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Connecting the Visible World with the Invisible: Particulate Diagrams Deepen Student Understanding of Chemistry

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CONNECTING THE VISIBLE WORLD WITH THE INVISIBLE

Particulate diagrams deepen student understanding of chemistry

Thomas Pentecost, Sarah Weber, and Deborah Herrington

Research suggests that connecting the visible (macroscopic) world of chemical phenomena to the invisible (particulate) world of atoms and molecules enhances student understanding in chemistry (Birk and Yezierski 2006; Gabel, Samuel, and Hunn 1987; Johnstone 1993; Nakhleh 1992). This approach aligns with the science standards (see box, p. 58) and is fundamental to the redesigned AP Chemistry curriculum. However, chemistry is usually taught at the abstract symbolic level, rarely incorporating particulate-level instruction. This article addresses that shortcoming by describing how to use particulate diagrams in a chemistry course.

Why particulate diagrams?

Using particulate diagrams in such topics as nature of matter, chemical/physical changes, ionic compounds, balancing equations, colligative properties, and acids/bases enhances students' critical-thinking skills as they experience the science and engineering practice of Developing and Using Models. Instead of simply memorizing vocabulary words or solving problems with math, students learn to accurately represent an element or chemical equation, interpret these representations, and use them to explain or predict phenomena.

Students in both college-prep and regular chemistry classes participated in the following activities, using particulate diagrams in class and lab activities. The diagrams were incorporated into pre- and post-assessment, lab questions, and explanations given in class. Figure 1 lists examples of their implementation. Detailed student and teacher guides and supplemental materials for all the activities described in this article are available online (see "On the web").

FIGURE 1

Examples of activities using particulate diagrams.

Type of activity or assessment	Example
Pre-assessment	Before any material was covered, students were asked to provide a particulate representation, definition and example of element, mixture, and compound.
Class activity: Change you can believe in (physical and chemical properties)	Students were asked to look at several different particulate representations and classify them as physical or chemical changes.
Lab activity: Freezing point depression (colligative properties)	Students generated particulate diagrams of solutions of various salts. These diagrams were used to interpret freezing point depression data collected in lab.
Post-assessment (elements, compounds, and mixtures)	After completing a lab activity where students had to classify both macroscopic and particulate representations of matter (Classifying Chemical Substances Oh My!), students were asked to complete the same task as the pre-assessment.

FIGURE 2

Early student efforts to produce particulate diagrams for element, compound, and mixture.

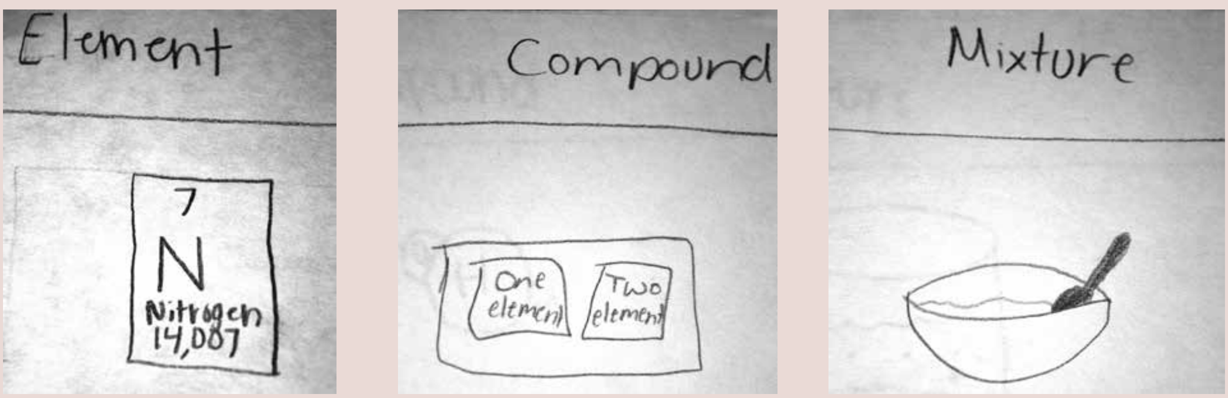
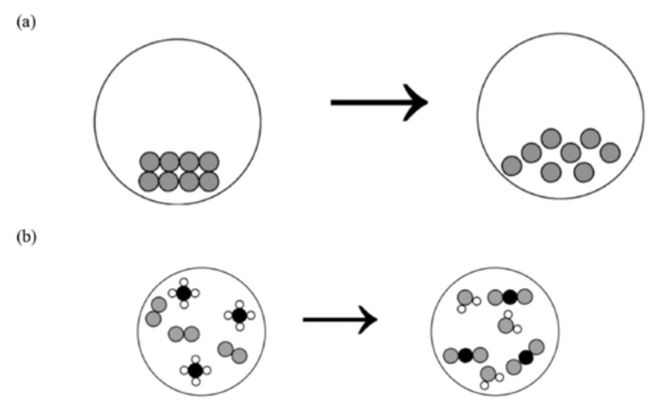


FIGURE 3

Examples of particulate-level physical (a) and chemical (b) change representations. The physical change was melting, and the chemical change was combustion.



