IS2 Integrated Grade Six Instructional Segment 2: Earth System Interactions Cause Weather

An integrated approach to weather phenomena investigates the causes of weather in terms of a PS understanding of energy transfer, the mechanisms of weather in terms of ESS systems, and the effects of weather on living systems. When drawing DCIs from all the disciplines, students apply their understanding of systems [CCC-4] from IS1. Students will consider cause and effect mechanisms [CCC-2] at a broad range of scales [CCC-3] from the level of particles of matter up through the entire Earth system.

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Guiding Questions

- Why is the weather so different in different parts of California?
- How is weather related to the transfer of energy?
- How do models help us understand the different kinds of weather in California?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.*]

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*]

MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments

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could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*]

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [*Assessment Boundary: Assessment does not include calculations of energy.*]

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

**The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or Disciplinary Core Idea.*

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

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Highlighted California Environmental Principles and Concepts:

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: MP.2, 6.RP.1, 6.SP.5

CA CCSS for ELA/Literacy Connections: SL.6.5, RST.6–8.1, 3, 7, 9 WHST.6–8.1, 7, 8

CA ELD Connections: ELD.PI.6.6a–b, 9, 10, 11a

Different parts of California experience dramatically different weather. As an anchoring phenomenon for this instructional segment, students will consider how some parts of California are dry with desert vegetation while others are greener and wetter. When students examine a true color satellite image of California (figure 5.4), they notice the effects of weather patterns: green coastal ranges, brown deserts, fluffy white clouds, and snowcapped peaks of the Sierra. Students ask questions [SEP-1] about specific patterns [CCC-1] that they notice and what might cause [CCC-2] them. Understanding the processes that drive day-to-day weather can help explain these longer-term weather patterns. The vignette below describes a learning sequence that focuses on explaining the phenomenon of California's climate zones drawing in DCIs from Earth and space sciences and physical science. Students will look at this same phenomenon through a lens that also integrates life science during IS3 and IS4.

Figure 5.4. Satellite View of California

Source: NASA 2014

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Performance Expectations

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MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.*]

MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of

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ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*]

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion and quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles and Conservation

CA CCSS Math Connections: 6.NS.7b, 6.NS.8, 6.EE.9, 6.SP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 4; WHST. 6–8.1, 7; SL.6.1, 2, 3

CA ELD Connections: ELD.PI.6–8.1, 9, 10b

Introduction

Weather phenomena naturally integrate all disciplines of science and engineering. Processes usually classified as "physical science" govern the movement and changes of matter, those classified as "Earth science" describe these processes at the macroscopic scale, and "life science" processes describe how organisms respond to these weather conditions. Engineers design solutions to minimize weather hazards and for building devices that gather detailed weather data (especially satellite imagery) that helps inform other scientists.

Days 1–2: What is Smoke/Fog/Steam?

Students make observations and ask questions about a mystery material.

Days 3–4: A Watched Pot Never Boils

Students collect data about how temperature changes as ice is heated until it melts and boils. They relate these observations to energy changes in different states of matter.

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Days 5–9: Questions about California's Climate Zones

Groups of students research individual climate zones in California and report back to the class. Students ask questions about what they learn.

Days 10–11: Planning an Investigation

Students plan and conduct an investigation to compare the effects of heat on water versus air.

Day 12: Crafting an Explanation

Students create, critique, and revise a scientific explanation that explains their observations from the previous day's investigation.

Days 13–14: Analyzing Rainfall Data

Students make graphs showing the relationship between elevation and precipitation in California and relate these findings to changes of state from previous days.

Day 15: Explaining California Climate

Students synthesize their understanding from the previous three weeks to re-examine California's climate zones and explain the patterns they see.

Days 1–2: What is that Smoke/Fog/Steam?

Anchoring phenomenon: Students confront a mystery material that they describe as smoke/fog/steam.

In small group and whole-class discussions, students reviewed the reservoirs of the water cycle that they learned about in grade five. They described the physical state of water (solid, liquid, gas) in each of the reservoirs. However, even when they included the atmosphere as a reservoir of the water cycle, students tended to emphasize liquid water in clouds rather than the invisible water vapor gas in air.

Ms. L then got their attention by bringing out an insulated container with dry ice in it. She poured 91 percent isopropyl alcohol into the container to create an extremely cold bath that bubbled. Something visible formed and flowed around the insulated container. Students described it as smoke, fog, or steam. Ms. L challenged the students to make careful, detailed observations; to discuss these observations in small groups; and to make an **evidence-based [SEP-7]** claim about the nature of the smoke/fog/steam (SFS). She pointed out that while they were discussing, she put some small pieces of dry ice into a latex-free surgical glove, and tied off the end of the glove. That way the gloves captured some of the mystery SFS material so students could investigate its properties.

The students reached a general consensus that the SFS was visible, that it felt sort of cool and moist, and that it seemed to be flowing downwards around the container. They **argued with evidence [SEP-7]** that the SFS cannot be water vapor because it is visible. However, there was much more confusion than consensus about what the SFS could be.

When Ms. L lifted the hugely expanded glove, students laughed about its shape, and wanted

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to know more about the properties of SFS. Just before Ms. L cut one of the glove fingers to release the material, she asked students to predict what they expected to see. Ms. L never let her students make a prediction without explaining what influenced their expectation. She prompted students to describe what similar situation, background knowledge, and/or observations they based this prediction upon. Ms. L cut the glove and released the trapped material in a controlled manner. While they could see the glove deflating, students were surprised that nothing appeared to come out. After Ms. L extinguished a lit candle by "pouring" some of the invisible gas over it, they reached the conclusion that this material must be a gas denser than regular air. What was the relationship between the invisible gas and SFS? Had it somehow changed when inside the glove?

Students returned to their small groups to make a list of the most important observations and tried again to make **claims supported by evidence [SEP-7]** about the nature of the SFS. All the student groups realized that its visibility means that SFS could not be water vapor or carbon dioxide. Gradually, discussions within the groups and then between them resulted in the conclusion that SFS must be water drops that condense from water vapor in the air. One team shared a **model drawing [SEP-2]** that they made that illustrated a progression of three stages:

1. cold carbon dioxide gas flowing over the edge of the container and then sinking downward;
2. water vapor in the air cooling as the cold CO_2 gas contacted it;
3. the cooled water vapor condensing into small drops (fog).

Investigative phenomenon: Water in a test tube freezes when placed into the dry ice/isopropyl alcohol bath.

Ms. L concluded the lesson by putting a test tube of water with an inserted temperature probe into the dry ice/isopropyl alcohol bath. She showed how quickly the water froze. She called on students to read the temperature on the probe, and they noted that it was in minus degrees Celsius, meaning that it was colder than the freezing point of water. She took the test tube out and carefully suspended it in warm water. Students recorded the increase in temperature as the super-cooled ice warms towards zero degrees C.

