Online Supplemental Materials for

Classroom-Scale Experiments in System-Scale Modeling

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Example Student Work

With Annotations, Comments, and Analysis

List of Figures

Figure 1. Example of 8th Grade Student Work in response to watching the Video of Global Water Vapor Movement as a preliminary activity to the condensation experiments.

Name [redacted] Date [redacted] Period [redacted]

Water Vapor in the Atmosphere
Invisible but OH SO IMPORTANT!

Questions we've had this year:

1. Can water evaporate when it is cold?
2. Where does the water come from that becomes our precipitation?

Experiment you need to do at home:

1. Put 2 tablespoons of water into a small cup or glass. Mark the water level with an inked line or a piece of tape.
2. Place container upright, open in your family's freezer so that the water is LEVEL.
3. Let it be in the freezer for 2 weeks.
4. After one week, check the ice level and water level. Are they the same?
5. After two weeks, check the ice level and water level. Are they the same?
6. How long did it take for about 1 half of the water to evaporate?

Introduction to the movement of water in the atmosphere:

1. Watch the video at the URL listed below. It spans at least a year's worth of movement of water vapor in the atmosphere. https://tinyurl.com/ydx64hpm, (for the following longer URL. https://prairiepublic.pbslearningmedia.org/resource/ess05.sci.ess.watcyc.cloudprecip/water-vapor-circulation-on-earth/#)
2. What questions pop into your mind? Can be about the diagram itself, or about the natural process you are seeing.
   a. Why did the video stop every so often?
   b. How does water vapor stay moving?
   c. Does it always move in that pattern?
   d. Why is it less dense in some areas, and more in others?
   e. Why are the ends swirled?
   f. It seems in the video like the more dense
   g. water vapor is flowing in a different way than the less dense area is. why?
3. Describe what you think this video is showing.

I think this video is showing how water vapor moves around the world. I think it is showing where it is dense most, and where it might not be so dense. I think this video did a good job, because I see clearly how water vapor moves.

Figure 2 Example eighth-grade student expectations and thoughts about phases prior to doing the condensation experiment. Note the initial disconnect between the comments made in sections 2a and 2b: bubbles are made of carbon dioxide, but also the water turns into gas.

Name [redacted] Date [redacted] Period [redacted]

MOVEMENT OF WATER AND HEAT LAB – getting ready

Tape the drawing of the lab set-up into your journal, please don't laminate it with scotch tape – you will be drawing on it.

1. Label the following parts of the experimental setup:
   - a. tubing
   - b. beaker
   - c. stopper
   - d. flask
   - e. thermometer
   - f. hot plate

2. We will be heating the water in the flask so that it boils. You'll turn the heat down so the water keeps boiling. For now, think about what you have already observed when water boils on your kitchen stove.

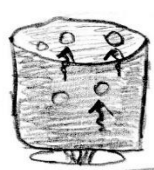
   a. What do you suppose the bubbles in the boiling water are made of?

   I think the bubbles are made of carbon dioxide. I think this because the heat forces the carbon out of the water.

   b. Water is made of molecules that are free to move past each other. What do you imagine happens to the molecules if you heat them up to make water boil?

   The water will turn into gas. and the molecules will escape the water.

   c. In the space below, devise a way to represent/draw your thinking that you describe above.



Three states of matter

- liquid – atoms or molecules are free to move past each other
- solid – atoms or molecules are not free to move + are fixed in place
- gas – atoms or molecules are free to move in any direction + take up (fill) all the available space

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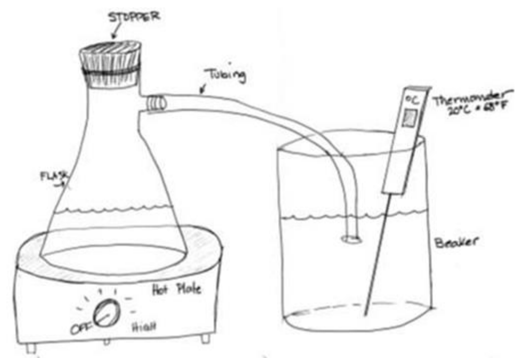
Figure 3 Annotated example of eighth-grade student predictions prior to doing the condensation experiment. Allowing students to make predictions about the experiments before doing it provides time to get familiar with the equipment and think about what might happen. This can heighten students' awareness when things they either anticipated or did not anticipate happen. In addition, this activity can alert the teacher to preconceived ideas. For example, in the student work below, the idea of heat transfer is present (although missing the idea of latent heat) but the idea of transfer of matter is missing.

