Eureka! Causal Thinking About Molecules and Matter

Rubric: Explaining cause-and-effect mechanisms about molecules and matter

Explaining cause and effect

Undeveloped	Beginning	Progressing
Students make scientific observations but may be limited in their ability to analyze data or draw a conclusion about a relationship between variables or a mechanism of causality. Students may overlook or ignore data to confirm a hypothesis.	Students make scientific observations and are able to analyze data so that a correlation, lack of correlation, and/or cause-and-effect relationship is described **or** student creates an explanation that provides a causal account of why phenomenon occurs.	**Multiple forms of evidence** are used to model and explain an underlying and unifying causal mechanism. Causality of why or how is articulated with multiple forms of **evidence and justification**. Quality and relevance of evidence are articulated. All evidence is considered; contrary evidence is not ignored.

Molecular models (Adapted from Merritt and Krajcik 2013)

Undeveloped	Beginning	Progressing
Model remains at the macro level.	Model uses particles (or molecules) to explain phenomenon but may not distinguish among different substances or the movement for all states.	Model represents a variety of substances (different particles) and represents the spacing and motion relevant to a particular state, including how movement changes as temperature or thermal energy changes.

Causal thinking

Undeveloped	Beginning	Progressing
Students are limited to intuitive or linear causal reasoning expecting step-by-step patterns of cause and effect; students may be biased to find a leader or central control system, purposeful encounters among components, and/or intentional causes for emergent patterns.	Students begin to talk about, write about, and model nonintuitive attributes such as how order or a group pattern can emerge out of random interactions; students may begin to notice that the overall property of a chemical system may emerge from many component interactions following rules outside the individual agents (they are system-level emergent properties instead of particle-level properties).	Students differentiate linear causal reasoning and nonlinear or emergent causal reasoning and begin to talk about the type of reasoning that best applies to different scientific processes.

Scientific discourse and negotiated meaning

Undeveloped	Beginning	Progressing
Group collaboration remains limited to dividing work, turn taking, or distributing tasks.	Students listen to, question, and respond to each other about the science content. With scaffolds, groups analyze and interpret data, discuss multiple forms of evidence, and talk about their reasoning and thinking.	Students talk about and find ways to reach consensus. Students socially reconstruct, alter, fine-tune, and defend their scientific explanations. Students initiate, direct, and fluently use the language and discourse of science without relying on scaffolds.

Lessons 1–3: Thinking Linearly About Volume

Materials (per group)

1 50 or 100 mL graduated cylinder
10–20 mL water
10 plastic centimeter cubes (available online; a Google search for "centimeter cubes" will turn up multiple vendors)
1 whiteboard or sheet of poster paper
1 set of markers

Vocabulary

causal mechanism
cause
cubic centimeter (cm^3)
direct
displacement
effect
evidence
explanation
graduated cylinder
linear
liquid
matter
milliliter (mL)
negative relationship
no relationship
positive relationship
reasoning
relationship
scatter plot
slope
solid
takes up space
units
volume

Activity Worksheets

Lesson 1: Comparing solid and liquid volumes

Work with your group to create a Venn-diagram poster comparing and contrasting solid volume and liquid volume. Brainstorm as many ideas, examples, measuring tools, phrases, and attributes as you can about solid volume and liquid volume. List all your ideas on the Venn diagram. You may pick up, observe, and talk about the cubic centimeters, graduated cylinders, and water to help you get started.

Display your poster. Tell the class which phrases were easy to place on the diagram and which phases were more difficult to place on the diagram. How did you reach agreement?

Lesson 2: Investigating the relationship between solid and liquid volumes

Discuss the following with your group: How could you use the graduated cylinder, water, and cubic centimeters to compare the volume of a milliliter and the volume of a cubic centimeter? On the back of your Venn-diagram poster, sketch and label a design for an investigation. What are the variables? How will you measure the variables? Which variable will be manipulated and which one will be responding? How will you collect and organize the data? After the teacher approves your group's plan, conduct your investigation. Each member of the group will record the data and use them to graph the relationship between milliliters and cubic centimeters. Each member will write a conclusion; use words from the word wall to label your graph and write your conclusion.