Days 3–4: A Watched Pot Never Boils

Investigative phenomenon: When ice is heated until it melts and boils, the temperature does not increase steadily the entire time.

The following day the students reviewed their observations of the super-cooled ice. Students then worked in teams to slowly and steadily heat a mixture of ice and water. They recorded the temperature every minute and also wrote a description about how much the ice

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was melting each time. The handout that she provided included a data table for recording temperature, elapsed time, and whether melting was happening. For safety reasons, the students stopped their experiments when the temperature of their water reached 45°C.

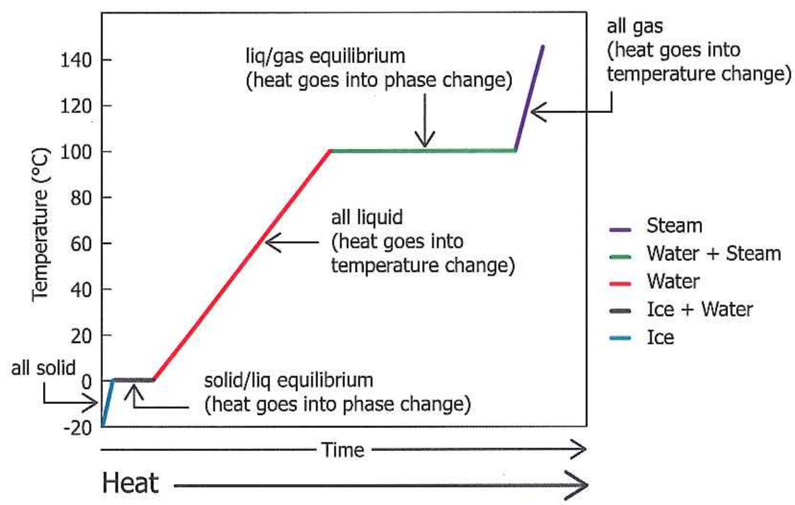
Using graph paper, each student team created a labeled graph and entered their data on the graph. The students generally obtained graphs that showed a mostly flat temperature line near 0°C during the time of melting, and then a steady rise in temperature after all the ice melted.

Ms. L then asked the teams to predict on their graph what it would look like the next day when she would demonstrate heating the water until it boiled and while it kept boiling. They also needed to note on their prediction when the boiling would happen just as they had noted when the ice was melting.

The following day the teams shared their predictions and their reasoning. Then Ms. L demonstrated the heating of water to the boiling stage and for a period of continued boiling. Students recorded the observed temperatures on their graphs and compared the observations with their predictions. At the end of the demonstration, students discussed the results as a whole class.

The next day, Ms. L projected a graph of changes in the state of water that was posted on the Web by a chemistry teacher. Students discussed this graph in small groups, and wrote explanations for what they thought was happening in the parts of the graph labeled A, B, C, D and E (figure 5.5).

Figure 5.5. Temperature Changes When Constantly Heating Ice



Continuously adding thermal energy increases the temperature from supercooled ice to superheated steam. Heating does not cause the temperature to significantly increase during the state changes of melting (B) and boiling (D). Heating when there is no state change happening results in temperature increasing (A, C, and E).

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The students consistently identified temperature as a measure of the average kinetic energy of invisible particles of water. They correctly related higher temperatures with increased particle motion, and lower temperatures with decreased particle motion. Using data from their own experiments and the teacher's demonstration, students readily **explained [SEP-6]** that the upward lines occur when there is no state change happening. They also readily observed that the flat lines at B and D occur when there was a state change happening. However, they had a hard time clearly explaining why the temperature did not increase during melting and boiling even though more thermal energy was being added.

Ms. L then displayed a graphic showing the state changes as equations (figure 5.6). She walked students through the example of melting, pointing to each component as she described it: "If you start with water as a solid (ice) and add energy, you get liquid water." Then, she asked students to identify which of the equations applied to the day's observations. Once they identified the right equation, she told students to use that equation to **explain [SEP-6]** why the temperature remained fairly constant during evaporation even though thermal energy continued to be added. After five minutes, one of the student group started clapping and cheering. Other students asked them what happened.

Figure 5.6. Equations Representing State Changes in Water

Evaporation: Water (liquid) + Energy ➔➔➔ Water (gas)

Condensation: Water (gas) ➔➔➔ Water (liquid) + Energy

Melting: Water (solid) + Energy ➔➔➔ Water (liquid)

Freezing: Water (liquid) ➔➔➔ Water (solid) + Energy

Evaporation and melting involve absorption of thermal energy. In contrast, condensation and freezing involve the release of thermal energy. Illustration by Dr. Art Sussman, courtesy of WestEd.

One student stood up and said that they thought they had finally explained it, but didn't know if they could repeat the explanation. After encouragement, they said, "The hot plate kept giving off thermal energy. Usually that makes the water particles move faster, so then the temperature went up. But once the water boiled, the hot plate energy made the boiling thing happen instead of making the particles move faster. So then the temperature did not change. I think I just said that the right way, didn't I?"

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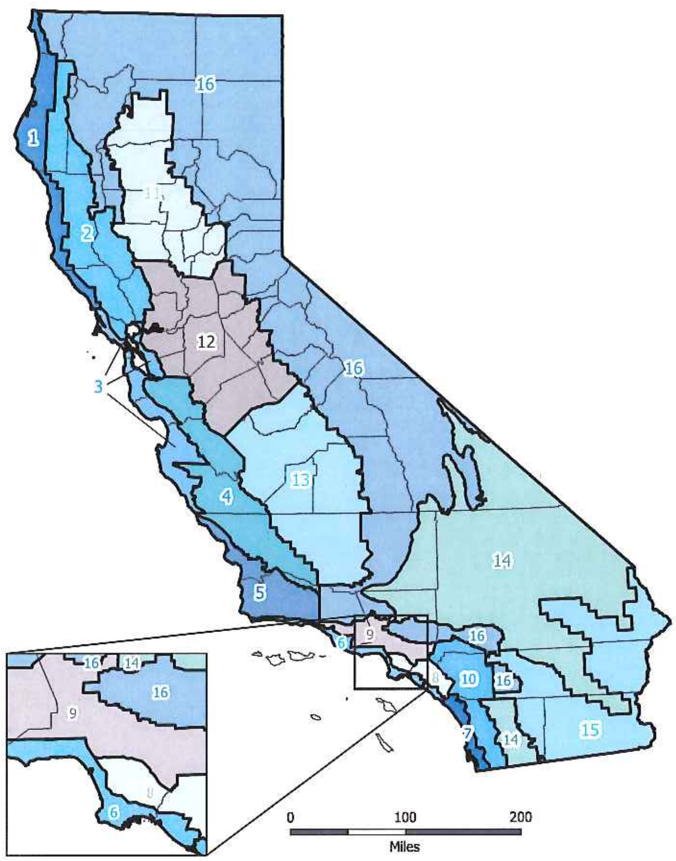
Days 5–9: Questions about California's Climate Zones

Investigative phenomenon: California has different climate zones

Ms. L began the next set of lessons by asking students how many different kinds of places they knew about in California. The conversation led to a beginning list with names of some cities, and also some descriptions based on types of natural environments (beach, mountain, desert, redwood forest). She then distributed a map showing 16 different California climate zones (figure 5.7). Students worked in eight groups to identify the previously listed locations on the map and any new locations that the map made them think about. They also discussed what they thought a "climate zone" meant.