3. On the table below, describe what you think will happen when we heat the water in the flask. Think of a series of steps that might occur. Then explain what causes each step to happen. You can add parts and arrows to the diagram to show what you are thinking.

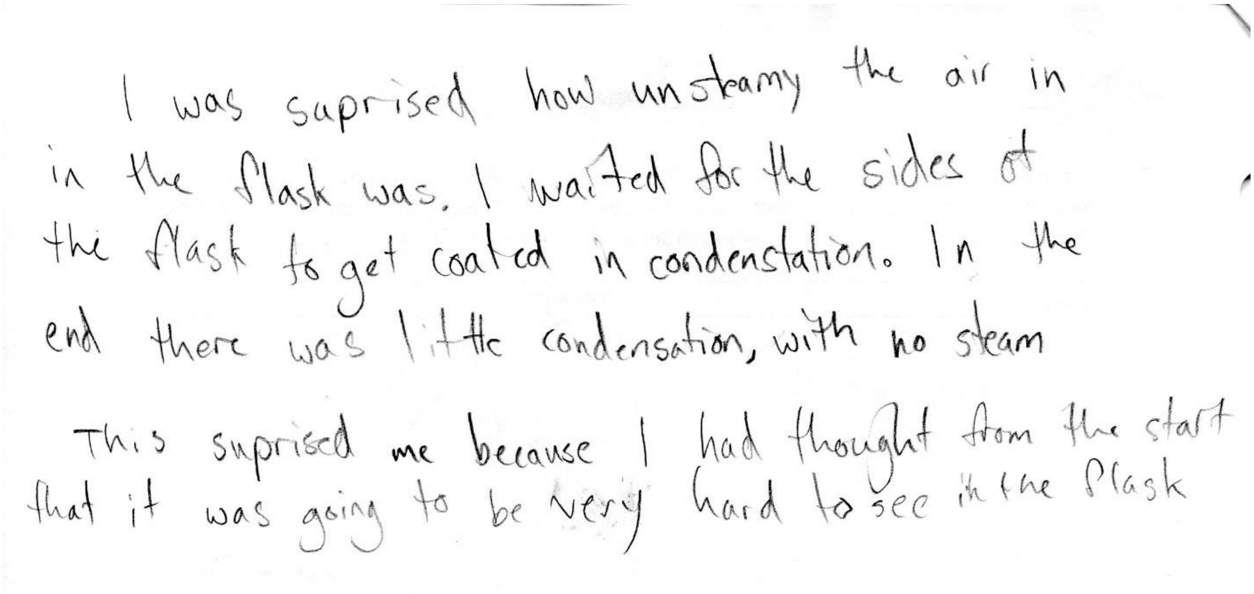
I think	______________	will happen because	______________
I think	the water will start boiling quickly	will happen because	the heat is high & it is closed
I think	Condensation will collect at the top.	will happen because	the water vapor has nowhere to go.
I think	The beaker will heat up	will happen because	The hot gas will fill the tubing & heat the water
I think	The condensation will fall back into the flask	will happen because	too much will collect at the top.



One student's expectation prior to doing the experiment, but after naming the experiment parts on the diagram above.

Students typically did not anticipate the transport of either water or latent heat out of the flask, for example, this student comments that the water vapor has no place to go and that condensation will collect at the top of the flask. Although there is an expectation of the beaker being heated by hot gas, the idea of latent (hidden) heat is not present.

Figure 4. Example student feedback on a trial run of the experiment—in response to the question "What surprised you?"


I was suprised how unsteamy the air in in the flask was. I waited for the sides of the flask to get coated in condenstation. In the end there was little condensation, with no steam

This suprised me because I had thought from the start that it was going to be very hard to see in the flask

Figure 5. Example graph of beaker water temperature versus time after doing the condensation experiments. Graph shows a sharp change in slope once water vapor begins to condense at the end of the tube, an observation that became a key part of understanding the results and arguing from evidence about the release of latent heat. Data are shown from two different eighth-grade student groups (groups 2 and 7) in the same class period.

