CaSTL Center

Thermal Energy and Change of State

NSF Center for Chemical Innovation
Chemistry at the Space Time Limit (CaSTL)
https://www.castl.uci.edu/

Essential Question: How is energy transferred between water molecules?

Content Standard(s) Addressed:
MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

NGSS Practice Standard:
Develop a model to predict and/or describe phenomena. (MS-PS1-4)

Disciplinary Core Ideas:
PS1.A: Structure and Properties of Matter
Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. (MS-PS1-4)

In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. (MS-PS1-4)

The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. (MS-PS1-4)

PS3.A: Definitions of Energy
The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (secondary to MS-PS1-4)

Cross-Cutting Concept
Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-PS1-4)

Content Learning Objective:
After teacher shows students the different temperatures between two cities at the same latitude (Los Angeles and Phoenix), students will investigate how heat affects the change of state of water molecules. They will use this evidence to explain why the city near the ocean has milder temperatures.

Cooperative Groups:
Teacher will have already set norms for working in groups:

- Take turns
- Everyone shares
- Look at the speaker
- Actively listen
    - Nodding
    - Asking questions for clarification
- Respect others' thinking
- Think before speaking
  (from Ferris, S. (2015, July). Making talk productive. *Science and Children, 52*(9), 67 – 73.)

Group Roles

♣ **Emperor** ♣
In charge of:

- Making official decisions
- Reading materials to the rest of the group
- Coordinating presentations
- Filling in for absent group members

♦ **Ambassador** ♦
In charge of:

- Making sure that everyone in the group participates and understands the activity
- Checking for understanding
- Facilitating discussions

♠ **Spy** ♠
In charge of:

- Making sure the group finishes the activity on time
- Asking questions to the teacher (The Spy is only allowed to ask a question if no one at the group knows the answer)
- Visiting other groups on the suggestion of the teacher

♥ **Designer** ♥
In charge of:

- Acquiring & returning materials
- Making diagrams and drawings
- Making sure that everyone at the group writes the work in their own notebook

This is a multiple day lesson.

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ENGAGE: ***Anchoring phenomena and central question, relating lesson to phenomena found in students' everyday lives or phenomena that are potentially intriguing, students come up with ideas or hypotheses that may help answer the central question, students construct an initial model***

Estimated time: 30 minutes

Description of Engage: Teacher shows students images of a Los Angeles beach and Phoenix, Arizona and gives students data about average high and low temperatures in both places. Teacher tells students that both cities are the same distance from the equator so they should get the same amount of sunlight and asks them to look at the data to see what they notice. Students will come up with ideas in their small groups to explain this phenomenon and will create a drawing on the molecular level that will attempt to explain it. Model must have: components that they think account for the temperature differences, arrows to designate energy input and output, and a written explanation of the difference in temperatures in both places.

Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Asking questions Developing a model	I am going to show you some data about two cities at the same distance from the equator and I want you to look at the data for 3 minutes without talking to your group. (After 3 minutes transpire), now I want you to talk to your group to share your ideas about the data and why these cities have these average temperatures while they get the same amount of sunlight. The question we are trying to answer is: **How is energy transferred between objects?**	Students independently look at the images of the cities and the data. Students talk in their groups and share their ideas.

	You are going to create a model to conceptually and visually explain the difference in the average temperatures of these cities. Be sure to label the components in your drawing, including the components that you think account for the temperature differences, arrows to designate energy input and output, and a written explanation of the difference in temperatures in both places. The teacher will walk around the room and probe for understanding. *"Where is the energy in your drawing? How are you displaying that? What is your evidence for the energy input and output that you drew?"*	They get chart paper and markers and draw why they think the two cities have such different temperatures, using everyone's ideas. Groups put their models aside for later. They will add to these models after the investigation. *"Here is the energy coming from the sun. We put wiggly arrows to indicate the energy hitting the ground and wiggly arrows for the energy rising from the ground."*
EXPLORE: ***Students conduct a set of empirical investigations about the phenomena, investigations provide evidence that might be useful for addressing the central question and for revising the students' model, students make observations*** **Estimated time: 45 minutes** **Description of Explore: Teacher assembles the materials ahead of time (1 set for each group): hot plate, 250 ml glass beaker, thermometer, 150 ml room temperature water, and a timer (students can use their phones). Teacher creates a post-it for each table group. In the middle of the post-it is a number from 1 to 9 for each table. In the corners of the post-it are the suits of a deck of cards: in each corner the teacher will draw a heart, a diamond, a spade, or a club so that each corner has a different suit. The student sitting closest to a corner will acquire the role related to that suit. For example, if a student is sitting closest to the heart, that student would be the designer (see group roles above). As the students explore in this investigation, they fulfill the roles of their suits in order for the team to be successful.**		

Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Asking questions Planning an investigation	The teacher will tell the students that they will conduct an investigation to collect evidence to help explain the phenomenon.	Designer collects the materials.
	The teacher tells students that they will take the temperature of the beaker of water while it is heating. They will record the temperature every 5 minutes until it boils. The students will use this data to graph temperature vs time.	Students need to determine which variables they will measure. Depending on when in the school year the students do this investigation, the teacher may give them more or less support. Students need to decide when to take the temperature, where to place the thermometer while taking the temperature, when to stop taking the temperature, and how to arrange the variables on the graph.
	The teacher may model the procedures as well so that the students can see how they will conduct their tests.	Students watch the teacher to review the steps of the investigations.
	The teacher will walk around the room and probe for understanding.	
	"*What do you notice?"*	"*The water stays at the same temperature for a while."*
	"*What might be going on here that we can't see?*"	*"The energy is not making the water boil. Where is the energy going?"*
	"Are there any patterns or trends?"	The Spy may visit other groups to see if they are getting the same results. The Spy reports back to the group.
	"*Why do you think this happens this way?*"	**"***The energy is doing something else besides making the water molecules hotter?"*
	Teacher monitors students' conversations and answers to questions to plan which groups will report out in	

	the Explain. The teacher selects groups purposefully and decides how to sequence ideas shared to build conceptual understanding.	
EXPLAIN: ***Students identify and analyze the patterns they find, explain the result, and reflect the results in relation to their model*** **Estimated time: 30 minutes** **Description of Explain: Students talk in their groups about the data and the patterns that they observe. They try to explain what happened in the investigation and try to apply their explanations to the phenomenon and their model. Teacher also asks questions related to the central question that arose from the phenomenon.**		
Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Creating an explanation Drawing a conclusion from evidence	Teacher tells students to talk in their groups to be sure everyone has an explanation for the patterns they observed in the investigation. Teacher asks questions and chooses groups to reply based on the monitoring done in the Explore, choosing groups based on misconceptions, then simple answers then more complex, abstract answers. "*What did you find in your activity?"* "*What patterns did you see in the data?"* "*How might what we did in this activity explain the phenomenon of why Los Angeles near the ocean is*	Students talk in their groups to be sure they all agree on their explanation. "*We found _____.*" **"***Even though we were adding energy to the water, the temperature stayed the same for a long time. Everyone had the same data."* Student displays graph of data. *"The energy from the sun goes into the ocean and it stays there. This keeps the land near the ocean cooler."*

	cooler than Phoenix that is inland?" "*How could energy transfer help us understand what we saw?"* Use evidence from the investigation to support your statement.	*"The energy from the sun is stored in the ocean. When the sun sets in the winter, the ocean releases the energy to the air which moves inland to warm the land in the winter."*
EVALUATE: ***Students evaluate their initial model with empirical findings and revise their model*** **Estimated time: 20 minutes** **Description of Evaluate: Students return to their models and revise their models based on their new information from their investigation. They refine their explanations based on their evidence.**		
Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Developing a model Arguing from evidence Communicating information	Teacher directs students to take out their models and add to their drawing, labels, and explanations based on any new evidence they collected in the investigation. Teacher walks around and monitors student work to assess whether students are changing their ideas and adding to their explanations.	Students work productively to change or add to their models and explanations.
EXPLORE: ***Students investigate fundamental scientific concepts, ideas, and theories related to the phenomena or model that they cannot access through empirical investigations—through text, the teacher or computer simulations*** **Estimated time: 30 minutes** **Description of Explore: Teacher gives the students the link to Test Tube Games: Bond Breaker Classroom Edition https://testtubegames.com/bondbreaker3.html Students can work independently or with one partner to play the first 4 levels of the game. These levels will give the students more information about attraction and repulsion of particles. Students could access the game in class or on their own since the game can be**		

accessed by their phones or by their tablets if they are in a one-to-one district. The levels that pertain to this lesson are Levels 36 – 40, including the video. The students should write down important information that they think could help them revise their models.		
Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Planning an investigation Drawing a conclusion from evidence Obtaining information Communicating information	When students have completed the levels of the game, both the introductory levels and the later ones, including the video, students share with each other what they learned in the game that they think can help them with their model. Teacher brings them together to ask questions about water molecules. "*What did you learn about the structure of water that you might use in revising your model?"* *"What did you learn about the states of matter that pertain to our phenomenon?"* *"Have you ever walked on the beach on a hot day in the summer. What did your feet feel? What did your feet feel when they went into the water?"* *"Both the sand and the water have absorbed the same energy from the sun. Why is there a difference in the temperature your feet feel?*	Students tell each other what they learned in the lesson. "*Water molecules are attracted to other water molecules."* *"Liquids have less energy than gases. It takes a lot of energy to get liquid water to become water vapor. So the energy from the sun goes into the ocean and is trapped there because there is so much water and it takes a lot of energy to warm it up enough for it to boil."* *"The sand is much hotter."* *"The water felt much colder."* *"The sand and the water store energy differently."*