Figure 5.7. California Map Showing 16 Different Climate Zones



California can be described as having 16 different climate zones. *Source:* California Energy Commission 2015

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After the students had time to engage with the task and do a preliminary sharing with the whole class, Ms. L provided a handout describing eight representative zones that she condensed from the *Pacific Energy Center's Guide to California Climate Zones*. She used a combined student-choice/teacher-assignment technique to allocate the eight zones among the groups. Each team researched one climate zone and developed posters **communicating [SEP-8]** key features about their climate zone including topography, geographic location, distinctive climate features, and representative graphs of annual temperatures and precipitation.

Students shared and learned about the different climate zones through a gallery walk of the posters, listening to presentations by the groups, and **asking questions [SEP-1]**. Most of the student questions were about factual matters at first, so Ms. L encouraged students to ask about the relationship between different features (i.e., "Your picture shows a flat desert. Is the desert dry because it's flat?") or to compare one geographic region to another (i.e., "Why is your region so much hotter than my region during June when they have such similar temperatures in December?"). Facilitated whole-class discussions helped summarize the differences between weather and climate, the different climate zones in California, and possible **causes [CCC-2]** for the differences in annual temperatures and precipitation. Students highlighted key **patterns [CCC-1]** (e.g., **effects [CCC-2]** of latitude, altitude, closeness to the ocean, and closeness to mountains). Student teams also recorded any **cause and effect [CCC-2]** or "why" questions they had about the data.

Toward the end of the week, each team shared their "why" **questions [SEP-1]**. The questions tended to cluster into four groups:

- Why it is so much colder in Northern California than in Southern California even though they are both in the same state?
- Why do places near the ocean have temperatures that change less between day and night?
- Why do higher altitudes have so much rain?
- Why are deserts located where they are?

Ms. L concluded this discussion by saying that they would conduct some investigations during the next week to help answer the last three questions, and that they would cover the first question in their next instructional segment about climate around the world.

Days 10–11: Planning an Investigation

Investigative phenomenon: Air heats up faster than water.

At the start of the third week, Ms. L provided students a procedure to **investigate [SEP-3]** differences between heating air and heating water. They used an electric light to heat two identical bottles closed with rubber stoppers. One of the bottles was filled with water and the other bottle is filled with air. Their task was to record and graph the temperatures for 10 minutes while the light was on and then another 15 minutes after turning off the light. Ms. L

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found that her students took poor-quality measurements when they did not understand the procedures. While one approach was to ask students to plan the entire investigation themselves, she found that they were not quite ready at this point in the school year to design sophisticated investigations. Ms. L developed a technique to scaffold the planning of investigations. Her handout of procedures had two columns—one with the procedures and a second one with the label "reason for this step" that also had blanks for students to record data. Ms. L demonstrated how to fill in the table by demonstrating what she would write as the justification of step 1. For step two, she wrote two possible justifications and asked the students to select the explanation that they think was most clear. For step three, she wrote an incomplete reason and asked students to evaluate why the explanation was insufficient. Ms. L then had students work in groups to record the reasons for the remaining steps. Ms. L called their attention to the data sheet and labeled graph that she had included in the written procedures. She told them that in future experiments, student teams would design their own data sheets and graph labels. Before students recorded any actual data, she had them draw a sketch of what they thought the graph would look like after the experiment. As she circulated around the room, she prompted students to add labels to their sketches to indicate what might cause key changes in their graph.

Both bottles started at a temperature of 20°C. With the light on, the temperature in the air bottle increased on average to 55°C while the temperature in the water bottle only increases on average to 23°C. After the lights were turned off, the air bottle temperature generally decreased about 30°C, while the water bottle decreased on average only 1.5°C. Ms. L had the students compare their prediction to the actual observations and discuss whether anything was unexpected.

After **conducting the investigation [SEP-3]**, each student team created and displayed a poster showing their results. In the poster, each team made a claim about the differences between heating air and heating water, and they wrote or illustrated the **evidence [SEP-7]** for their claim. After a gallery walk and whole-class discussion, the class reached a consensus claim that the same amount of added thermal energy **caused [CCC-2]** the temperature of air to increase much more than the temperature of water, and that the water released its thermal energy much more slowly than the air did.

One student group agreed with the statement about the increase in temperature. However they **argued that the evidence [SEP-7]** for a difference in cooling was very weak. It is not fair, they point out, to compare cooling from 55°C with cooling from 23°C. Ms. L took this unplanned opportunity of the excellent student critique to ask if there was a way to make a better comparison of the cooling rates of air and water. Several student groups proposed pre-heating bottles of air and water to the same temperature, and then comparing their rates of cooling. A team of students volunteered to demonstrate the experiment the following day. Their subsequent demonstration confirmed that the same volume of water cooled at a much slower rate than the same volume of air. Since thermal energy depends on the amount of the material (its mass) rather than the volume of material, the student comparison was not the

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most scientifically accurate. MS-PS4-3 requires that students be able to design an experiment that holds mass constant, but Ms. L was happy to see that her students recognized the need for consistency when they used equal volumes of material.

Investigative phenomenon: A small amount of water heats up faster than a larger amount of water in a beaker.

She pointed out to students that the bottle with water feels much heavier and wondered if that has something to do with it. This prompted another demonstration comparing two different masses of water. Students completed this exercise realizing that both the amount (mass) of the material and the type of material affect how quickly its temperature changes.

Day 12: Crafting an Explanation

Everyday phenomenon: Coastal towns have mild climates while inland valleys have temperature extremes.

Ms. L challenged her students to use the key ideas from their investigation to **explain [SEP-6]** the **pattern [CCC-1]** that California locations near the ocean have less variation in day/night temperature than locations farther away from the ocean. Each team then **communicated [SEP-8]** its explanation and reasoning to a different team. The process of creating, critiquing, and revising these explanations took an entire class period.

Days 13–14: Analyzing Rainfall Data

Everyday phenomenon: It rains and snows a lot in the mountains.

