SeasideGearhartEvacBrochure-6-3-13_onscreen.pdf or https://www.redcross.org/get-help/how-to-prepare-for-emergencies/survival-kit-supplies.html . Suggested items include water (1 gallon per person per day), 3-day supply of non-perishable food, first aid kit, non-prescription drugs, tools and supplies, sanitation items, entertainment (games, books), clothing and bedding, special requirements, and copies of important family documents.

1. Examples of student reflections upon discussing earthquake and tsunami preparedness with a friend or family member

A guest, Douglas Lownsbery, facilitated a class session in which he provided information and set up four centers about earthquakes and tsunamis: a set of items for students to choose within 10 seconds which they would put in a "go bag," a large plastic container with sand, water, and toy people and houses with which to model a tsunami occurring, a long slinky® to model p- and s-waves, and a core sample that he had prepared with 5th graders at a local beach, that included evidence of a previous tsunami in our area. After the session, the students wrote about their experiences discussing earthquake and tsunami preparation with a friend or family member. A student provided the reference for an article and a reflection on a conversation with a roommate. The article was a follow-up to an earlier article about the expected major earthquake in the Pacific Northwest, *The Really Big One* by Kathryn Schulz in *The New Yorker*, July 13, 2015 issue (https://www.newyorker.com/magazine/2015/07/20/the-really-big-one).

> *The New Yorker Magazine, How to Stay Safe When the Big One Comes https://www.newyorker.com/tech/annals-of-technology/how-to-stay-safe-when-the-big-one-comes*
>
> *My "learner" this week was one of my roommates. I had her read over the article that I had chosen from the New Yorker and we had quite a big discussion about it. We talked about how we and no one we know bolt things down in our homes for safety. We also do not have a kit to be prepared for a tsunami or an earthquake.*
>
> *After talking about the article, I started talking about how we should all have "go bags." Many of us do not think that this would affect us, but it could happen at any time we are near the coast and it is best to be prepared to help yourself and to help others. We were wondering what exactly we SHOULD put in our go bag because that was not extremely clear when we were learning about it in class. The city of Seaside Oregon has a "go bag" section on their website. They recommend that you pack:*

- *First Aid kit,*
- *prescriptions and non-prescription medication*
- *Water bottle and treatment supplies capable of providing 1 gallon per person per day*
- *Non-perishable food*
- *Cooking and eating utensils, can opener, cook stove.*

- *Waterproof matches, lighter or flint*
- *Shelter (tent, tarp or poncho)*
- *Emergency blanket*
- *Portable NOAA weather radio*
- *Flashlight or headlamp, and extra batteries*
- *Warm clothing*
- *Personal hygiene items (toilet paper, soap, toothbrush)*
- *Tools and supplies (pocket knife, shut-off wrench, duct tape, gloves, whistle, plastic bags)*
- *Cash*

This did not include things like rope or an emergency blanket, but a "go bag" can be different for everybody. The important part is that we always have one in our car.

We talked a lot about cause and effect. When an earthquake hits-what do we do? What happens next? When can you tell a tsunami is about to hit? Where should you go when it is hitting? What happens to houses and people that are not in the safe zone? What does a town look like after a tsunami hits? How far away from the coast can a tsunami travel?

The cause: the earthquake/tsunami

The effect: how it effects people and towns

In doing this we used the science and engineering practice of asking questions and defining problems. This was an easy one to cover because we do not know much about tsunamis and earthquakes because this area does not seem to be worried about them even though we should be.

Another student talked with a family member who lives in a tsunami evacuation zone

I decided to engage my mom in learning about earthquakes and tsunamis. I chose to talk to her about this topic because she lives on the coast and will directly be impacted by the earthquake and tsunami that are due to occur anytime soon. I have noticed that many people are aware of the fact that Oregon is expecting a natural disaster in the near future but no one has done anything to prepare for this.

I first began by asking my mom what she knew about earthquakes and what she has done so far to prepare for an earthquake and tsunami. She knew a lot of facts about earthquakes along with understanding the scientific reasoning for why tsunamis happen but unfortunately she has not done anything to prepare.

I took this time to pull up the elevation map that was shown in class to show the *best places to run to during a tsunami. While looking at this map we both realized that our house is in a zone that is expected to be under water in the event of a tsunami.*

"I am not even sure what I would put in a go bag if I needed to make one." stated my mother. I took this opportunity to talk to her about the activity we did in class where we had 10 seconds to pack 10 items in a bag. I told her about some of the items I put in the bag and why I put these things in. She asked what types of food would be best to start stocking up on.

I told my mom the story about the little girl named Tilly that saved not only her family but also other people while on vacation in Thailand. Since my mom is a fourth grade teacher I told her the importance of talking about this topic with her students. She understood and agreed with me and said she wants to start talking about earthquakes and tsunamis more in her classroom.

…We also talked about evacuation routes, plans, and communication. My mom made the decision to continue this investigation by researching different ways to educate her students on the importance of being prepared during this type of event. The crosscutting concept that we used during this discussion was cause and effect. We talked about earthquakes and tsunamis and the impact it would have on our family physically, mentally, and emotionally.