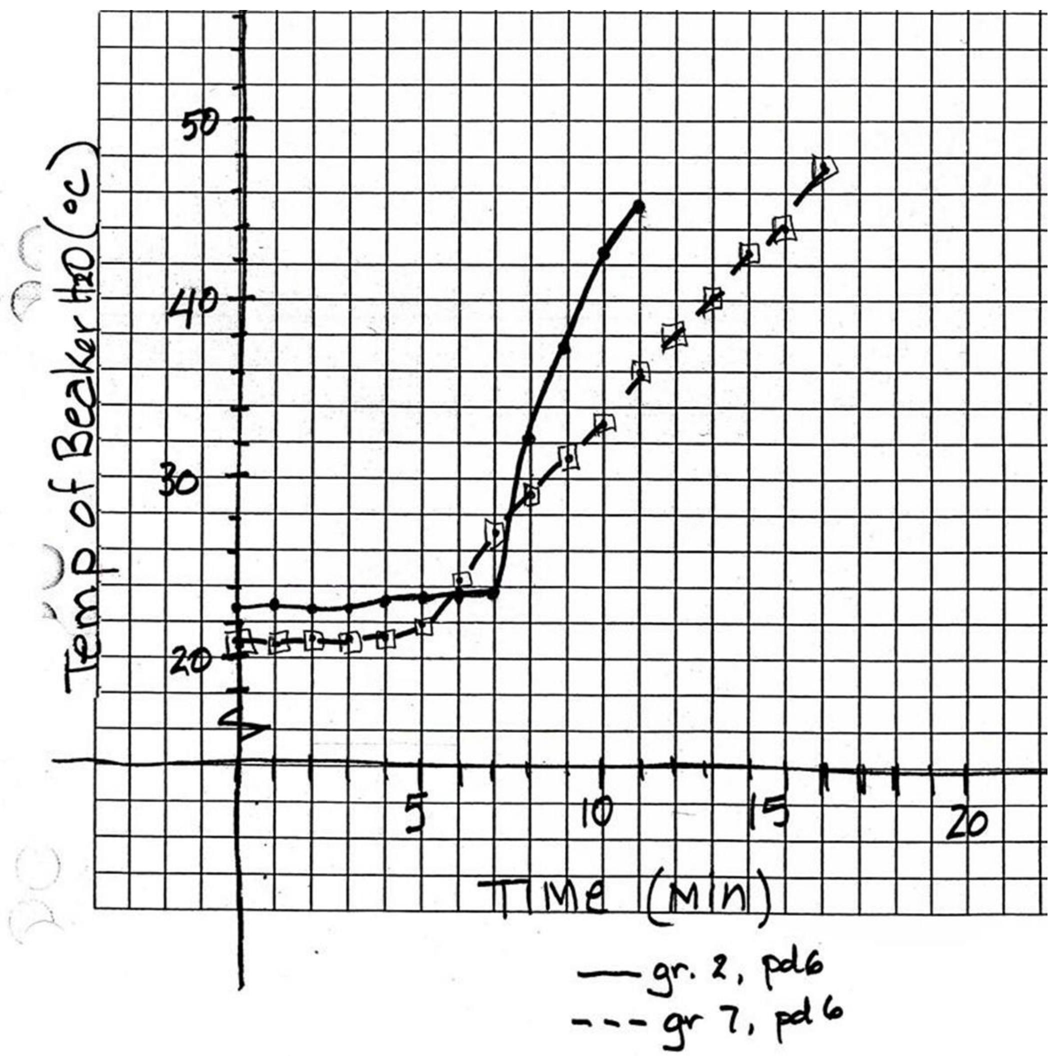


Figure 6. Example 8th grade student work analyzing the results of the condensation experiment. In this case, the students does not recognize or differentiate the initial rate of temperature change from the rate after vapor condensation begins, which is seen in Figure 5 and prompted by the two different temperature-change rates asked for in the table.