Having discussed the temperature differences among California regions, students transitioned to their questions about the precipitation differences. Students knew it snows in the mountains, so Ms. L decided to have them investigate the amount of rainfall in east-west transects across California. Students obtained rainfall amounts from an online database by clicking stations on a map (see California Data Exchange Center at http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link3). For each station, the database reported the latitude, longitude, monthly rainfall, and the elevation of the station (along with other weather data). Students made a graph of rainfall versus longitude and a graph of elevation versus longitude (figure 5.8). Because they wanted to compare the shapes of the two curves, Ms. L taught students how to plot the two lines on the same graph using different vertical axes.

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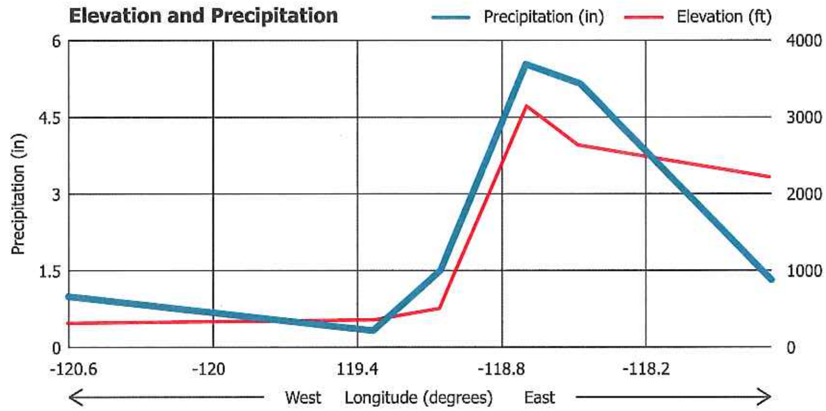
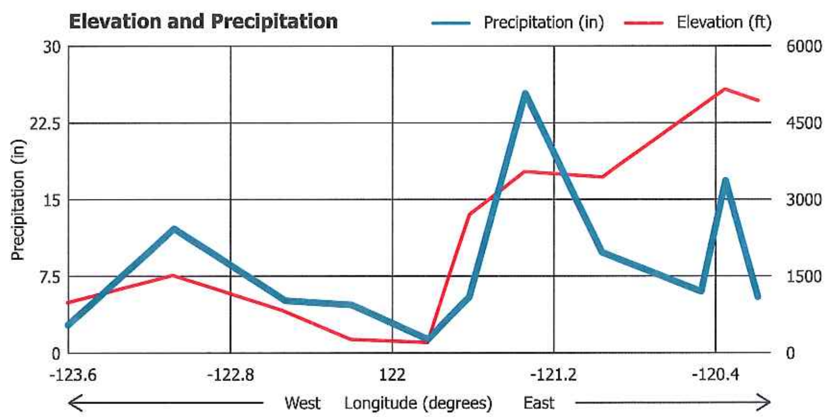
Figure 5.8. Profile of Annual Rainfall Across California Heading East From San Luis Obispo



The thinner red line shows the elevation at each point. Chart by M. d'Alessio with data from California Department of Water Resources 2015

Different students plotted different locations in California and they all discovered a remarkable **pattern [CCC-1]** where the rainfall seemed to go up as elevation went up (figure 5.9).

Figure 5.9. Profile of Annual Rainfall Across California Passing through Chico



The thinner red line shows the elevation at each point. Chart by M. d'Alessio with data from California Department of Water Resources 2015

When Ms. L asked students to explain what caused this relationship, students came up with some crazy theories. Students did know that it tends to be colder in the mountains, so Ms. L asked them to relate this idea back to the condensation they learned about earlier in the lesson sequence. What happened to water when it got colder? Ms. L asked students to

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write an explanation in their science notebooks that responded to the prompt, "It rains more at higher elevations because______." In the middle grades, their model was relatively simplistic and did not include the effects of relative humidity, but they were able to tie together many of the essential concepts.

Some students noticed that the eastern part of the graphs tended to be high elevation, but the rainfall was lower there. They **asked questions [SEP-1]** about what could cause this pattern. Ms. L showed them animations of satellite maps of atmospheric moisture and precipitation for several storms moving across California. The storms tended to move from west to east, with the precipitation stopping as the storm moved to Eastern California. Ms. L introduced the idea that the matter had moved. Students needed to develop a conceptual model to describe the movement of water in space and time through all these different forms.

Based on the California climate data that they had learned, each of the student teams drew a systems **model [SEP-2]** of the water cycle for a location in their assigned climate zone during two different seasons of the year. As a class, they began by reviewing the features of a systems diagram (boundary, components, inputs/outputs, interactions, and system property).

After the student teams completed their initial models, Ms. L initiated an activity that helped them create more accurate and complex water cycle diagrams. She knew from experience and research that while students often can list where water is located, they tend to have limited or simplified ideas about the dynamic nature of the interconnections among these reservoirs. For example, even though they may have seen clouds disappear because of evaporation of their water back into the atmosphere, they tend to think that water in clouds can only precipitate (Ben-zvi-Assarf and Orion 2005). Students also tend to forget about all the possible pathways water can take to leave a reservoir. For example, they tend to model water in a river as only flowing into the ocean, whereas in reality the river water can evaporate, soak into the ground, or be taken into the body of a plant or animal.

To help students consider these complexities, Ms. L led students through a simple kinesthetic game. Each student played the role of a water particle (or H_2O molecule if students are comfortable with that terminology) and moved around the room through different stations that represented different places where water is located (ocean, soil, plant, atmosphere, cloud, mountain glacier, polar ice cap, etc.). At each station, the student rolled dice and read from an instruction sheet whether to stay at that station for another turn or move to a different station as part of a water cycle process. In essence, the students used their own bodies as components in a physical **model [SEP-2]** of all the processes of the water cycle.

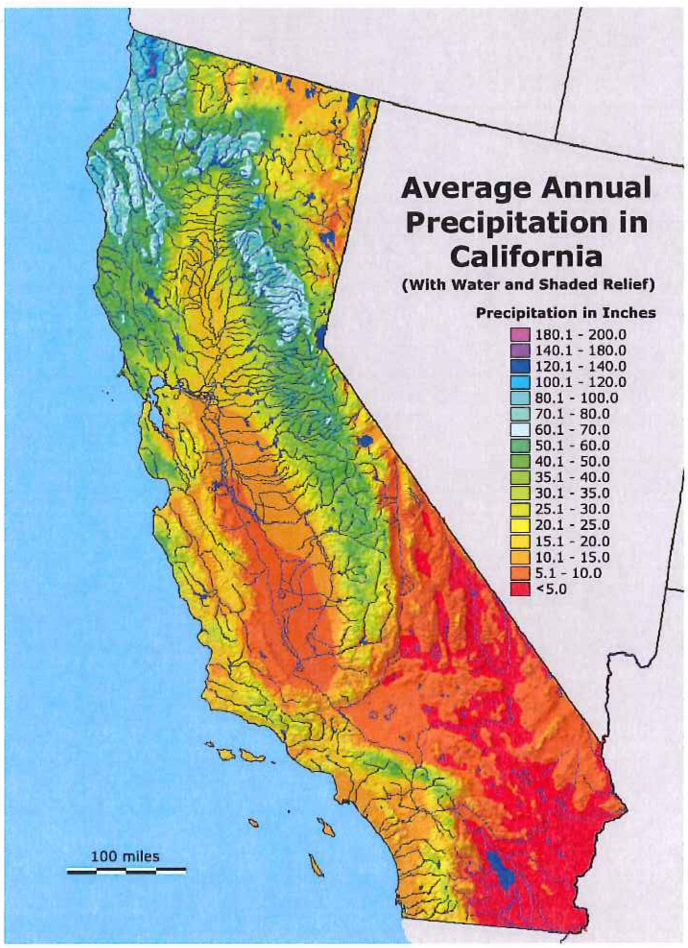
After the exercise, students commented about it and summarized what they learned. Key points included