Lesson 3: Explaining the relationship between solid and liquid volumes
Discuss with your group and then individually explain the relationship between milliliters and cubic centimeters. What did you observe? Why did that happen? Why did it happen that way? Explain the cause of the relationship between milliliters and cubic centimeters. Could there be an alternate explanation for why it happened that way? What evidence supports your explanation(s)? Tell clearly why the evidence supports the explanation.

Role play with a partner
Take turns role-playing that you are a technician at a gems company that uses water displacement to measure the volume of irregular-shaped objects. Your company has a skeptical client who is not sure the procedure works to measure volume. You need to convince the client that your procedure is accurate. Use what you know about volume and the relationship between milliliters and cubic centimeters to explain why water displacement correctly measures volume. Use evidence from your investigation to explain why the procedure can be used to measure volume. Explain or show your reasoning. Tell the client why your evidence supports your explanation. You may use sentences, labeled pictures, diagrams, a chart, math, or a combination of these for your explanation. Use words from the word wall in your explanation.

Rubric

5 Data are analyzed to form evidence. The relationship between the variables (milliliters and cubic centimeters) is linked to the underlying causal mechanism and both are explained. Multiple forms of evidence are used to make a convincing explanation.

4 Data are analyzed to form evidence. The relationship between the variables is linked to the underlying causal mechanism and both are explained. Evidence is used to make a convincing explanation.

3 Data are analyzed to form evidence. The relationship between the variables is explained. The underlying causal mechanism is not well explained.

2 Data are analyzed to form evidence. The relationship between the variables is not well explained. The causal mechanism is not well explained.

1 Observations and data about volume are collected but data are not analyzed. The relationship between the variables and the causal mechanism is not well explained.

0 The response is missing or does not include observations about matter and volume.

Lessons 4–6: Moving Molecules and Emergent Thinking

Materials

2 9 oz. clear plastic cups or 50 mL beakers (per group)
2 1 gal. electric teakettles (per class)
2 1 gal. pitchers of ice water (per class)
2 0.25 oz. containers of food dye with built-in droppers (per group)
1 pair indirectly vented chemical splash goggles (per student and teacher)
1 set colored pencils (per group)
1 set of teacher-prepared attribute cards (per group)

Vocabulary

change
decrease
diffusion
evidence
food dye
freezing
increase
interaction
macroscopic
melting
model
molecular level
molecular model
molecular motion
molecules
prediction
substance
system
temperature
thermal energy
water (H_2O)

Activity Worksheets

Lesson 4: Collecting evidence in support of a molecular model

Let's find out what is happening at the molecular level in these liquids we are studying. The digital animation [*http://esminfo.prenhall.com/science/BiologyArchive/lectureanimations/closerlook/diffusion.html*] shows a representation of the diffusion of molecules of food dye added to molecules of water. Work with your group to make and analyze observations about the simulation. To do this, take turns reading a card and looking for observations of that attribute in the simulation. Which cards will you accept as evidence you can use to develop a molecular model? Observe and analyze the simulation. Collect cards in your envelope labeled "evidence" that can be used to support a claim about what is happening at the molecular level in the liquids. What will you do if you disagree about an observation or an interpretation of the observation? What actions, phrases, or questions might help you reach consensus?

Teacher information: Attribute cards
Directions: Prepare a set of cards for each group before the lesson. The phrases for the cards are listed below. During the lesson, each group is given a set of mixed cards to use while observing and analyzing the digital simulation. The digital simulation can be projected on a wall or screen so all students are able to make observations throughout the lesson. Students work in groups of three or four. Students take turns reading a card and leading the group to interpret the observations to decide if there is enough evidence to accept the card in support of a molecular model.

Phrases for which students may find observations that can be interpreted as evidence in support of a molecular model:

Cannot occupy the same space at the same time
Change direction
Close together
Collide
Contact
Decrease in speed
Different speeds
Different temperatures
Disordered (not in a pattern)
Do not follow a leader
Do things all at the same time
Far apart
Increase in speed
Interact
Molecular motion
Molecules
Molecules are displaced
Particle energized
Particles
Random movement
Same constant speed
System composed of particles

Phrases for which students may not find observations that can be interpreted as evidence in support of a molecular model:

Arranged in a pattern
Arranged in order
Carefully planned movement
Do things step-by-step
Follow a leader
Have a goal
Have a purpose
Have intention
New particles made
One-to-one correlation
Particle changes shape
Particle changes size
Particle gets bigger
Particle gets heavy

Particle gets rigid
Particle gets smaller
Particle is hard or soft
Particle is wet
Stop moving

Lesson 5: Investigating differences in thermal energy at the molecular level

Student procedure

1. Put on indirectly vented chemical splash goggles.
2. Obtain a cup of warm water and a cup of cold water.
3. Release one or two drops of food dye into each cup at the same time.