Name [redacted] Date [redacted] Period [redacted]

Pg. 2

3. What do the patterns and connections mean? Use the back if needed.

Observations	Measured T Change PER # of minutes	Questions to Consider and Answer
The bubbles came out of the tube slowly. They were big and they rose to the top.	14.3 °C in 15 minutes	Would you expect the bubbles to be made of air or water vapor? Water Vapor Explain your reasoning. Use science ideas. Because they are made from water that bubbled up, because it was heated.
The bubbles came out of the tube quickly, they were small and they didn't rise to the top.	____ °C in ____ minutes	Would you expect the bubbles to be made of air or water vapor? Water Vapor Explain your reasoning. Use science ideas. It is the same bubbling from before just happening faster.

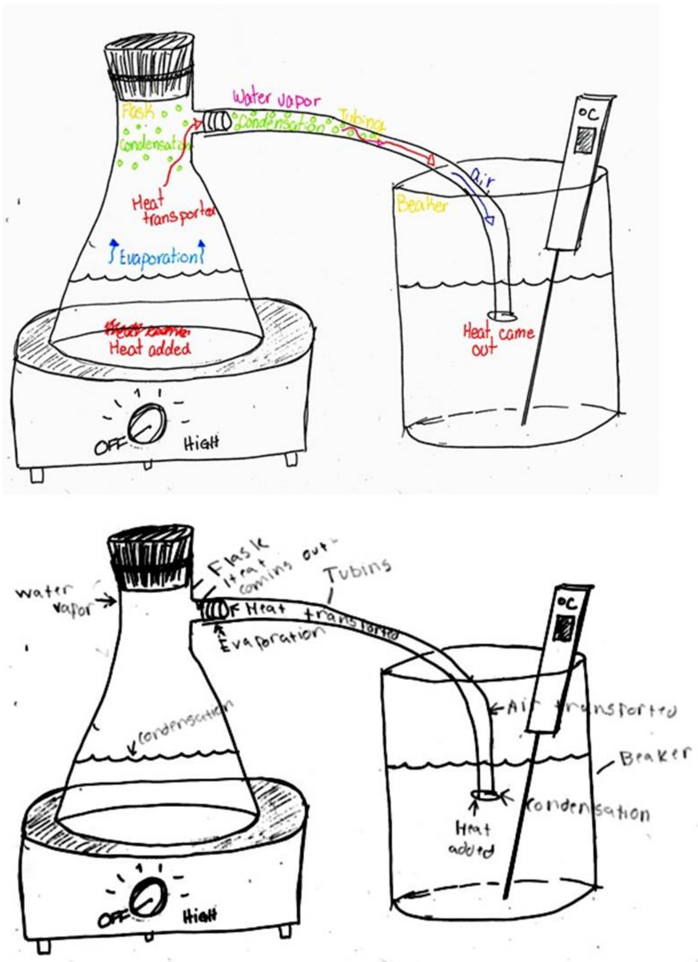
What may have caused the slow rise in T in the water of the beaker in the first part of your experiment? Explain why you think this.

The water heated up, then evaporated into the tube, it went from the tube into the water and heated the water up.

What may have caused the fast rise in T in the water of the beaker in the second part? Explain why you think this.

There was more bubbles, so more hot water vapor went through the tube.

Figure 7 Annotated examples of eighth grade student formative assessment shortly after doing the condensation experiment. The students are responding to the assignment: *Label the drawing of your experiment with the words flask, beaker, tubing, hot plate, water is evaporating, water vapor is condensing, heat energy added to the system, hidden heat energy is given off, hidden heat energy transported (arrow), water vapor transported (arrow), air transported (arrow). Where matter and energy are moving draw in arrows to indicate the direction of movement and label the arrows with what is moving.*