- the number of inputs and outputs for the different reservoirs;
- the different residence times in the reservoirs;
- the changes in state associated with the water cycle interconnections;
- the cyclical, rather than linear, nature of the water cycle; and
- the role of gravity in **causing [CCC-2]** precipitation, downhill flow of surface water, infiltration of surface water into the ground, and downhill flow of glacial ice.

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

After this kinesthetic lesson, student teams returned to their regional water cycle diagrams and incorporated more of these interconnections, inputs and outputs. Students then shared their regional water cycle diagrams, critiqued and extended each other's presentations, and achieved a more complete group understanding of water reservoirs and processes. As a whole class activity, they created a color-coded map representing the average annual precipitation that included all of their California regions. To create this representation, they needed to collaborate on deciding the range of values to use, and how to represent the entire spectrum of data. They compared their whole-class model with a representation that Ms. L had downloaded from the Internet (figure 5.10), which they then used to complete and revise their state map.

Figure 5.10. Map of Average Annual Precipitation in California



Color-coded map of average annual precipitation in different California regions with mountains indicated by shaded relief. *Source:* Geology Cafe 2012

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

Day 15: Explaining California Climate

The lesson sequence concluded with presentations that the class made for different audiences about California climates. In each presentation, students highlighted the patterns [CCC-1] of temperature and precipitation in each of the eight California regions that they had investigated. They also explained [SEP-6] the different factors that were involved in causing [CCC-2] significant climate patterns such as the comparatively small variation in coastal day/night temperatures, high levels of mountain precipitation, and the rain shadows of coastal mountains and the Sierra Nevada on the Central Valley and on Eastern California respectively.

Vignette Debrief

In this multi-week vignette, students applied physical science concepts to explain an Earth and space science observation about climate and a life science observation about habitats. Ms. L struggled with how long to spend on each section but quickly realized that spending even three weeks on this learning sequence felt rushed. She allowed students to plan their own experiment, grapple with revising their models of changes of state, and construct well thought out scientific explanations with evidence and reasoning; all these activities took much longer than she thought. But her assessment of student work showed that students gained a much better understanding using this student-centered approach than when she sped through things, as in previous years.

This vignette illustrates the CA NGSS vision of blending SEPs, DCIs, and CCCs. Ms. L began each part of the lesson sequence with an engaging phenomenon and spent each lesson applying the three dimensions. While the lesson describes this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties to the CA CCSS and the EP&Cs.

SEPs. As the students became more engaged with the content and comfortable with the underlying physical science concepts, they began to have larger roles in designing and conducting the investigations [SEP-3].

DCIs. Days 1–2 focused on different states of matter (PS1.A) and the definition of thermal energy (PS3.A). Students built on this definition on days 3–4. On days 5–9 the focus was on general observations of weather and climate in California (ESS2.D). On days 10–12, they explored the relationship between thermal energy, states of matter, and a particle model of matter (MS-PS1-4). On days 13–15, students engaged in integrating the physical science and Earth and space science ideas, using the PS mechanisms to explain ESS phenomena.

CCCs. In the process, students developed system models [CCC-4] of their regional climates and engaged with key factors that cause [CCC-2] climate patterns, such as increased precipitation at high elevations. The observed weather and climate effects in California of latitude, altitude, proximity to the ocean, and locations of mountains all set the stage for deeper explorations in IS2 and IS3 of the patterns [CCC-1] that determine regional climates (MS-ESS2-6).

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

EP&Cs. As written, Ms. L did not explicitly address any of the EP&Cs, though students will build on their understanding of California climate later in the course when they consider human impacts to the Earth system. Her focus on explaining the California climate is important because it provides a familiar context and on day 9 students were able to ask informed questions based on their own experiences.

CA CCSS Connections to English Language Arts and Mathematics. On day 4 and days 13–14, students focused on developing and interpreting graphs (6.SP.4). Students obtained and evaluated information about California's climate zones on days 5–9. Students engaged in structured discourse with teams throughout the vignette, including evaluating and reviewing the ideas of their peers on days 5–9 and again on day 15 (SL.6.1). They practiced writing an informational text with the explanation on day 12 (WHST. 6–8.1, 7).

Resources:

Ben-zvi-Assarf, Orit, and Nir Orion. 2005. "A Study of Junior High Students' Perceptions of the Water Cycle." *Journal of Geoscience Education* 53 (4): 366–373.

California Energy Commission. 2015. California Building Climate Zone Areas. http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link4

Geology Cafe. 2012. Precipitation and Relief Map of California. http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link5

The Water Cycle in the Earth System

In IS1, students looked at Earth's systems and began to consider the water cycle that involves all of them. When students consider all the places that they see water in its many forms, water is often moving (raindrops fall, a river flowing, steam rising, etc.). In IS2, students investigate the physical mechanisms that drive this process. MS-ESS2-4 highlights the special role of sunlight in driving the state changes that occur as water moves in multiple pathways between the reservoirs of the water cycle. The first learning sequence in the IS2 vignette focused on these state transitions and the associated movements of thermal energy, almost all of which entered the Earth system in the form of sunlight.

The force of gravity also **causes [CCC-2]** movement of water between reservoirs of the water cycle. Most students can explain the role of gravity in causing precipitation ("raindrops fall") or surface water ("rivers flow downhill"), but they often overlook the crucial role that gravity plays in the infiltration of surface water into the groundwater, the flow of groundwater itself through tiny pores (similar to the way a saturated sponge drips water down out of the bottom), and the flow of ice downhill in glaciers (illustrated by time-lapse videos of glacier movements).