An emphasis on how to prepare helps to mitigate the fear that one may experience in realizing what might happen should a major earthquake occur.

B. Exploring computer models designed to predict the weather

Computers also can make weather predictions based on complex mathematical models. Many of these are developed by government agencies and are available for public use on the Internet.

Question 3.12 How do meteorologists predict the weather?

Meteorologists use mathematics to build complex computer models that they use to predict the weather. See an example provided by the National Oceanic and Atmospheric Administration's Weather Prediction Center at http://www.wpc.ncep.noaa.gov/ Also put in http://www.weather.gov and enter a zip code for a local prediction.

VII. Making Connections to Educational Policies

Many US states have adopted the *Next Generation Science Standards* (NGSS, Lead States, 2013). In addition to science and engineering practices and crosscutting concepts, this document recommends disciplinary core ideas that student should learn at various grade levels.

A. Learning about the US *Next Generation Science Standards: Disciplinary Core Ideas*

Question 3.13 What NGSS science and engineering practices, crosscutting concepts and disciplinary core ideas have you used in developing an explanation for the occurrence of hot sand, cool water, clouds, and sea breezes late in the afternoon after a sunny day at the beach?

The *Next Generation Science Standards* describes *disciplinary core ideas* in terms of *learning progressions* (NGSS, Lead States, 2013, Appendix E) (See: https://www.nextgenscience.org/resources/ngss-appendices.) These indicate what students should learn about a topic in Kindergarten-2nd grade, 3rd-5th grade, 6th-8th grade and 9th-12th grade.

Disciplinary core ideas in physical science, for example, include:

PS3.B *Conservation of energy and energy transfer*:

- During Kindergarten-2nd grade, students should learn that s*unlight warms Earth's surface.*
- During 3rd-5th grade, students should learn that e*nergy can be converted from one form to another form.*
- During 6th-8th grade, students should learn that t*he relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.*

    - During 9th-12th grade, students should learn that t*he total energy within a system is conserved.*
- How are these disciplinary core ideas relevant to the development of an explanation for sea breezes?
- Provide an example of how the explanation of sea breezes incorporates one or more of the eight NGSS science and engineering practices: asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information.
- Provide an example of how the explanation of sea breezes incorporates one or more of the seven NGSS crosscutting concepts: patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter: flows, cycles, and conservation; structure and function; and stability and change.

The disciplinary core ideas, science and engineering practices, and crosscutting concepts are called *dimensions* of science learning and teaching. It is important to consider all three dimensions when designing learning experiences in science contexts.

B. Reflecting upon this development of a complex explanation

Explaining sea breezes is complicated. As the conversation with Ava above illustrates, however, even four-year-old children know that "hot air rises" and can support that claim with evidence "in our room during the summer it was always way hotter on my top bunk than it was on Ruby's bottom bunk. And it was way hotter at the top of the house than in the downstairs…" This four-year-old already has understood the essence of the nature of science, being able to make an argument based on evidence. Young children are capable of scientific reasoning in contexts with which they are familiar and have had relevant experiences upon which to draw in making sense of what they are learning.

What happens when energy radiated from the Sun shines on sand and water at a beach in the same way for the same time? A more complex version of Ava's scientific reasoning occurs in making an argument about what happens when different materials absorb incoming energy. One way to explore this question is to create a model of the situation in the laboratory. What happens when energy radiated from a lamp shines on equal masses of sand and water in the same way for the same time?

The graphs in Fig. 3.17 and 3.19, for example, demonstrate a major difference in that the temperature versus time line for the sand was clearly steeper than the line for the water. This replicates the effects seen at the beach, that equal input of energy results in very difference changes in temperature for sand and water. Using specific heat information from outside sources indicated that the *specific heat* of sand was about 0.2 calories of energy to change the temperature of one gram by one degree C whereas the specific heat of water was by 1.0 calories of energy to change the temperature of one gram by one degree C.. This difference in the property of specific heat, *in* how much energy is needed to change the temperature of one gram of a material by one degree Celsius, is the key to explaining why sand at the beach is hot and the water cool even though the sun has been shining on both in the same way for the same time.

Differences in other properties, such as *thermal conductivity* and *reflectivity*, also contribute to causing this effect. The temperature near the bottom of the cup of sand was lower than the temperature near the surface, whereas the temperature of the cup of water was the same throughout. This indicates that the sand had a low thermal conductivity. This means that the incoming energy absorbed by the sand stayed near the surface, warming the surface sand whereas the incoming energy absorbed by the water on the surface flowed throughout the cup of water. Using reflectivity data from outside sources also demonstrated that reflectivity effects were minor compared to the big difference in effect due to the property of specific heat.

Tracing the flow of energy in a system also is useful in understanding what is happening. As shown in Fig. 3.14, convection occurs when a circular current forms as warm fluid rises and cold fluid sinks. Similarly, as energy flows from the warm sand to the dry air above it by conduction, the less dense warm air rises; as energy flows from the warm air into the cooler upper atmosphere, the cooling air becomes more dense, and sinks back down toward the surface, setting up a convection current. Meanwhile some of the liquid water absorbs enough energy from the sun to evaporate into the cool air above the water's surface. As the warm air rises above the hot sand, the cool moist air above the surface of the water blows toward shore, forming a sea breeze. When the moist air warms, rises, and cools in the upper atmosphere, the moisture condenses back into liquid water droplets and forms clouds.