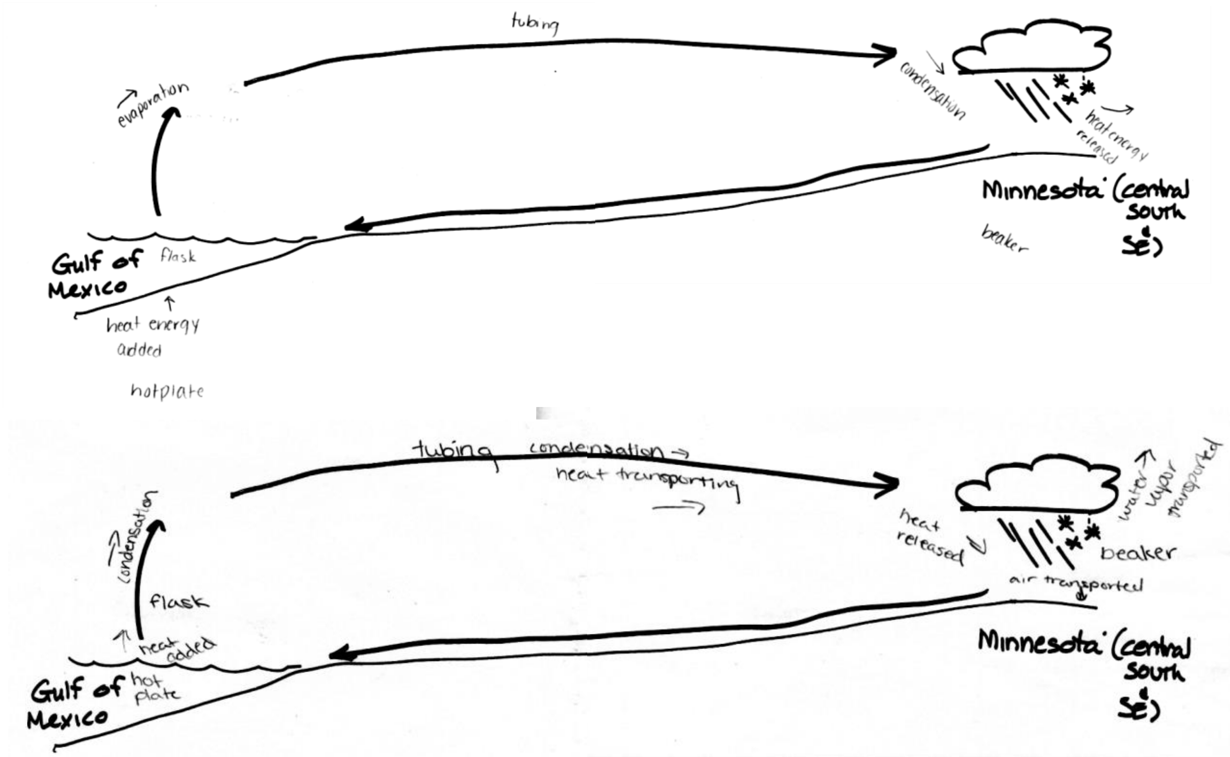


Formative Assessment of two students' understanding of the movement of heat and water vapor in the experiment the day after the experiment but before more substantial discussion and analysis. Students were asked to identify where heat was added, released, and transported, and where evaporation and condensation occurred.

Commonly, students identified condensation at the top of the flask or in the tube, but not in the beaker, despite taking specific note of the disappearing bubbles of water vapor and the rise in water in the beaker. This is seen in the first student example. Both students' work suggest that they are thinking of condensation as the condensed liquid phase, but not as a process of converting gas to liquid.

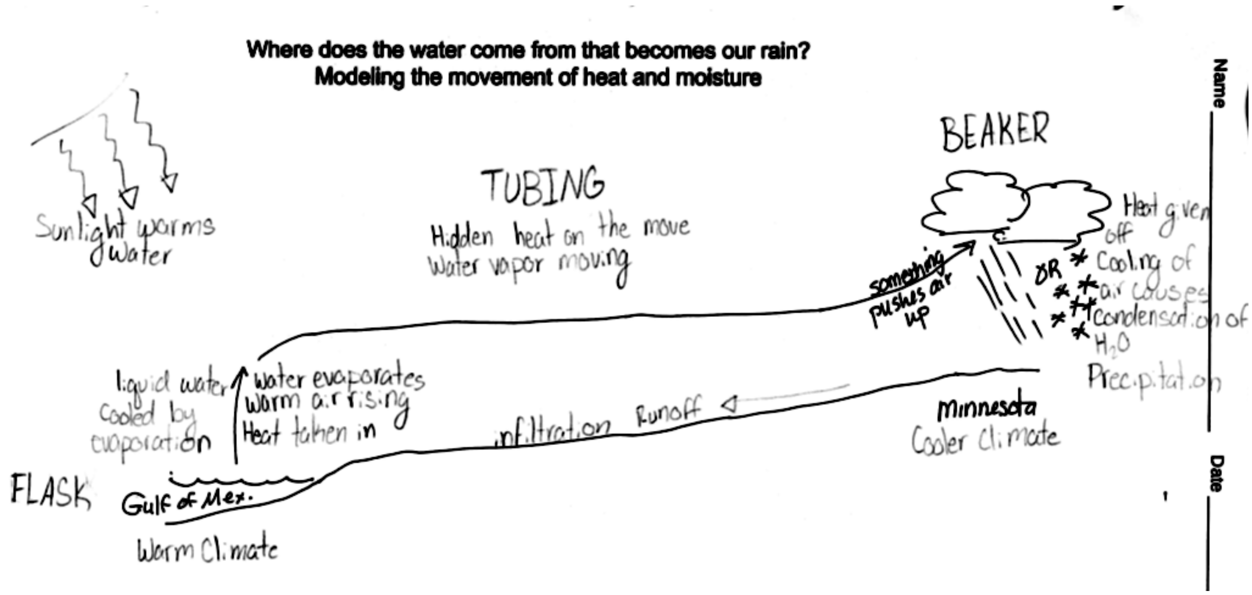
Most students understood the idea of heat being added to the flask and then released in the beaker. However, the "where was heat added" question proved unclear to many students because the release of heat due to condensation of water vapor could also be interpreted as "adding" heat to the water in the beaker. This shows up in the second student example.