Opportunities for ELA/ELD Connections

To reinforce these cause and effect relationships [CCC-2] involving gravity and sunlight, engage students in understanding the water cycle processes by investigating the levels of the tides in one coastal city. After identifying and documenting patterns [CCC-1] in the tides and the position of the Sun and Moon, students use a cause and effect chart to illustrate the role that gravity plays in causing water to move between reservoirs in the water cycle such as the ocean and a nearby estuary. Students then create a commercial to pitch to local fishermen on the best time to fish according to the tidal patterns of that coastal city. Provide feedback on the student-created commercials to make sure they include appropriate vocabulary and accurately demonstrate actions that convey the roles of gravity and sunlight on tidal patterns.

CA CCSS for ELA/Literacy Standards: WHST.6–8.4; SL.6–8.1, 4, 5
CA ELD Standards: ELD.PI.6–8.9

Because of the water cycle, Californians are able to obtain a steady supply of fresh water for drinking, irrigation, industrial, and agricultural uses (EP&C III). Even in years with abundant precipitation, California still draws water from a total of seven nearby states to add to its own supply (Klausmeyer and Fitzgerald 2012). In this way, California itself can be considered a system [CCC-4] with inputs and outputs. Of the developed water supply for the state, more than 75 percent of it goes to agriculture and helps California grow more food than any other state.

Integrated Grade Six Snapshot 5.1: What's in the Water?

Anchoring phenomenon: Tiny microscopic organisms live in pond water.

Mrs. N's class took occasional walking field trips to a creek near the school to study the local ecosystem. Recently, students collected water samples and brought them back to the classroom. Mrs. N asked students if they would want to drink the water in the creek, and they all said no because it is too "dirty." But what does it mean for water to be dirty? Students took turns looking at drops of water under the classroom microscopes. They noticed all sorts of tiny plants, moving animals, and bits of dirt even in water samples that appeared clear to the naked eye. Mrs. N gave the students the opportunity to compare water from a local pond with tap water. They compared the pond water to filtered pond water and then tap water. Students observed

Integrated Grade Six Snapshot 5.1: What's in the Water?

that the filtered pond water had fewer particles than the unfiltered pond water, and that the tap water had almost no particles in it. Mrs. N challenged students to come up with a system to quantify [CCC-3] the amount of contamination in a water sample. Each group constructed a bar graph showing the relative amount of contaminants and then compared their measurements to the other groups. Were the differences related to the measurement technique or to the water samples themselves? Student groups decided to switch water droplet microscope slides with another team to test out their ideas.

Everyday phenomenon: Our drinking water is not pure H_2O.

Water is one of California's most important natural resources (ESS3.A). Students then obtained information [SEP-8] from their water utility about the different contaminants in their local drinking water (water agencies are required to publish an annual report and most of these are available online. They evaluated how their water compares to another city (such as Flint, Michigan which experienced unacceptable levels of lead contamination in 2015). They learned the distinction between organic contaminants (like bacteria) and inorganic ones (like lead and arsenic). To link to PS1.A (Structure and Properties of Matter), students drew a diagram in which they modeled [SEP-2] the liquid water and heavy metals as particles too small to be seen that move and interact. They used this model to address the question, Why does the solution appear clear and clean when it is actually contaminated? Inorganic contaminants such as heavy metals often take many years to cause observable health effects, so Mrs. N decided to focus on infectious diseases with their short-term health impacts.

Everyday phenomenon: Outbreaks of disease were common in California during the Gold Rush Era.

While students could see the differences in both the real-life water and the measurements, they did not yet appreciate why these numbers mattered. Mrs. N set the stage about the prevalence of water-borne diseases by having students read an article about life in Gold Rush-era California, including the regular deaths from diseases like cholera and typhoid. An outbreak in 1850 may have killed 15 percent of Sacramento residents (Roth 1997).

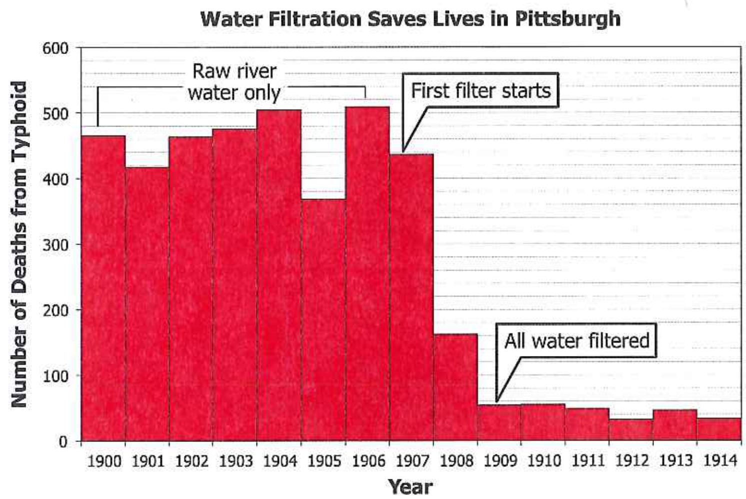
Investigative phenomenon: When Pittsburgh installed a citywide water filtration system, the number of people dying from disease dropped within a year or two.

Sacramento was not an unusual situation. Infectious diseases were a major problem in U.S. cities until midway through twentieth century. Mrs. N was born in Pittsburgh

Integrated Grade Six Snapshot 5.1: What's in the Water?

where the rate of death from diseases in 1900 was the highest of any major U.S. city. Students read an article about how city health officials and engineers changed that by installing a water-filtration system in their public water system that cut the death rate from typhoid by almost a factor of ten within two years (figure 5.11). Mrs. N emphasizes ETS2.B ("Influence of Engineering, Technology, and Science on Society and the Natural World").

Figure 5.11. Effect of Water Filtration on Typhoid Deaths in Pittsburgh



Source: Adapted from Pittsburgh City Photographer 1917.

Mrs. N wanted to make sure that students were able to see the connection between the water-filtration technology, the diseases, and the hands-on experience with the organisms in the pond water. Working in groups, she had students draw a simple **pictorial model [SEP-2]** that illustrated the relationships. Each student then individually wrote a caption with an **explanation [SEP-6]** about how water filters remove organisms that **cause [CCC-2]** disease. Mrs. N told students that in the following week they would design and test their own water filters.

Before moving on, Mrs. N led a discussion of one more aspect of the Pittsburgh story. One factor that made the city so vulnerable to disease was that the local drinking water source, the Alleghany River, was also a dumping ground for raw sewage for many upstream communities. Mrs. N told students that people releasing materials like sewage into a river is called water pollution. She asked students if they are aware of any water pollution at the school or in the local community. Students identified several examples of pollution on campus and in the streets by the school, including oil dripped from cars that then flowed down the gutters on the street and into the storm drains. One of the students mentioned that she had seen drains along the street that are labeled, "No dumping, leads to ocean." Mrs. N asked, "Why is this important?" Several students mentioned that on a

Integrated Grade Six Snapshot 5.1: What's in the Water?

recent field trip to the coast they learned that oil coming from the storm drain system had been observed along the coast and it had damaged parts of the coastline and some of the wildlife that lives there (EP&Cs II and IV). Mrs. N asked students to reflect on who is affected more by human pollution: natural systems or humans themselves (the discussion sets the stage for the grade eight performance expectation MS-ESS3-4).