Discussion

What do you notice about the movement of the dye molecules? Watch the molecular-level simulation of diffusion. This time pay special attention to the differences between diffusion in the “warm” water and diffusion in the “cold” water. How does molecular evidence explain what you saw in the cups? Why did it happen that way? Are there alternate explanations?

Creating models

Use the evidence you collected during the simulation and placed in your evidence envelope and colored pencils to create a model. Work with your group to share and talk about your set of evidence; however, each student should sketch a model on paper. The model should show what happened in the investigation activity and include your best explanation about what happens at the molecular level to cause the differences between the two cups. Questions to ask yourself before you create your model: Which evidence will you include in your model? Which evidence is most important? How will you illustrate that evidence in your model? What other evidence is important? How will you show that evidence? What words from the word wall will you use to label your model?

Lesson 6: Explaining a change in state

Imagine that you show a coworker your molecular model about the dye in the different cups of water. The coworker says, “This model shows what happens when thermal energy is added to or removed from a substance.” Your coworker suggests that you could infer and extend your model to predict a change of state from liquid to solid. Add to your model. *Your addition should show your best explanation of what happens at the molecular level to cause a change from liquid to solid.* This means your addition will show a causal mechanism for freezing. Use labeled drawings, diagrams, and sentences to add to your model. Explain or show your reasoning on paper and in discussions with your group. While you are working on your model, meet with a partner in your group. Take turns role-playing with your partner the job of convincing a skeptical coworker that your model is correct. Tell your reasoning so you are able to convince a skeptical coworker that your model is correct. Use words from the word wall to label your model and in the language you use to defend your model. You may add to or revise your model after role-playing with your partner.

Rubric

5 Your model is labeled, is detailed, and shows molecular interactions. Your freezing model shows and explains all the important evidence from the investigation. Your model and explanation could convince a skeptical coworker. You explain your reasoning that links the evidence to your prediction.

4 Your model is labeled, is detailed, and shows interactions. Your model shows and explains most of the important evidence from the investigation. Your model shows freezing at the molecular level and includes your thinking or reasoning.

3 Your model is labeled and shows molecular interactions. You describe observations.

2 Your model is labeled and shows observations.

1 Your model may not be labeled. Your model does not show observations.

Lessons 7 and 8: Making and Defending Molecular Models

Materials
5 lb. dry ice per day
Gloves for handling dry ice (1 pair, for the teacher0
Hammer or ice pick for breaking the dry ice into smaller pieces
1 demonstration-size beaker (100 mL) of water with food dye (per class)
1 pair indirectly vented chemical splash goggles (per student and teacher)
1 whiteboard or sheet of poster paper (per group)
1 set of markers (per group)

Vocabulary
CO_2
dry ice
freezing
gas
liquid
molecular interactions
prediction
solid
solid carbon dioxide
state of matter
sublimating

Lesson 7: Making a group molecular model
As a group, discuss the model you each made in lesson 6. How are the models alike? How are the models different? How does each model represent the following:

• The macroscopic level?
• Different substances?
• Different states (solid, liquid)?
• Molecules?
• Different types of molecules?
• Molecular movement?
• Differences in molecular movement?
• Thermal energy?
• Temperature?
• Differences in temperature?
• Change over time?

Discuss as a group: What criteria are important when making and evaluating a molecular model? Share with the class your group's ideas about what is important for making and evaluating a molecular model.

Teacher information: Preparing the demonstration
1. Read, follow, and enforce all safety guidelines (see Resources) for handling and using dry ice. (Guidelines remind us not to touch the dry ice, to wear gloves when handling it, to wear chemical

splash goggles, and to ensure proper ventilation and air circulation wherever it is being stored, used, or transported. Do not store dry ice in a sealed container as the sublimating gas will cause the container to expand and possibly explode.)