EVALUATE: ***Students evaluate and revise their model using scientific ideas to which they have been introduced***

Estimated time: 15 minutes

Description of Evaluate: Students return to their models one more time to add more information from the game. Students then visit each other's posters to see what others have done with the intent of adding to their own poster. While they look at the posters of other groups, they carry post it notes with them to ask clarifying questions, agree with the information they see on the posters, disagree with the information they see, or add on to the information. Each group then returns to its poster and reads the post its that were left by other students. The students make one last revision to the model.

Science Practice	**Teacher's Role and Teacher Questions**	**Students' Role and Expected Student Answers to Teacher Questions**
Developing a model Creating an explanation Arguing from evidence Communicating information	Teacher tells students to add information to their poster based on the class discussion. Teacher then gives directions on how students will ask clarifying questions, agree with the information they see on the posters, disagree with the information they see, or add on to the information. Students then visit each other's posters to observe what others have done. They leave feedback on the posters with post it notes.	Students work productively to make more revisions. Students then walk around and leave productive comments on post its as feedback to classmates.

EXTEND/ELABORATE: ***Students construct a consensus model either within a small group or as a whole class, using the strengths of each individual's model, students use the consensus model to predict or explain other related phenomena, students determine strengths and limitations of their model for further revision***

Estimated Time: 10 minutes

Description of Extend/Elaborate: Teacher replays the States of Matter video from the game. The teacher asks the students if they agree or disagree based on evidence from their investigation or information from the game. Students decide if their model is sufficient to explain the phenomenon.

Science Practice	Teacher's Role and Teacher Questions	Students' Role and Expected Student Answers to Teacher Questions
Arguing from evidence Communicating information	The teacher replays the States of Matter video from the Bond Breaker game. After the students have had a chance to think about what the narrator said, teacher gives them time to talk in their groups about whether they agree or disagree with the narrator based on their evidence or information from the game. Teacher facilitates a whole class discussion. Teacher asks students if their models have enough information to explain the phenomenon. What is their evidence? Teacher then asks students to write three sentences that explain the difference in the yearly average temperatures between Los Angeles and Phoenix they observed in the	Students might have an alternative explanation for the phenomenon that is different from the narrator's, based on their investigation or the game. Sentence frames that they can use are: *"The evidence I use to support _____ is _____.* *I believe _____ (statement) because _____ (justification).* *I know that _____ is _____ because _____.* *Based on _____, I think _____.* *Based on _____, my hypothesis is _____."* Students will look at their model and decide if they can explain the phenomenon based on what they put on their posters. They need to support their statements with evidence from their model. Students should write about: What do water molecules do when heat is added to them? What does sand do when heat is added to it? Why they think Los Angeles is generally cooler than Phoenix, using

	phenomenon.	evidence from the investigation and the game?

Tools, Materials, & Resources

Equipment needs:	Item: hot plate, 250 ml glass beaker, thermometer, 150 ml room temperature water, and a timer
Safety requirements	Be careful near the hot plate and hot water. Take precautions to avoid getting burned.
Visual aids, Powerpoint slides, handouts.	**TestTube Games: Bond Breaker Classroom Edition** **https://testtubegames.com/bondbreaker3.html** **TestTube Games: Bond Breaker 2.0 (full game)** **http://www.testtubegames.com/bondbreaker.html**

Manhattan Beach CA

https://images.app.goo.gl/eBao9qHqMti2qpyd6

Phoenix Arizona

https://images.app.goo.gl/WWUZ66HPfGRqVH5i9

Average Los Angeles temperatures

High °F	Low °F		High °C	Low °C
68	48	January	20	9
69	49	February	20	10
70	51	March	21	11
73	54	April	23	12
75	57	May	24	14
78	60	June	26	16
83	64	July	28	18
84	64	August	29	18
83	63	September	28	17
79	59	October	26	15
73	52	November	23	11
68	48	December	20	9
75	56	Year	24	13

https://www.currentresults.com/Weather/California/Places/los-angeles-temperatures-by-month-average.php