Mrs. N asked students if they think that we still dump our sewage into rivers and water. They then learned more about modern wastewater treatment (see "Our Water: Sources and Uses" at http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link6) in preparation for a trip to a local wastewater treatment plant.

Physical Science Models of the Water Cycle

Students experience the water cycle as everyday weather, and the process of weather forecasting is one way that scientists use measurements to model and predict interactions in the water cycle. Students can explore weather forecasts and weather maps and notice the different variables being tracked, especially temperature. Weather is ultimately driven by uneven heating of the planet. How do these temperature differences cause air movements that drive weather changes? In grade five, students learned that objects that they could see or touch have kinetic energy when they move and that matter is made of particles too small to be seen. In grade six, students combine these ideas to show how temperature is just kinetic energy at the invisible scale of particles. The snapshot below presents a phenomenon that allows students to begin to relate motion at the macroscopic scale to motion at the microscopic scale and temperature.

Integrated Grade Six Snapshot 5.2: Motions and Thermal Energy

Anchoring phenomenon: Our hands warm up when we rub them together.

Mr. A began IS2 by eliciting what students knew about the forms and transformations of energy based on daily experiences or what they remembered from classroom investigations in grades four and five. He steered student small group discussions toward phenomena in their daily lives such as the warming effect of rubbing hands together or doing vigorous exercise. Building on those kinds of experiences, students **conducted investigations [SEP-3]** that connected motions of objects with changes in thermal energy. Mr. A emphasized these **energy [CCC-5]** transformations because these experiences from our macroscopic level of reality are necessary to help students connect the motion energy of invisible particles with the observed temperature of materials.

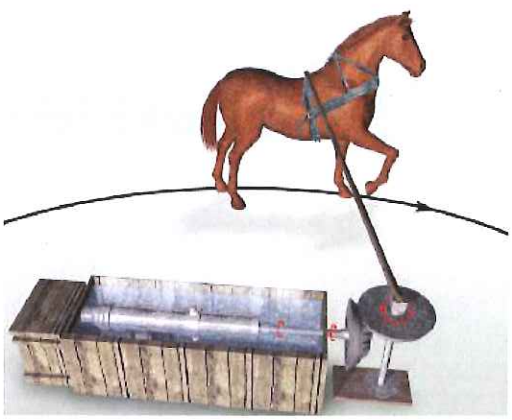
Investigative phenomenon: Count Rumford showed a horse was able boil water by running around in circles to turn a metal cylinder.

For homework, students read an illustrated one-page handout about a scientific paper published by Count Rumford in 1798. Count Rumford was born with the name Benjamin Thompson in Massachusetts. During the War of Independence, Thompson fought for the British against the American revolutionaries, and had to flee from his home to save his life.

In Europe after the war, Thompson became famous as a scientist and inventor and he was honored with the title and name of Count Rumford. In one famous public experiment, Count Rumford used the process of making a cannon to investigate the change of motion energy to thermal energy. He set up an experiment in which a horse trotting in a circle caused a metal borer to dig a hole into an iron cylinder that was completely covered with water (figure 5.12). All the people watching were amazed when the friction of the borer grinding into the cannon **caused [CCC-2]** the water to boil.

Integrated Grade Six Snapshot 5.2: Motions and Thermal Energy

Figure 5.12. Count Rumford's Energy Conversion Experiment



The kinetic energy of a horse moving in a circle heated water surrounding a cylinder of iron so much that the water boiled without any fire. *Source:* Sussman 2006

The day after the homework reading, the students in small groups discussed the **flows of energy [CCC-5]** that were involved in the making of the cannon. They diagrammed the **cause and effect [CCC-2]** relationships that were happening at the macroscopic level (horse, metal boring machine, water) and also at the invisible level of the water particles. After extensive small-group and teacher-facilitated whole-class sharing of diagrams and discussions, they reached the following consensus statements:

- The motions that the people saw caused the heating and boiling that they could feel and see.
- At the macroscopic level (our level), kinetic energy of the horse was transferred to kinetic energy of the iron boring machine, which was transferred to thermal energy of the water.
- At the particle level, kinetic energy of the boring machine was transferred to kinetic energy of the water particles.

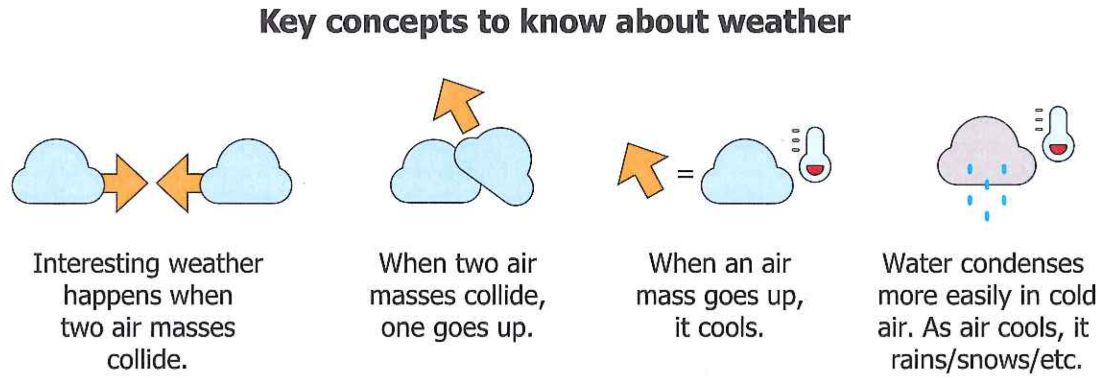
The following day, Mr. A introduced the design challenge for students in teams of three to **design, construct, and test a device [SEP-6]** that either minimized or maximized the transfer of thermal energy. Mr. A facilitated a whole-class discussion about constraints (such as safety, cost, class time, and availability of materials and equipment) and criteria for success. Student teams brainstormed the materials and the **flows of thermal energy [CCC-5]** that they would investigate. In their initial design proposal, they specified the materials and processes they would use and how they would test their devices. Student teams provided most of the feedback to each other, with Mr. A intervening only as absolutely needed to keep the teams on task and within the criteria and constraints. The engineering challenge concluded with student teams presenting and comparing their project results and how their projects developed over time.