Pre-assessment

At the beginning of the school year, before instruction, students were asked to produce a definition, particulate diagram, and an example for the terms *element, compound,* and *mixture* (Figure 2). Many students remembered partial definitions from previous instruction but most could not draw reasonably accurate particulate diagrams. Most represented these concepts at the macro level rather than showing atoms and molecules.

Class activity: Change you can believe in

A good way to introduce the activity of drawing particulate diagrams is having students evaluate existing particulate diagrams first, before drawing their own, early in the year. Accordingly, in this activity, students classify various existing particulate diagrams as depicting either physical or chemical change and must justify their classification (examples, Figure 3). In a class discussion afterward, students consider key features that distinguish a physical from a chemical change. Students also were asked to match the particulate diagrams to "real world" situations such as rusting iron, steam locomotives, and the use of sodium bicarbonate in baking. As an assessment, students drew their own particulate diagrams for a given chemical and physical change.

Lab activity: Freezing-point depression

Using particulate diagrams in the laboratory requires students to connect the macroscopic level of chemistry—observable in experiments—to the chemistry occurring at the particulate level. The topic of colligative properties, which depend on the ratio of the number of solute particles to the number of solvent molecules in a solution, provides an excellent opportunity to connect the different scales of these two levels of chemistry.

In this activity (see "On the web" for details), students are guided through the creation of particulate diagrams for various solutes (both ionic and covalent) dissolved in water. They then as a class determine a method for collecting freezing point data for each of these solutions and are asked to look for patterns between the change in freezing point and the number of dissolved solute particles per unit mass of water. In this way students use their particulate diagrams as the basis for explaining their data.

This explanation can be generalized to other colligative properties so that instead of just memorizing a definition for the vocabulary term *colligative properties,* students have constructed a relationship between the number of particles in solution and the change in the property. The key is students connecting the particulate level diagrams they created and the data they collected. Another way of making this connection is to ask the student to predict, based on their drawings, which solution would have the greatest change in freezing point. Thus, particulate-level models can serve as a predictive tool.

Post-assessment

After completing the above activities, students were asked to complete the same task as the pre-assessment given at the beginning of the year—creating particulate diagrams, defining, and giving examples of an *element, mixture,* and *compound.* This time, the students' particulate diagrams (Figure 4, p. 56) demonstrated a deeper understanding of these terms; their diagrams no longer represented only the macro level.

Assessing particulate diagrams

To assess particulate diagrams, we developed a rubric based on other published rubrics (Merritt and Krajcik 2009). The general rubric in Figure 5 (p. 56) is adaptable to any assignment involving a particulate diagram. Teachers need only to identify the major and minor aspects they wish to see in the student drawing. In the diagrams of elements, compounds, and mixtures, for example, we wanted the particulate diagrams to represent matter as being made up of atoms and to show how these atoms are arranged in elements, compounds, and mixtures. For elements, students could draw circles to represent individual atoms; for compounds, the student should show atoms combined in correct ratios. A minor aspect in a drawing of a mixture would be an indication that substances are mixed rather than discrete.

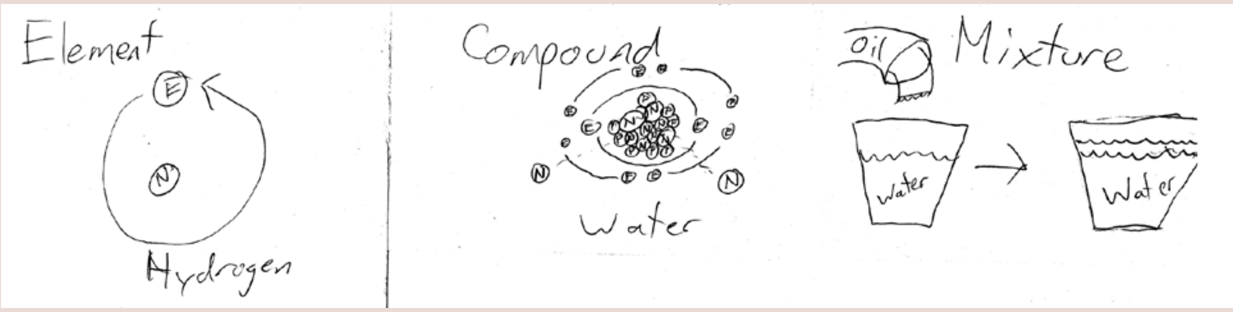
Results

To measure the change in students' ability to think at a particulate level, we administered the Particulate Nature of

FIGURE 4

Comparison of a student's responses when asked to produce a particulate diagram for the terms *element, compound,* and *mixture.*

a) Beginning-of-year example:



b) End-of-year example:

