



ADVICE ON LEADING STUDENTS TO A DEEPER UNDERSTANDING OF THE THREE STATES OF MATTER

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ABSTRACT: The following is an activity that utilizes the learning cycle to actively engage students in constructing a deep understanding of the states of matter. Students initially explore properties of solids, liquids, and gases through concrete experiences with familiar materials. Science jargon is appropriately delayed until after students have accurately interpreted their experiences. During the application phase students employ their knowledge of the states of matter to investigate the characteristics of an unusual substance to try to identify its state of matter. Key nature of science ideas are explicitly addressed throughout the activity. *This article promotes National Science Education Standards A, B, and G, and Iowa Teaching Standards 1, 2, 3, 4, 5, and 6.*

Understanding basic properties of matter is an important physical science concept (National Research Council, 1996). When students acquire a deep understanding of states of matter, teachers can more readily help students scaffold to complex concepts such as energy transfer, physical and chemical properties and changes, and pressure. States of matter are often quickly addressed in physical science classrooms before students have developed a working understanding of these fundamental ideas. Identifying substances as solid, liquid or gas is typically intuitive to science teachers and students. However, understanding the unique properties that characterize these three states of matter is a much more challenging task. The learning cycle can be used to help

students explore and apply important concepts such as shape, volume, and compressibility in relation to the states of matter.

The Role of the Teacher

Appropriate teacher behaviors are crucial for helping students develop criteria that help identify states of matter. Embedded in the following activity are examples of thought-provoking, yet guiding, questions that require students to express their thinking and identify characteristics useful for categorizing states of matter. We encourage student participation through the use of welcoming nonverbal behaviors, student-centered responses, using student ideas during discussion, and using appropriate wait time I (the time

after we ask questions) and II (the time we wait after students have responded). We do all this to draw out students' ideas and help students scaffold from their initial interpretations to the desired understanding.

Shape, volume, and compressibility are properties of matter that help define the state, but the terms themselves are not required knowledge during the exploration phase. Instead, we use students' words to demonstrate that their ideas are welcome and move toward the desired science vocabulary. Importantly, we ask for clarification of words that students use when describing properties to ensure that both we and the students understand the language they use.

Teachers cannot hide from the often uttered student question, "Do we have to write this down?" Explain to students that their investigation of the states of matter will not end after this activity, for they must identify unique characteristics of each state of matter and use that knowledge to investigate the properties of an unknown substance. We ask students questions such as:

- As you investigate the properties of substances in the future, what might you want to do to ensure that you remember what you are finding today?
- How could you communicate your findings to others?
- What information might be necessary for you to understand the results of this investigation in the future?

These questions help students make appropriate decisions and understand the rationale behind those decisions. Additionally, they assist students in organizing their thoughts.

Exploration Phase

Helping students construct a deep understanding of the characteristics of states of matter begins with a key set of developmentally appropriate concrete experiences. We first have students explore specific properties of various substances we have located. Materials which work well include marbles, coins, action figures, inflated balloons, deflated and inflated basketballs, colored water, and clear containers of various shapes and sizes. Approaching this investigation as a class provides a comfortable environment for students to trade ideas in their own words.

Exploration of Shape

Pass various examples of solids, liquids, and gases around the room and ask students to make some initial observations about the shape of the substances. Encourage students to place the solids and liquids into many different containers and ask questions such as:

- How does the shape of the substance change when placed into different containers?
- What determines the shape of the substances?

Students may have a narrow definition of what a container is

and may not realize that the balloons and even the classroom could be considered a container. When students have proposed that the shape of liquids is determined by the container, challenge students by asking them to predict the shape of the water if it is poured on to the floor or desk. Pour the water on to a desk and ask students:

- How can you account for the change in the shape of the liquid?
- What container is now determining the shape of the water?

The key here is to ask questions that help students come to the realization that liquids take on the shape of the part of the container that they occupy and have a flat surface.

Contrast the shape of gases from solids and liquids by manipulating inflated balloons to demonstrate how gases completely fill their container taking on its shape and volume. Ask students to explain how a balloon stays inflated. Encourage students to examine the balloon and try to change the shape of the air inside. Pose such questions as:

- How could you change the shape of space that the gas occupies?
- Why must you change the shape of the balloon to change the shape of the gas?

Build on the idea that the classroom is a container, and encourage students to consider what will happen to the shape of the gas if the balloon is popped.