Figure 8. Annotated examples of eighth grade student initial efforts to apply the results of their condensation experiment to modeling the global water cycle. This activity also serves as a formative assessment. The students are responding to the assignment: *On the water cycle diagram provided, label the same parts and processes listed above (listed in Figure 7.)*



Formative Assessment of two students' understanding of the relationship between the condensation experiment and the movement of heat and water in the water cycle, done the day after the experiment but before more substantial discussion and analysis of the results. Students were asked to indicate which parts of the water cycle corresponded to the flask, the tube, and the beaker, and where heat was added, where heat was transported, and where heat was released. The first student does not indicate the transport of heat with the movement of water vapor in the top arrow. The second student models most condensation happening in the tubing rather than in the beaker, a misunderstanding also noted in Fig. 7.

Figure 9. Annotated example summative assessment of the connection between the condensation experiment and the water cycle (eighth-grade student example). In this case, the assessment followed additional studies of the atmosphere and surface and ground water runoff than is addressed in the 6-day unit shown in Fig. 8 of the main article, Classroom-Scale Experiments in System-Scale Modeling.



A portion of a Summative Assessment done at the end of the unit after a couple weeks of discussing the water cycle and the experimental results. This assessment is for the same 8th grade student as in the initial expectations in Fig. 3 and the first of the annotated examples in Figs. 7 and 8, reflecting a progressive improvement in understanding of the heat transport by water vapor as well as ideas addressed in other parts of the unit (heat from the sun, ideas of infiltration, effect of rising air on condensation). The student still has not quite got the idea that 'hidden' heat is being released by the condensing water vapor, not simply by air that is cooling. The full summative assessment, along with an example student performance, are available in the online resources.

Example of summative assessment—8th grade student

TEST

The Movement of Heat and Moisture in the Atmosphere

Part 1:Information Recall: states of matter, heat transfer, water cycle, composition of air, the atmosphere as a system.

1. The two most abundant (plentiful) gases in the atmosphere are ___ and ___. Circle two only.
    a. Dust particles
    b. Salt particles
    c. Smoke particles
    d. Water vapor
    e. Carbon dioxide
    f. Argon (most abundant of the 'other' gases)
    g. Oxygen
    h. Nitrogen

2. We live at the bottom of an ocean of air, this ocean of air is called the _____.
    a. Atmosphere
    b. Biosphere
    c. Geosphere
    d. Hydrosphere
    e. Cryosphere

3. Clouds form when _____. Chose the step that happens right before you will be able to see the cloud.
    a. Water evaporates from a body of water like an ocean.
    b. Warm moist air rises because the molecules have more energy, move away from each other and the less dense gas floats upward.
    c. Moist air cools and the water vapor condenses.
    d. Rain, snow, sleet or hail fall to Earth's surface, pulled down by gravity.

