An Investigation into Students' Interpretations of Submicroscopic Representations

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Abstract: Applying a particulate model of matter requires learners to translate among several levels of representations–macroscopic, microscopic and symbolic. Successful instruction and assessment require that students properly interpret representations. As part of the development of validated assessments to place students along a learning progression, this study explores how students' interpretations of representations change and affect their responses to items as they progress through the science curriculum. We find that different representations may enhance different alternative conceptions.

A particulate model of matter provides a basis for understanding the structure and behavior of matter, and enables learners to explain a vast number of phenomena. Applying a particulate model requires learners to translate between the macroscopic representations of the phenomena that they can experience in their daily lives, and submicroscopic representations (e.g., molecules, atoms) that explain what is happening at the molecular level, as well as representations such as chemical symbols, formulas, and equations (Harrison & Treagust, 2002). The abstract nature of submicroscopic representations and symbolic representations make it difficult for students to connect them with macroscopic phenomena (Griffiths & Preston, 1992). When students first begin developing a particulate model of matter, they tend to focus on phenomena involving molecules (e.g., water in different phases; how smells travel). The terms particle and molecule are often used interchangeably to describe molecules, while individual spheres, multiple spheres or multi-lobed figures, may be used to represent them. As students progress, they are expected to be able to transfer between more types of submicroscopic representations (e.g., Lewis structures, space-filling models, ball-and-stick figures).

The larger goal of our project is to develop assessments that place students along a learning progression (LP) for the nature of matter, which focuses on the structure, properties and behavior of matter (Stevens, Delgado, & Krajcik, in press). In order to create validated assessments, it is critical that students understand the item, which includes correctly interpreting the meaning of the question, the answers and any associated representations. Extensive learning research has focused on how students use and translate between the three types of representations required to explain phenomena using a particulate model (e.g., Keig & Rubba; Kozma & Russell, 1997). We extend this work by investigating students' ability to translate among different submicroscopic representations and how those interpretations affect their thinking. This work will inform assessment and curriculum materials development linked to students developing a particulate model of matter.

Methods

We developed assessment items to measure how well students apply ideas within and across topics to explain phenomena involving transformations of matter following the Construct-Centered Design process (Stevens et al., in press). The items were validated through rounds of internal and external review, followed by collection of student data. To ensure that students interpret the questions and representations as intended, the items were each accompanied by a set of questions (e.g., Was the question clear? Were there any words that were confusing? What does the picture represent? DeBoer, et al., 2008). Each item will be piloted with students of grades 6-14. Semi-structured interviews with a subset of students supplemented this data. We will also investigate the range of representations students connect with atoms and molecules over grades 6–14 using a written survey.

Results and Discussion

Tests and textbooks often use multiple submicroscopic representations for atoms and molecules, and we questioned whether students can readily shift between them. To this end, we created four versions of an item designed to measure students' submicroscopic models of the solid, liquid and gas states of water. The four versions contain the same four answer choices that are represented differently (version **1**–molecules as spheres and ice represented as a close-packed lattice [CPL]; version **2**–molecules as spheres, and ice represented as a hexagonal patterned lattice [HPL]; version **3**–molecules as three-lobed structures and ice as a CPL; version **4**–molecules as three-lobed structures and ice as a HPL). The HPL is a more scientifically accurate representation for the structure of ice than the CPL; distinguishing between the two models will help separate students at the higher levels of the LP. In addition, the set of models associated with response A is consistent with amorphous solids (e.g., wax) in which the molecules do not arrange in a regular pattern, potentially providing another way of measuring students' understanding of the structure of matter in the upper levels of the progression.

Middle school students appeared to favor the traditional representation of a solid (CPL) with either form for the water molecules (versions **1** and **3**; see Figure 1), as only slightly over 11-12% of students did not provide a response to the item. Not unexpectedly, the middle school students struggled with the hexagonal representations of solid water. Approximately 25% of the students did not provide an answer to either version **2** or **4**. Ten percent of students answering version **2** considered response A and response D to be equivalent, perhaps not recognizing the hexagonal pattern or its meaning in the representation of ice.

The different versions of the item seem to draw out different alternate conceptions from the students. Slightly over 50% of the middle school students responded correctly to version **1**. Approximately twice the number of students with versions **1** and **3** chose response B (no water molecules in the gas phase, much more space between molecules in liquid as compared to solid form–two common alternative conceptions; Harrison & Treagust, 2002) relative to the other incorrect answers. This result suggests that the alternate idea that 'the space between molecules in liquid form is significantly greater than that in the solid form' dominates students' reasoning leading to the observed preference for choice of response B. The hexagonal arrangement of water molecules in the solid form elicited a different proportion of responses. Students with version **2** exhibited a very strong preference for response B (2-3-fold greater than for response A or C). In contrast, very few students with version **4** chose response B (2-3-fold less than for response A or C), while the other incorrect answers were chosen with fairly even distribution. Thus, the relative amount of space between the molecules in the solid and liquid form do not seem to dominate students' thinking with the version **4** set of representations. Further investigation through interviews will help explain the observed change in students' responses. These results also suggest that using different representations of a solid in assessments will help assign students' location on a LP for the nature of matter. Piloting the four versions of the items with more advanced students will provide information on the effectiveness of this strategy. While we only focused on results related to students' interpretation of models of water molecules and their arrangement in representations of different phases here, in the final poster, we will discuss students' interpretation of representations in multiple contexts for students throughout the LP (grades 6-14).

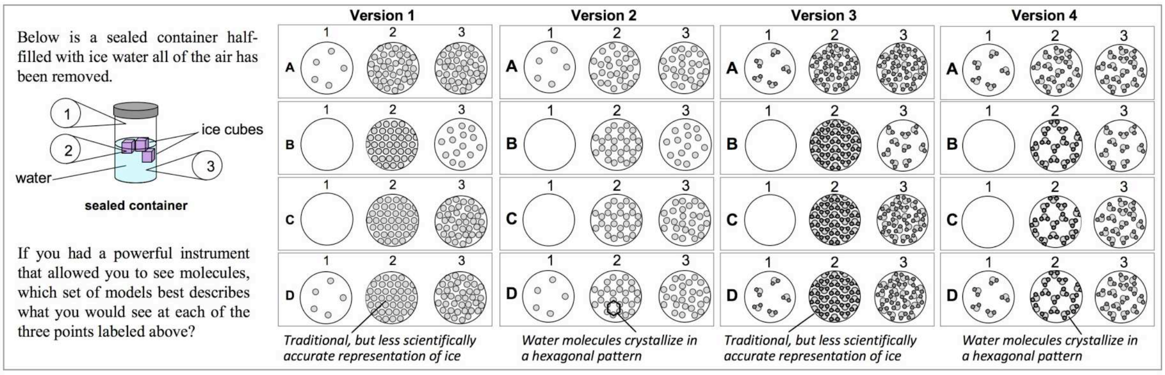

Figure 1. Item requiring students to choose appropriate models to represent water in various states.

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