Students may naively conclude that the air disappears once the balloon is popped. This misconception may stem from the fact that air cannot be seen and that students may think that gases have no mass. Challenge this idea by contrasting the mass of a deflated basketball, and the same basketball fully inflated. Using basketballs works better than the more common balloon demonstration because its buoyancy in air is not as significant as that of a filled balloon. The point here is to illustrate that the gas in a previously enclosed object now takes the shape of its new container, whatever that may be.

Exploration of Volume

Next, ask students to consider the amount of space a substance or object takes up. Again, encourage students to place solids and liquids in different containers and make observations. Students quickly realize that solids are able to maintain their own volume in addition to shape, but may have difficulties interpreting the volume of liquids. Ask students,

- What do you observe about the amount of water when it is poured into different containers?
- What do you observe when you place the water back in its original container?

Students may think that the volume is changing because the level of water appears higher or lower in different containers. Address this misconception by challenging students to develop a method to test whether or not the volume of the water is changing when placed in different containers. For instance, students often suggest measuring a known amount of water and placing that same amount of water in a variety of containers.

Using examples such as the balloon and basketball, ask students to consider the following:

- How much space do solids occupy? How can that volume be determined?
- How much space do liquids occupy? How can that volume be determined?
- How much space do gases occupy? How can that volume be determined?

If some students suggest that gases do not take up space, ask them to consider the differences between a deflated and inflated basketball and explain how it is possible that the ball maintains its shape. Ask students to recall their explanation of how the shape of gases changes depending on the container and predict what might happen to the amount of space a gas takes up when the container changes. If students are having difficulties understanding the idea that gases completely fill the volume of a container ask questions such as:

- Without seeing someone baking, how do you know that cookies are being made?
- How does the smell of cookies get from the oven to your nose?

Exploration of Compressibility

Compare the ease of compressing gases to the difficulty of compressing liquids and solids. Students tend to believe that liquids are easy to squeeze and be made smaller. Ask students to try to push down water in a large container with their hands. A closed syringe filled with water also demonstrates the idea that liquids cannot be easily compressed. Use the syringe again, but only containing air, to illustrate the ease of compressing gases.

Encourage students to squeeze their desks or textbooks to consider the ease of compressing solids. Students may question the validity of solids not being easily compressed, citing examples of stuffed animals, foam materials, or cotton balls. If students do not address this idea challenge students by asking:

- What happens when you squeeze a cotton ball or stuffed animal?
- How do you explain the ease of making these objects smaller?

If students do not understand that these solid materials have

many air spaces that are actually being compressed, have them view these objects under a microscope to view the air spaces between cotton and foam fibers.

Content Introduction Phase

The characteristics used to classify solids, liquids and gases are not explicitly addressed until after students have thoroughly explored the three states of matter as described above. Having direct experiences precede verbal instruction significantly helps students make desired connections to abstract descriptions (Colburn & Clough, 1997). Help students come to the desired generalizations regarding characteristics of solids, liquids and gases by asking questions that have students refer back to the explorations:

- Using your experiences in our explorations, what are some categories that might help in characterizing solids from liquids and gases?
- For each category, what are the characteristics of solids, liquids and gases?

With further questioning and using students' experiences and ideas, a chart like that appearing in Figure 1 will emerge.

Application Phase

In order to accurately assess students' understanding of concepts and extend their understanding, students must be presented with novel situations to apply their understanding in a different way (Colburn & Clough, 1997). During the application phase students are presented with a unique substance that requires their investigation in order to try to determine the substance's state of matter. We use a previously prepared mixture of cornstarch and water, often referred to as oobleck. Some students have previously experienced activities that refer to "oobleck," so to maintain the novelty of this activity give the gooey mixture a new name (or ask students to name the mixture).

Introduce students to the unique mixture as a substance that was recently produced in a local laboratory. Scientists recognize the value of investigating the properties of substance, and have sent a portion of the substance to our classroom and asked for your assistance in determining its state of matter. Tell students that the scientists believe the substance to be safe to handle, but like all laboratory investigations, safety precautions are to be followed (e.g. wear safety goggles, never taste substances, etc.).

Students work in groups of two to explore the properties of the unknown substance. Groups are responsible for determining their investigation procedures and asking for materials and approval of procedures. Anticipate the need of access to a freezer and microwave. Encourage students to refer to their notes from the exploratory activity and the table of characteristics they created to help them in the process. Promote students' development of creativity during the lab by encouraging students to develop their own methods of investigation. Science can be messy, but remind students

that it should always be done safely.