Students need opportunities to investigate how different materials respond to heating (solids such as ice melting, liquids such as a pot of miso soup, gases such as a flask with a balloon on top, or a comparison of soil and water being heated). After initial observations of the phenomena, they should determine ways to systematically monitor the mass and temperature to see if changes in either of these quantities can help explain the macroscopic behaviors they see (MS-PS3-4). As they **analyze their data [SEP-4]**, they find that mass is unaffected by heating or cooling changes, but temperature changes are systematically based on the amount and type of material. With scaffolding, students can be prompted to try to **apply a model [SEP-2]** of matter made up of tiny particles to **explain [SEP-6]** each of the phenomena, slowly enhancing their understanding of the **conservation of matter and flows of energy [CCC-5]**. Students refine these models using computer simulations of solids, liquids, and gases, observing relationships between temperature and particle motion in the simulation (PhET http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link7). Students will return to these models in grade seven (MS-PS1-4). In grade six, students can use this conceptual model to **explain [SEP-6]** how air masses become less dense as they warm up, and how particle motions change as matter changes state between solid, liquid, and gas. These simulations also introduce students to the physical basis of air pressure. Density and pressure differences along with state changes drive air movements and precipitation.

Explaining Weather Patterns

Students then use their models of the water cycle, air pressure, and state changes to investigate specific weather patterns. Using animations of real-time observations (such as satellite data from visible light that reveals clouds and other wavelengths that reveal water vapor; see Geostational Satellite Server: GOES Western U.S. Water Vapor at http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link8), students collect data about the movement of large air masses, noticing that the most intense precipitation and weather events occur where air masses collide (MS-ESS2-5; figure 5.13). They also use these maps to predict the motion of air masses and predict the weather. These observations form the **evidence [SEP-7]** that can be used to construct a complete **explanation [SEP-6]** or a **model [SEP-2]** of the relationship between air masses and changing weather conditions.

Figure 5.13. Air Mass Interactions



Important components of a model of weather that describes the interaction of air masses. Diagram by M. d'Alessio

These same physical principles allow students to explain weather patterns within California. Why does it rain and snow more at higher elevations than lower elevations in California? Why is the temperature near the coast milder than areas further inland? Why is it cooler in the mountains than lower elevations? The EEI Curriculum unit *Precipitation, People, and the Natural World* at http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link9 provides a variety of resources that can support this instruction.

Students may be able to share based on personal experience that mountain temperatures tend to be cooler than temperatures at lower elevations. A very important climate consequence of the colder temperatures at higher altitudes is that rising air becomes colder and can hold less water vapor. As a result of this cooling, water condenses, clouds form, and there is a much greater likelihood of precipitation in the forms of rain or snow. The **analyses [SEP-4]** of California climate regions revealed this correlation of increased precipitation with higher elevations.

Two generalizations could emerge from consistent research. If wind from a moist area is blowing toward a mountain range, it is very likely that there will be high amounts of precipitation on the side of the mountains that the winds first hit (called windward or upwind). The other side of the mountain (leeward or downwind) tends to be much drier because most of the water vapor has condensed and precipitated on the other side of the mountain. On the other hand, if the wind blowing toward the mountain has very low humidity, then it is likely that both sides of the mountain will be dry. This condition tends to occur in the middle of continents or locations where the prevailing winds tend to blow toward the ocean.

The temperature and amount of humidity in a mass of air reflects where that mass of air first formed. If it first formed over a warm ocean, the air mass will be warm and humid. If it first formed over a dry continental area, the air mass will be dry and its temperature will depend on whether the continental area was hot or cold.

The clarification statement for MS-ESS2-5 indicates that students will not be assessed on weather map symbols. This is largely a reaction to the fact that these symbols are no longer necessary for illustrating weather patterns in the digital age. For example, real-time wind patterns are indicated with animations of the flow of individual particles (Viégas and Wattenberg 2016) or with familiar rainbow color scales (Beccario 2016). These visualization tools allow teachers to spend more time helping students recognize and **explain [SEP-6]** **patterns [CCC-1]** with less time devoted to memorizing symbols.

Engineering Connection: Finding the Optimal Site for a Wind Farm

As air masses move, they go up, over, or around mountains. The landscape shape therefore has a big impact on wind speeds. Students **analyze data [SEP-4]** showing the average wind speed at different locations around their city. They look for **patterns [CCC-1]** that provide evidence that the landscape shape influences wind speed. Using information about topography and typical wind speeds and directions, they determine the optimal placement of a wind farm that could provide clean energy for their city. They might also need to consider human constraints such as how the land is currently used and who owns it (EP&C V).

Integrating the CCCs in Grade Six Instructional Segment 2

The CCC of **Scale, Proportion, and Quantity [CCC-3]** at the middle grades level includes the notion that "[t]ime, space and energy phenomena can be observed at various scales using models to study systems that are too large or too small." Clearly this concept applies when we relate the macroscopic property of temperature with the submicroscopic motions of particles. Similarly, both weather and climate describe the same conditions of the atmosphere (temperature, moisture, and movement), but at different **scales [CCC-3]** of time (and space). In general, climate describes a relatively long period of time (decades to millennia) and often applies across relatively large geographic areas. Weather generally refers to the same conditions at a specific location during a very short period of time.

The color-coded map of average annual precipitation in California in figure 5.10 is an example of a model that describes phenomena (climate properties) that occur at scales that are too spatially and temporally large to directly observe. Each small area of color corresponds to a calculated average based on many locations that measured and recorded the amount of precipitation each day for decades or perhaps a century or more. This kind of map is a systems **model [SEP-2]** that is especially useful and prevalent in Earth and space science. Color-coded maps can display data in ways that reveal important **patterns [CCC-1]** related to spatial location. Students may initially respond to the aesthetics of the colors rather than the science patterns and the vast amounts of data that these kinds of **models [SEP-2]** summarize and communicate.

While this kind of color-coded modeling representation is also used to some extent in other scientific disciplines, its special appropriateness in Earth and space science topics helps reveal a general principle about CCCs. While the CCCs do apply across many domains, they still may apply in somewhat different ways and extents in the different scientific disciplines.

The CCC of **Systems and System Models [CCC-4]** that is featured so prominently in IS1 still has a very significant presence in IS2. It is a vital and underlying aspect of many of the other CCCs. As mentioned when discussing **scale [CCC-3]**, many systems involve interactions at scales that are so large or so small that they are best understood through system models. Descriptions of the CCC **Energy and Matter [CCC-5]** often refer to tracking the flows of energy and matter into and out of systems. Finally, each of the California regional climates investigated in IS2 is an example of a whole system property that emerges or arises from the interactions of the components of the regional system with each other and with the incoming sunlight.

IS3 Integrated Grade Six Instructional Segment 3: Causes and Effects of Regional Climates

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 3: CAUSES AND EFFECTS OF REGIONAL CLIMATES

Guiding Questions

- Why is the climate so different in different regions of the planet?
- Why are organisms so different in different regions of the planet?
- What makes organisms so similar to but also different from their parents?
- What makes animals behave the way they do, and how does their behavior affect their survival and reproduction?