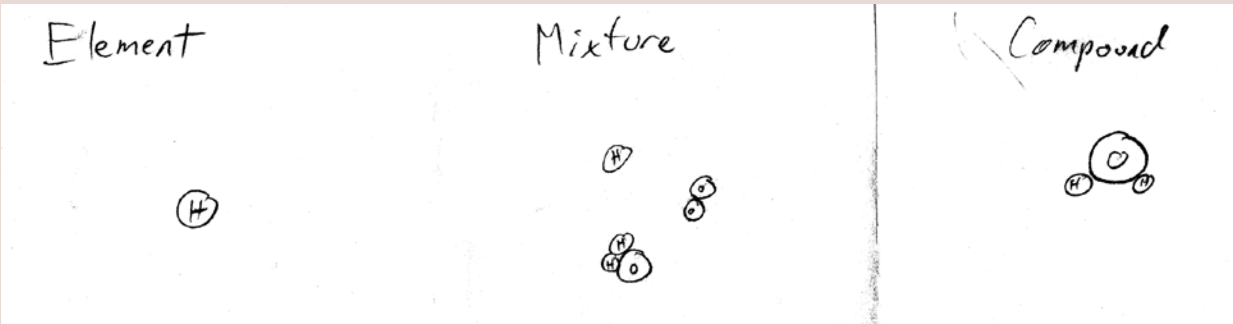


FIGURE 5

General rubric for particulate representations.

Rubric Score	Rubric Description
0	No drawing Student description is only in words/symbols Shows wavy lines/continuous matter
1	Shows particles but does not attend to the following important feature (changes with assignment/assessment):
2	Shows particles but does not attend to the following minor features (changes with assignment or assessment):
3	Provides correct particulate representation that attends to all the important and minor features.

FIGURE 6

ParNoMA score changes during the school year.

ParNoMA Administration	Mean (N=51)	Stn. Dev.
First Week	9.37	0.59
End of First Semester	11.18	0.67
End of Second Semester	13.02	0.65

Matter Assessment (ParNoMA) (Birk and Yezierski 2006) three times during the school year (summary of scores, Figure 6). Analysis indicates the differences in scores were statistically significant. To further assess student learning, we evaluated the pre- and post-assessment element, mixture, and compound drawings of 10 students, using the rubric (results summarized in Figure 7).

At the beginning of the year, many of the student diagrams did not contain particulate representations but rather other drawings such as a square on the periodic table, a beaker containing dots, a drop of water, or electrons around a nucleus. Their final diagrams were greatly improved. When we reduced scores, it was generally due to small mistakes in their definition of element, mixture, or compound, which they were asked to write in addition to the particulate diagram. Diagrams generally illustrated the correct bonding for compounds and a clear and correct difference between an element and a compound.

Conclusion

Assessments showed that students' ability to use and understand particulate-level thinking improved over the school year. This ability developed through repeated use of particulate models in different chemistry topics. Teachers reinforced particulate thinking with physical models and computer simulations in the classroom and by asking pointed questions about the features students chose to include in their drawings. Having students create particulate diagrams provided insights into their level of understanding that are generally unavailable via other assessment methods. (Teachers also were careful to discuss the limitations and simplifications that are inherent in particulate drawings, as in all models [Harrison and Treagust 1998]).

The most daunting aspect of incorporating particulate diagrams was scoring them. Having a flexible scoring rubric, however, made this less onerous. The benefits of using the particulate diagrams far outweigh any added effort needed to score them. ■

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On the web

Student and teacher guides and supplemental materials for all activities in this article: *www.gvsu.edu/targetinquiry* (free registration required).

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FIGURE 7

Rubric results pre-and post-test (scores out of 3).

Student	Pre-test score	Post-test score
1	0	2.5
2	0	2.5
3	0	2.5
4	0	2.5
5	0	3
6	0	2.5
7	0	2.5
8	0	2
9	1	2
10	0	3

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
MS-PS1 Matter and Its Interactions
HS-PS1 Matter and Its Interactions

Performance Expectation
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures. (Note: Although this is a middle school performance expectation, we find that high school students have difficulty developing particulate-level models of atoms and molecules and their interactions and structures.)

Dimension	Name and *NGSS* code/citation	Specific connections to classroom activity
Science and Engineering Practice	Developing and Using Models • Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.	Students draw particulate diagrams (models) to explain what they see at the macroscopic level. Students use particulate-level diagrams to help identify patterns in lab datas. Students classify particulate diagrams as representing a physical or chemical change.
Disciplinary Core Idea	**PS1.A: Structure and Properties of Matter (MS)** • Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. (MS-PS1-1)	Students create particulate diagrams for various chemistry concepts such as element, mixture, and compound. Students illustrate the differences between how ionic and covalent compounds dissolve in water using particulate diagrams. Students analyze particulate diagrams to show the difference between chemical and physical changes. Students illustrate chemical reactions in particulate diagrams when balancing equations.
Crosscutting Concept	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students use particulate diagrams to recognize patterns in various chemical reactions or situations, for example, colligative properties.