Developing this complex explanation of local weather that students have experienced at the beach seems to be motivating. Several have identified this session as a highlight of the course. The pleasure students seem to experience in this accomplishment may help them to appreciate the hard work of figuring something out as well as understanding the emotional satisfaction that scientists derive from their studies.

One goal of this course has been to build confidence in using the tools of science, particularly graphs and diagrams. Creating a graph of data and telling the 'story' that the graph displays can be a powerful skill to have, both professionally and personally. Also powerful is the ability to create and use diagrams that visually explain whatever needs explaining. In addition, the process of articulating what was done, found, and understood in this complex context can help students gain confidence as science writers, able to set forth their own ideas and reasoning in clear and coherent ways.

C. Making connections to NGSS understandings about the nature of science

This unit provides a good example of the NGSS science and engineering practice of *constructing explanations*as well as the crosscutting concept of *cause and effect* in focusing upon the difference in the property of specific heat for sand and water. The very low specific heat of sand compared to that of water causes large differences in increases in temperature when light from the Sun shines on sand and water in the same way for the same time. This is an example of aspects that students in grades 3-5 should learn to do, to *identify the evidence that supports particular points in an explanation.* They also should understand that *the transfer of energy can be tracked as energy flows through a designed or natural system* while they are learning disciplinary core ideas about the *conservation of energy* and energy transfer.

Unit 3 also has provided additional examples of the nature of science such as that *science knowledge assumes an order and consistency in natural systems* (NGSS Appendix H https://www.nextgenscience.org/resources/ngss-appendices . This unit assumes, for example, that what happens with small amounts of sand and water warmed by a lamp in the laboratory is consistent with what happens with large amounts of sand and water at a beach. Also assumed is that similar mechanisms cause the apparent paradox that the sand is very hot but the water is cool even though the Sun is shining on both in the same way. The students explored possible causes for these different effects by considering the role of differences in three properties of sand and water: their reflectivities, thermal conductivities, and specific heats. They observed differences in how much the temperatures changes on the surface when energy flowed from a lamp placed equal distances from cups of sand and water.

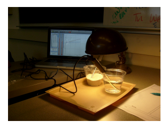
The process of explaining why the sand is hot but the water cool as well as why sea breezes and cloudy skies often appear in the afternoon after a sunny day at the beach was a culmination of the earlier explorations of the nature of light and thermal phenomena. Students may gain from this exploration some understandings about how scientific knowledge grows and connects in multiple ways across many contexts. The process of engaging friends and family members in learning about sea breezes at the beach also may help convey some of these understandings about the nature of science to others.

VIII. Physical Phenomena: Summary of Equipment and Supplies for Unit 3

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3			
When used	For instructor and demonstrations	For each group of 3	For each student
Unit 3 **Week 5** Day 9 **Question 3.1 Connecting to initial knowledge about water and weather**		1 cup of water	
Question 3.2 Exploring changes in states of matter	Rice cooker or pot and hot plate Tray of ice cubes 2 digital thermometers to connect to laptop computer (or two regular thermometers with range below 0°C and above 100°C)		U3H2 Diagnostic Question about Changes in States of Matter

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3			
Question 3.3 Exploring the water cycle	Evaporation: Tray, food coloring, water to make puddle, lamp, Transpiration: Plant, plastic bag to fit over it, Condensation: metal container, blue ice cubes, Precipitation: Large jar, cup that fits inside opening, ice for cup, about ½ jar of very hot water, Convection: Plastic bin (shoe box size) Red food coloring, Blue ice cubes, 4 paper cups to support bin, 1 ceramic or Styrofoam cup for very hot almost boiling water, **Room temperature** water to fill bin 2/3 full  Container for waste water if no sink in room	If feasible, provide equipment for convection demonstration for each small group U3H1 Exit Ticket	U3H3 Table.III.1 U3H4 Table.III.2 U3H5 Water cycle diagram

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3			
Unit 3 **Week 5** Day 10 **Question 3.7 Explaining hot sand, cool water, clouds, and sea breezes in the afternoon after a sunny day at the beach** **Question 3.13 Reflecting upon the NGSS Crosscutting Concepts Experienced in Unit2 and 3**		2 digital temperature probes connected to laptop (or regular thermometers) 2 clear plastic cups Sand (about 1/3 cup) **Room temperature** water (about ½ cup) Lamp with bendable stem 1 tray  U3H1 Exit Ticket	U3H6 Table.III.3 & graph U3H7 Sea breeze diagram) U3H8 NGSS Crosscutting concepts U3H9 Anonymous questionnaire U3H10 NGSS practices review Units 1-3 U3H11 NGSS crosscutting concepts review, Units 1-3

UNIT 4: CONSIDERING THE INFLUENCE OF LIGHT AND THERMAL PHENOMENA ON GLOBAL CLIMATE

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

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