4. Most of Earth's water vapor is concentrated in a band on either side of the _____.
    a. Prime Meridian
    b. International Dateline
    c. Equator
    d. Arctic Circle
    e. Antarctic Circle

5. The type of heat transfer that occurs because more energetic atoms or molecules vibrate and against less energetic molecules is called _____.
    a. Radiation
    b. Conduction
    c. Convection
    d. Hidden heat

1

Name ______________________________ Date ______________ Period ______

6. The type of heat transfer that occurs when warm (energetic) molecules in a fluid move from place to place is called_____.
   a. Radiation
   b. Conduction
   c. Convection
   d. Hidden heat

7. The type of heat transfer that occurs because of the energy moving as electromagnetic waves is called _____.
   a. Radiation
   b. Conduction
   c. Convection
   d. Hidden heat

8. The type of heat energy that can be carried by convecting air and that is released when water vapor condenses is called _____.
   a. Radiation
   b. Conduction
   c. Convection
   d. Hidden heat

9. _____ is the total energy of motion of atoms or molecules in a substance (solid, liquid, gas or combination.
   a. Temperature
   b. Thermal energy
   c. Thermometer

10. _____ is the average amount of energy of motion of each particle of a substance.
    a. Temperature
    b. Thermal energy
    c. Thermometer

11. _____ is the device that measures the average amount of energy of motion of each particle of a substance.
    a. Temperature
    b. Thermal energy
    c. Thermometer

12. Which of the following temperature scales places the freezing point of water at 0° and the boiling point of water at 100°?
    a. Celsius
    b. Kelvin
    c. Fahrenheit

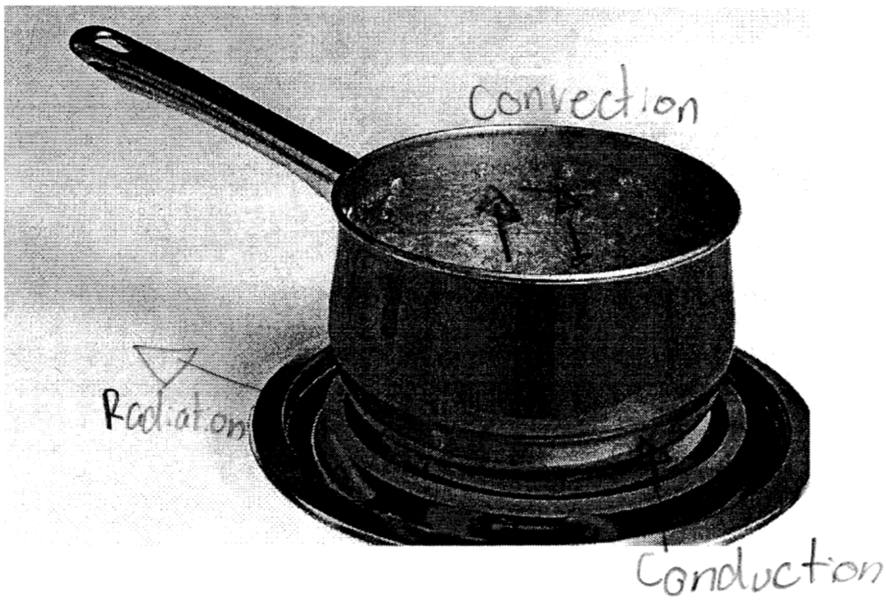
Name ______________________ Date ______________ Period _______

Part 2 - Short answer essay - constructing explanations

13. During our freezer experiments, some of us found that a small amount of white powdery residue was left behind in the cup when the water evaporated.
    a. Where did this material probably come from? minerals in the water
    b. How does this observation of the powdery residue and your inference of its origin relate to the big science idea that matter is not created nor destroyed (conservation of matter).

The minerals are not destroyed. So even though it looks like the water is gone, it really is just in a different place.

14. In the photo to the right, draw an arrow to where conduction, convection and radiation heat transfer are occuring. Label your arrows. The electric burner, in the original color photo, is red hot.