2. Place the dry ice in a secure and well-ventilated location where students throughout the room can observe it.

3. Place three or four drops of dye in the beaker of water. Place the beaker in a secure location where students throughout the room can observe it.]

Student procedure

1. Put on indirectly vented chemical splash goggles.
2. Observe the dry ice sublimating in the demonstration.
3. Observe the water colored with food dye in the demonstration.

Discussion

What do you notice about the substances? What can you infer about the states of matter in the demonstrations? What can you infer about what is happening at the molecular level to cause the macroscopic patterns that you observe in these demonstrations?

Creating a group model

Over the course of this and the next lesson, you will create a group model of these substances. On the front of your poster board you will sketch "before mixing." Then you will write a prediction on the poster. Finally, you will make a sketch representing "after mixing" on the back of the poster or individually as an assessment.

Before mixing

Use the evidence you collected during the simulation and placed in your evidence envelope and markers to sketch and label a group model on half of the poster board. This model can be labeled "Before Mixing" and should include a molecular model of the water with the dye in the beaker and a molecular model of the dry ice (solid carbon dioxide) sublimating. This model should include your best explanation about what happens at the molecular level to cause the macroscopic patterns that you see. Work with your group to represent each of the items below in your model:

- The macroscopic level
- The submicroscopic level
- Different substances (food dye, water, carbon dioxide)
- Different states (solid, liquid, gas)
- Molecules
- Different types of molecules
- Molecular movement
- Differences in molecular movement
- Thermal energy
- Differences in temperature

Lesson 8: Using molecular models to make and defend predictions

Prediction

Discuss with your group and write a prediction on the second half of your poster board. Label it "Prediction." What do you think will happen when the dry ice is added to the liquid? Why? What is your reasoning? What is the causal mechanism that you used to make your prediction? Explain.

[*Teacher information:* A station is set up to display each poster in the classroom. Students take turns presenting and defending their models and their predictions to other groups. Students rotate around the classroom taking turns being presenters and being listeners.]

When it is your turn, defend your model and prediction. When you defend your model, imagine that someone is skeptical. How would you convince the skeptic that your model correctly represents these substances and states of matter? What is your evidence? Why is your evidence convincing? Defend your prediction. What evidence and reasoning supports your prediction?

After mixing

[Teacher information: Preparing the demonstration

1. Read, follow, and enforce all safety guidelines (see Resources) for handling and using dry ice.
2. Use a hammer or ice pick to break off a piece of dry ice about the size of a golf ball. Gently add the piece of dry ice to the beaker of colored water. Place the beaker in a secure and well-ventilated location where students throughout the room can observe it.]

Student procedure

1. Put on indirectly vented chemical splash goggles.
2. Observe the demonstration.

Discussion

What do you notice about the substances? What can you infer about the states of matter in the demonstration? What can you infer about what is happening at the molecular level to cause the macroscopic patterns that you observe in this demonstration?

Creating a model

On the back of your poster board, as a group, sketch a molecular model representing "after mixing." Alternately, your teacher may ask you to create a model individually on a piece of paper that will be used as an assessment. Use the rubric below to help plan and revise this model.

Rubric

5 The model is labeled, is detailed, and shows molecular interactions. The model correctly shows molecules in three states of matter. The model explains the cause of phase changes using evidence from the investigations. The model explains how all the relevant evidence fits together. The explanation is convincing and tells why the observations count as evidence.

4 The model is labeled, is detailed, and shows molecular interactions. The model correctly shows molecules in three states of matter. The model explains the cause of phase changes using evidence from the investigations. The model shows and explains how multiple sources of relevant evidence fit together. The explanation is convincing and tells why the observations count as evidence.

3 The model is labeled and shows molecules. The model shows states of matter. The model shows at least one source of supporting evidence or observation.

2 The model is labeled. Observations or examples may not be relevant or fit together.

1 The model does not show scientific observations. Labels are missing.

Note: At the middle school level, students typically progress to understand that matter is made of different particles, that the spacing and motion of the particles are relative to a particular state, and that movement of the particles change as temperature or thermal energy changes. For a more advanced molecular explanation of how the fog is produced when dry ice is place in water see Kuntzleman, T.S., N. Ford, J. No, M.E. Ott. A molecular explanation of how the fog is produced when dry ice is place in water. *Journal of Chemical Education*. Published online July 11, 2014.