Average Phoenix temperatures

High °F	Low °F		High °C	Low °C
69	46	January	20	8
72	49	February	22	9
78	54	March	26	12
86	60	April	30	16
95	69	May	35	21
104	77	June	40	25
106	83	July	41	28
104	82	August	40	28
100	75	September	38	24
89	64	October	32	18
76	52	November	25	11
67	45	December	20	7
87	63	Year	31	17

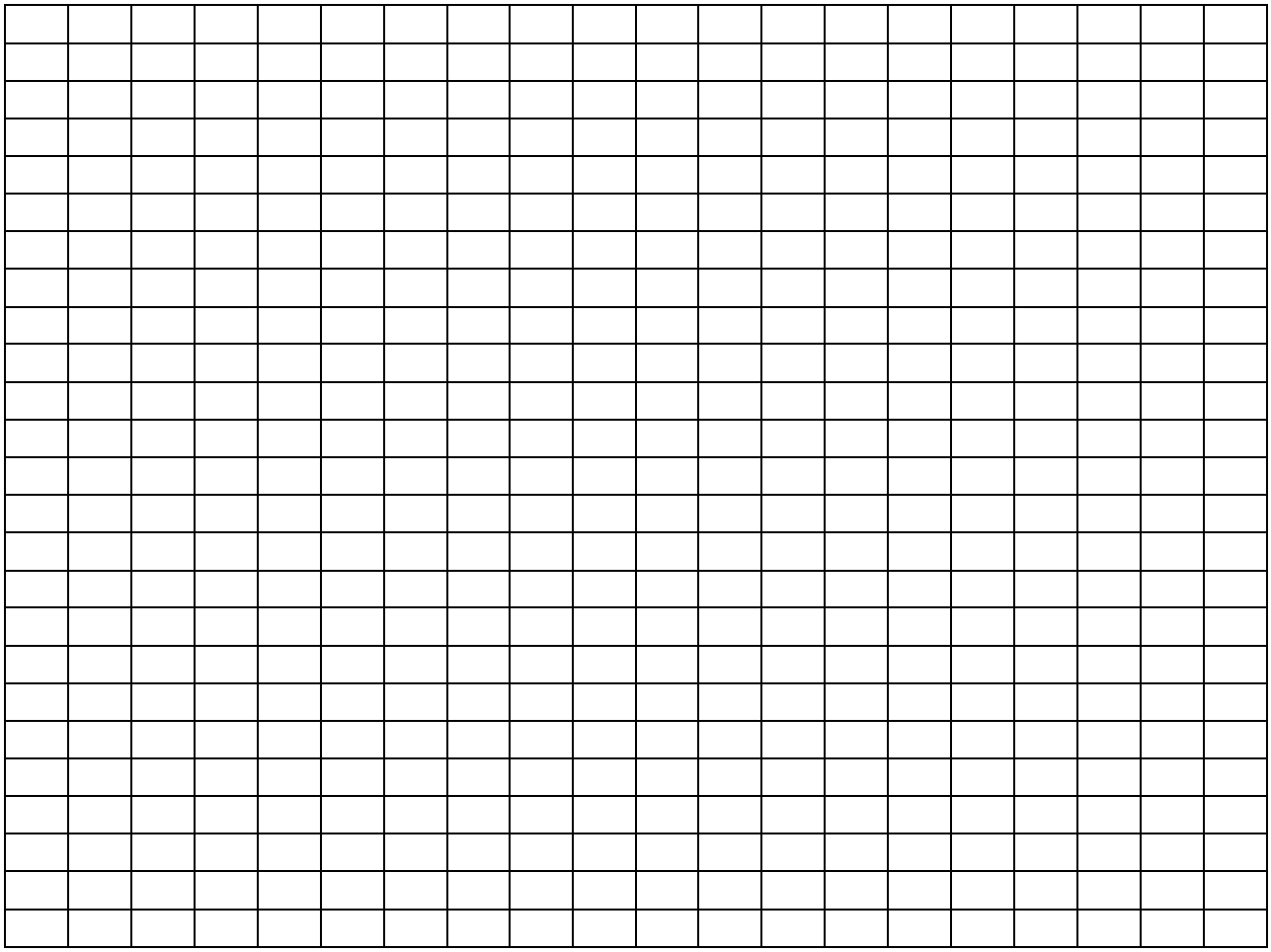
https://www.currentresults.com/Weather/Arizona/Places/phoenix-temperatures-by-month-average.php

Thermal Energy and Change of State

Data Table.

Time (in minutes)	Temperature (in degrees Celsius)	Observation of water in beaker

Create a temperature vs time graph. Be sure to create a title for your graph and label the axes with the variable and the units.



What patterns do you observe?

What causes the shape of the graph?