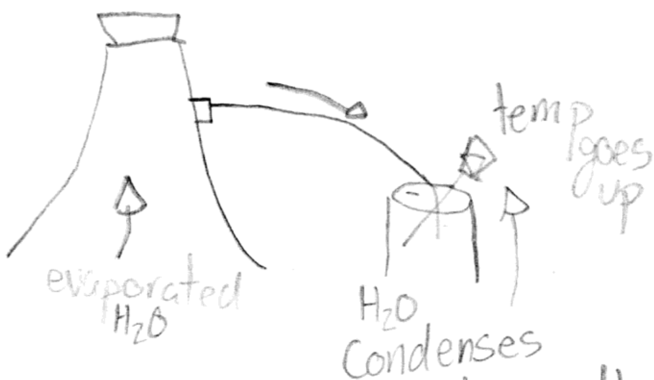
15. Refer to the photo above and describe the movement of heat from the burner to making the water boil. Use complete sentences. Don't use the work 'it'.

When the burner heats up, the molecules inside start to move faster & vibrate quicker. Those molecules hit molecules in the pan, which in turn hit molecules in the water. eventually, the water is evaporating from the bottom, which causes the water to boil.

Name ________________________________ Date _______________ Period _______

16. Explain how we know there is heat hidden in water vapor. You can include drawings to illustrate your answer. Use complete sentences. Don't use the work 'it'

Room for drawings.



In our experiment with a beaker & flask, once water vapor started going through the tubing & condensing into the beaker, the temperature started getting higher much quicker. We know that this isn't just hot water being added, because that would not heat the water sufficiently. That means that there must be heat released when water vapor condenses, or changes from a gas to a liquid. ~~Ga~~ Particles in gases move faster than in liquids, so this energy must go somewhere. Since when particles move faster, heat is the result, the energy must be transferring to the water in the beaker.

Name ______________________ Date ______________ Period _______

Part 3. Modeling the large-scale movement of heat and moisture in the atmosphere.

17. The diagram on the next page shows arrows that represents air moving from the Gulf of Mexico to Minnesota. Recognize that the drawing is a cross-section of the atmosphere (a vertical slice), not an astronaut's view of Earth's surface, like we saw in our water vapor video. Label the drawing with the following processes that transfer heat and moisture in the atmosphere.

Hidden heat on the move	Cooling of air causes condensation of H_2O	Warm climate
Water vapor moving	Water evaporates	Cooler climate
Warm air rising	Precipitation	Sunlight warms water
Heat taken in	Runoff	Liquid water cooled by evaporation
Heat given off (released)	Infiltration	

18. Which part of your labeled diagram on page 6 is like the **beaker** in our flask/beaker experiment? Label the diagram with the word BEAKER. Explain your choice. The Gulf of Mexico is very similar to the flask in our experiment because the gulf is warm, just like the flask on the hotplate. In both the Gulf & the flask, the water evaporated into water vapor, which was then carried away.

switch

19. Which part of your labeled diagram on page 6 is like the **flask** in our flask/beaker experiment? Label the diagram with the word ~~BEAKER~~. Explain your choice.

Minnesota is similar to the ~~beaker~~ flask in our experiment because both are cooler areas. They are also both the areas where water vapor condenses & releases hidden heat.

20. Which part of your labeled diagram on page 6 is like the **tubing** in our flask/beaker experiment? Label the diagram with the word ~~BEAKER~~ ~~Flask~~ tubing. Explain your choice.

The wind that carries the water vapor is most like the tubing because both brought ~~evapo~~ water vapor from a warm to a cooler place.

Name ______________________________ Date ____________ Period ______

21. Did the heat and moisture experiment simulate a complete water cycle? Yes or No and explain your answer. Start your response with your statement you claim to be true, and then support your claim with both evidence and reasoning in your answer.

The heat & moisture experiment did not simulate a complete water cycle. In a complete water cycle, there is runoff that goes back to the place of origin or another body of water. In our flask & beaker experiment, there was no runoff. Without runoff & infiltration the cycle is not complete because it cannot happen multiple times, it cannot cycle over & over again.

22. A student said "Snow come from the north with the cold air." Does our model of the movement of heat and moisture and our ideas about how clouds and precipitation form, support this statement? Start your response with your statement you claim to be true, and then support your claim with both evidence and reasoning in your answer.

Our model does not support the claim that snow comes from canada along with cold air. Snow instead comes from the water vapor origionating in the Gulf of mexico. Snow is formed when water vapor in the air from the gulf of mexico condenses, which it only does when it is high in the sky. Cold air is denser than warm air, so the cold air sinks & fails to get high enough to form clouds, which precipitation comes from.