General Chemistry Students' Perceptions of the Particulate Nature of Matter in Different Physical States

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Background

According to Johnstone's Triplet Theory, chemistry can commonly represented at 3 levels: macroscopic, sub-microscopic or particulate, and symbolic (Johnstone, 1991).

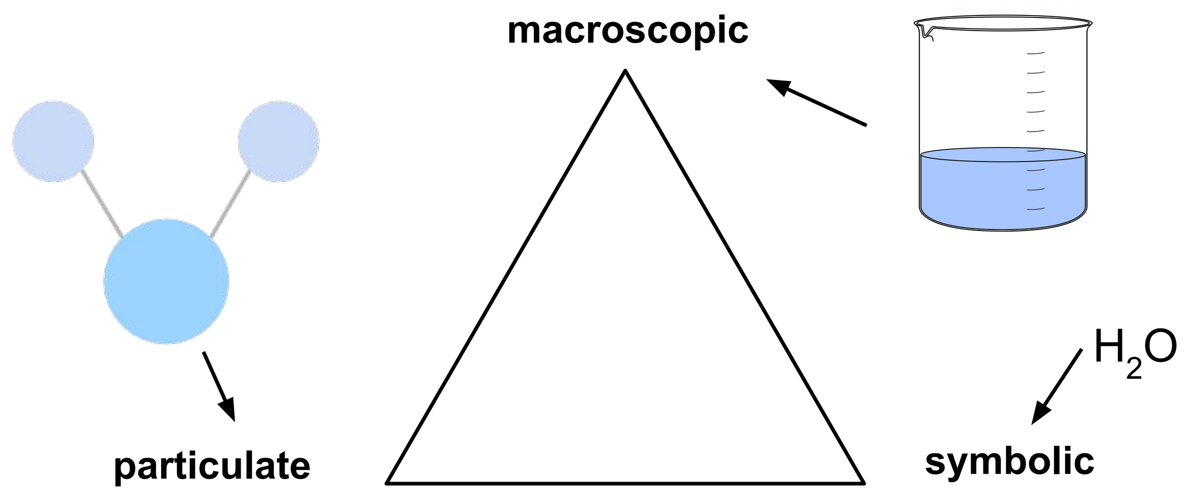


Figure 1: Johnstone's Triangle with water examples

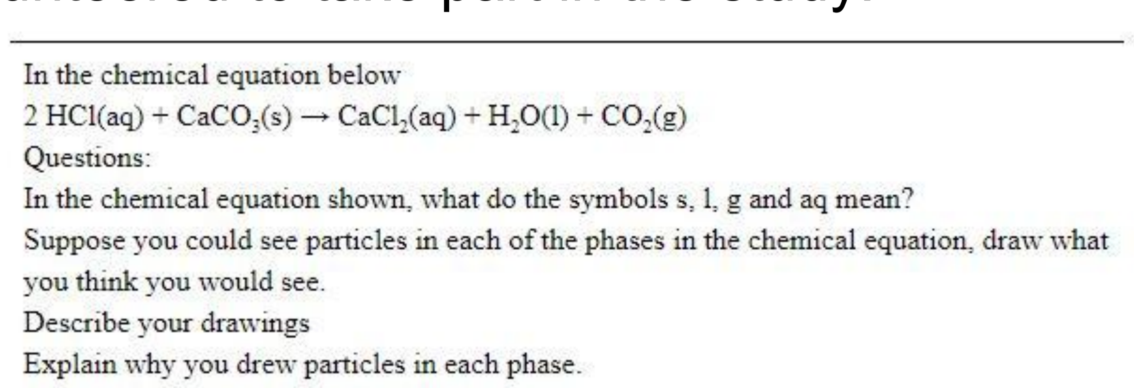
Understanding chemistry requires one to fluently navigate all three levels, but students tend to struggle with the particulate level the most.

Particulate Nature of Matter

The particulate nature of matter (PNM) is a central concept to the teaching and learning of science (Harrison and Treagust, 2002) and understanding chemistry (Yezierski and Birk, 2006). By the time that students leave secondary school, they are expected to have a firm understanding of PNM (American Association for the Advancement of Science, 1993). Using particulate level drawings and interviews to elicit student understanding of chemistry is a common approach in chemistry and science education, but there are not many studies that actually combine the two techniques.

Methods

The study took place in a second semester General Chemistry class. Ten students volunteered to take part in the study.



In the chemical equation below

$2\,HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Questions:

In the chemical equation shown, what do the symbols s, l, g and aq mean?