Be very clear that the purpose of the activity is not simply to reach a conclusion about the state of matter of the unknown substance, but for students to thoroughly support their conclusions using evidence and reasoning. During students' initial observations ask questions such as:

- What are you observing about the substance at room temperature?
- How can you manipulate the substance to investigate its properties?

Anticipate several challenges and misconceptions to surface during students' investigations. Students may focus on what the substance is made of instead of investigating its properties. Direct students' attention back to the purpose of the activity by asking:

- How could information about what the substance is made of help you investigate the substance's state of matter?

Students may become frustrated during investigations because the substance exhibits properties of both solids and liquids. Address such frustrations by revisiting the cotton ball and stuffed animal scenario and ask students to consider how they further investigate this unknown substance.

Expect students to need guidance when interpreting their results. Do not tell students what conclusions should be made from their investigations, but pose questions to help students consider all aspects of their methods. A common misconception among students is presented when using the freezer or microwave to manipulate the substance. Upon freezing or microwaving the substance it becomes hard and exhibits characteristics of solids. Because of this, students typically conclude that the substance is a solid without considering its state at room temperature. Encourage students to compare and contrast the characteristics of the oobleck before and after they put it in the freezer or microwave. We ask questions such as:

- How do you account for the changes in the properties of the substance before and after you put it in the microwave?
- Because you have observed a change in the properties of the substance what does that indicate to you about its state of matter at room temperature?

Assessment

We have students convey their understanding of states of

FIGURE 1
Characteristics of Gases, Liquids, and Solids

	SOLIDS	LIQUIDS	GASES
volume and shape	retains a fixed volume and shape	takes on the shape of the part of the container that they occupy; flat surface	takes the shape and volume of its container
compressibility	not easily compressible	not easily compressible	compressible

matter by writing a short report explaining their methods of investigation, interpretation of the results of their work, and suggesting the state of matter of the unknown substance. Students should include all of the tests that their groups performed and describe the physical properties of the unknown substance. Students are expected to support their conclusions with a sufficient rationale. An appropriate rationale is one in which conclusions are supported by sufficient interpretations and the student makes accurate connections between characteristics of the states of matter and their investigations (Figure 2). A poor rationale does not contain appropriate interpretations and does not accurately reflect the connection between investigations and the central ideas of shape, volume, or compressibility (Figure 3).

FIGURE 2
Example of a student who is able to accurately apply their understanding of the states of matter.

Test

The substance was left exposed to the air for 48 hours.

Observations

The original substance spread out and conformed to the shape of the plate. After exposure to the air for 48 hours, the substance became dry.

Interpretation

At room temperature for 48 hours, the substance takes on a fixed shape and volume that is not easily compressed.

Conclusion

The substance is a solid.

FIGURE 3
Example of a student who does not have a good understanding of the states of matter or cannot accurately apply their understanding.

Test

The substance was placed on a small plate and microwaved for 30 seconds.

Observations

The substance became hard when microwaved.

Interpretation

Solids are hard.

Conclusion

The substance is a solid.

Connections to the Nature of Science and other Science Content

Following the application phase, we hold a class discussion to focus on students' results and conclusions, characteristics of states of matter, and ideas regarding the nature of science. Students share and explain their conclusions on the state of matter of the unknown substance. Groups often come to different conclusions regarding the state of matter of the unknown substance. We encourage students to consider how the class could examine the same phenomenon, but report different results. Pose questions that encourage students to consider the creative and inventive natures of scientific research:

- How did you use your prior knowledge during your investigations?
- In what ways were you creative during your investigations?
- What is bothersome about coming to different conclusions?
- How do scientists address conflicting conclusions?

We have students reflect on the different tests that were done and the conclusions that were reached. Returning to the lab often results in consensus being reached that the unknown substance, when dried, is a solid. However, when hydrated, the situation is far more complex and characteristics of both solids and liquids are observed.

Later in the school year, when physical and chemical properties are thoroughly understood, students can be referred back to this activity to determine what liquid is driven off by evaporation. Explicitly revisiting content and addressing key nature of science ideas will enhance students' understanding of the nature of science and provides for another opportunity to draw out misconceptions as well as reinforce students' understanding of the states of matter.

References

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