Suppose you could see particles in each of the phases in the chemical equation, draw what you think you would see.

Describe your drawings

Explain why you drew particles in each phase.

Figure 2: Interview prompt

During the interview had started, students were asked to envision themselves able to see individual particles and then answer the questions from this perspective. Follow up questions were also asked to probe each student's understanding further.

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Data Analysis

Each participant's transcribed interview data was used alongside the corresponding drawings and analyzed based on three criteria:

- Drawings depict the appropriate orientation of particles in each of the phases.
- Descriptions of drawings were checked for conceptual accuracy and consistency
- Correct reasoning for the orientation of particles as drawn

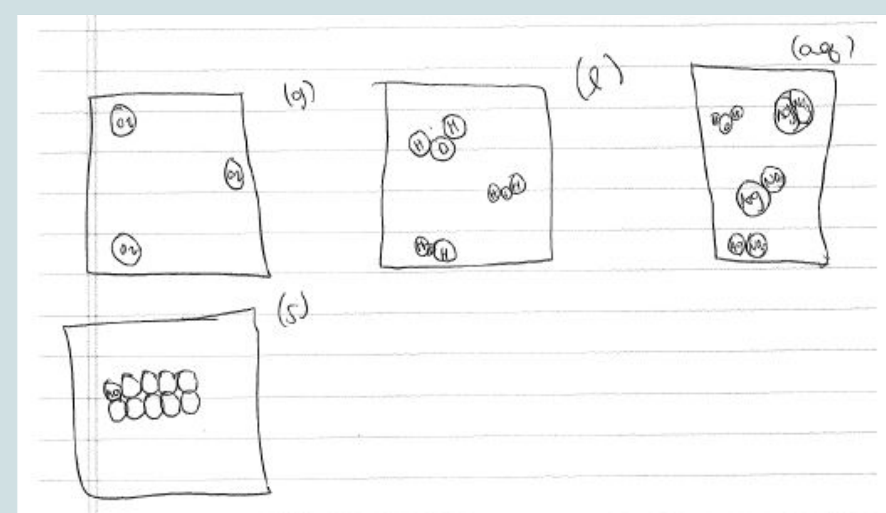

Figure 3: Drawings from student

- Decreased space between the particles in higher order compared to lower order states.
- No dissociated ions or charges in the aqueous drawing.
- Particles in the solid state drawing are touching.

Drawings

The drawings were coded either correct or incorrect based on particle spacing in *l, s,* and *g* phases, and dissociated, hydrated ions in the aqueous state.

Physical State	Number of pictures	Correct	Incorrect
Gas	10	10	0
Liquid	9	9	0
Solid	10	10	0
Aqueous	6	4	2
Total	35	33	2

Table 1: Table of drawings

Common incorrect features that were not included in the student drawings were:

- no space between solid particles
- no water particles in aqueous drawings

Descriptions

- None of the participants provided a completely accurate description
- The aqueous phase was as problematic to describe or define as it was to draw for all participants.

"Aqueous, that is when a compound is not dissolved in water but it is sort of in between solid and liquid like it is really small pieces like its ions are like floating in water so it is not quite a solid and not quite a liquid."

Explanations

Common reasons that were given for the difference between the gas, liquid, and solid phase include:

- Kinetic energy
- General reference to energy
- Temperature
- Density

"Temperature changes the density of the, like, particles in most states in a certain area...When temperature is higher, the density gets, like, more, like, dense, you know."

Discussion and conclusions

- The majority of students seemed to understand the arrangement of particles in the gas, liquid, and solid state. However, they were not always able to explain particle arrangement.
- The aqueous state was most problematic for students in all three sections of the study.
- When drawings, descriptions, and explanations were considered together, most of the participants lacked consistency in their understanding.
- Some students used macroscopic reasoning in sub-microscopic contexts, both consciously and unconsciously.
- Few students referenced the kinetic molecular theory when asked about the difference between physical states.
- Academic language (chemical vocabulary) was not always used appropriately. This shows that students are not fully understanding certain concepts.

Implications

- Students hold both correct and incorrect 'pieces' about the various phases of matter. It is important to identify and address the incorrect ones.
- It is necessary to ascertain students' prior knowledge and plan instruction accordingly.
- How we assess our students is as important (if not more important) as how and what we teach.
- Although challenging, interviews can be an effective way of assessing students.

Future Work

- The intersection of linguistics and comprehension of fundamental chemistry concepts
- Progression of understanding of physical states from middle school to college

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