Middle School Students' Development of the Particle Model of Matter

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Abstract: Prior research indicates that one of the most difficult concepts for students to understand is that of the particle nature of matter. One reason for this is that often, traditional curriculum materials present the particle model and related ideas as facts, without helping students to develop the ideas based on this model. The *How can I smell things from a distance?* chemistry unit takes the approach of building students’ ideas through the construction and revision of models. The purpose of this study is to describe the changes in students’ understanding of the particle nature of matter as they were engaged in an eight-week model-based curriculum. One teacher and her two 6th grade classes in midwestern school district were the focus of the study. Data sources include pre- and posttests, students’ artifacts and video recordings of the curriculum enactment. Pre- and posttest items and student artifacts included items in which students created models of various phenomena. Video recordings of classroom enactment were collected in order to examine how teacher’s enactment affected student models. Analysis of students’ assessment models indicate students can move from a non-scientific model to a particle model in order to explain phenomena, such as how a gas travels. Features of the curriculum that either aided or hindered student learning are discussed.

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Introduction

Numerous studies have documented the difficulties middle, high school, and college students have in understanding of the particle nature of matter (Harrison & Treagust, 2002). In chemistry, students must learn and make meaning of new terms, symbols, graphs, tables and several other representations (Justi & Gilbert, 2002; Kozma et al, 2000). However, students do not enter the classroom without prior knowledge. They have their own conceptions of how the world works. Many times these conceptions do not hold true within the confines of science.

One reason US students find it difficult to learn the particle model is that traditional curriculum materials just present the ideas to students without helping them to develop these ideas. Typically, the particle nature of matter is introduced in either a short paragraph, or as a chapter on the atom and the history of the atom. Often students don't develop appropriate ideas because they never apply and reapply these ideas to explain phenomena. The *Investigating and Questioning our World through Science and Technology (IQWST)* project (Reiser, Krajcik, Marx and Moje, 2003) takes the approach of building student's ideas through the construction and revision of models.

This study focuses on the 6th grade chemistry unit of the IQWST curriculum entitled "How can I smell things from a distance?" This unit emphasizes modeling as an important scientific practice for students to learn, as well as to help students understand the particle nature of matter. The approach of this unit is for students to create models at specific points throughout the curriculum. Students use these models to explain and predict different phenomena. The purpose of this study was to determine how 6th grade students' understanding of the particle nature of matter changed as they participate in a contextualized and model based unit in chemistry.

Students' (mis)conceptions of the Particle Nature of Matter

Learners and many adults hold non-normative science ideas regarding the structure of matter. Many of the misconceptions students possess have been documented (Driver et al, 1985, Driver et al, 1994). For example, students misconstrue mass and size of an object. For instance, students hold the idea that a balled up piece of aluminum has more mass than a flat piece of aluminum foil. In addition, there are areas in which students hold on to their non-normative models of matter despite instructional strategies used (Driver et al, 1994).

The particle nature of matter is a fundamental concept for learning and understanding many physical and chemical processes. As such, it has also been an intense area of research. Novick and Nussbaum (1978) studied students' ideas about the particle nature of matter as it relates to gases. They found that students did not internalize ideas related to the vacuum concept (empty space), the intrinsic motion of particles or the interaction between particles during a chemical change. Other studies have shown that students assign macroscopic properties of substances to the atoms/molecules that compose the substance (Ben-Zvi, Eylon & Silberstein, 1986; Nakhleh, 1992; Lee et al, 1993). But what is the source (or sources) of these misconceptions?

One source of these misconceptions is students' everyday experiences (Nussbaum & Novick, 1982). The other source often mentioned is that of instruction (Ben-Zvi, Eylon & Silberstein, 1986; Lee et al, 1993; deVos & Verdonk, 1996; Johnson, 1998). As Harrison & Treagust (2002) note, "this practice of providing token evidence and making the assumption that students will accept the new ideas as fact is not an uncommon phenomenon in teaching and learning chemistry" (p. 191). The concepts of the atom and the molecule in particle theory play important roles in explaining various phenomena. Research indicates that students must undergo a conceptual change in order for students to move from a continuous view of matter to a particle view (Nussbaum & Novick, 1982; Lee et al, 1993; Vosniadou, 1994; Harrison & Treagust, 2002; Niaz et al, 2002). Others have shown or promoted using, creating, and understanding the nature of models can help students understand physical phenomena (Grosslight et al, 1991; Hestenes, 1992; Vosniadou, 1994; Harrison & Treagust, 1998; Justi & Gilbert, 2002; MacKinnon, 2003; Saari & Viiri; 2003; Mikelsis-Seifert & Leisner, 2005; Schwartz and White, 2005).

Models and Modeling

An important tool for scientists is the scientific model. Scientists use scientific models to think about, explain, and predict phenomena in the world. Many studies emphasize the importance of students understanding models and the process of modeling in order to better understand scientific phenomena (Harrison & Treagust, 1996; Harrison & Treagust 1998; Harrison & Treagust 2000; White & Frederikson, 1998; Schwartz & White, 2005). These studies emphasize the importance of students not only understanding the different types of models that can be developed for a single phenomenon, but also the nature of models and modeling. Our study aims to look at how a curriculum can be developed to support the development of a scientific practice and science content knowledge (the particle nature of matter).

The central scientific practice for this unit is modeling. Modeling was chosen because the particle nature of matter is: 1) an abstract concept and 2) is a model for understanding science concepts on the micro-level. Models allow students to think about, explain, and predict phenomena. In addition, models enable the visualization of the structure and behavior of models. Most important for our study, the models that students develop provide a window into students' thinking.

Our approach also provides students with opportunities for using multiple models when students are initially developing their modeling skills. In this case, the use of multiple models refers to students creating and discussing a variety of models of matter (including their peers' models). In addition, teachers lead discussions of student models to help students understand both the particle nature of matter and the purpose of creating models.

Curriculum

The IQWST approach is to carefully develop ideas over times. A key component of this design approach is to use a learning-goals-driven-design process (Reiser, Krajcik, Marx and Moje, 2003). This process begins by selecting and clarifying learning goals derived from the national standards. For the development of this unit, we identified three standards (see Table 1) from the Benchmarks for Scientific Literacy (AAAS, 1993) and National Science Education Standards (NRC, 1996). The identification of a small number of standards sets the IQWST curricula apart because of our focus on breadth instead of depth, which has become a hallmark of state standards.

The benchmarks were then unpacked, clarified and elaborated to ascertain what each of these benchmarks means for teaching sixth grade students the particle nature of matter and how the particle model is used to describe the structure of matter and explain phase changes.

Table 1. Unit Learning Goals

AAAS 4D/M1: All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.
AAAS 4D/M3: Atoms and molecules are perpetually in motion. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions. Increased temperature means greater average energy of motion, so most substances expand when heated.
NRC B5-8: 1A: A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the substance

These standards were then used to construct learning performances. A learning performance results from combining the content standard with an inquiry standard. These learning performances clearly specify what students are expected to be able to do with the knowledge described in the benchmark (see Table 2).

Table 2. Learning Performance

Content Standard	Inquiry Standard	Learning Performance
…In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.	Develop…models using evidence. (NRC, 1996, A: 1/4, 5-8) Models are often used to think about processes that happen…too quickly, or on too small a scale to observe directly… (AAAS, 1993, 11B: 1, 6-8)	Students explain phase changes from gases to liquids and liquids to gases on a molecular level.

Thus, in this unit students use the particle nature of matter model to explain phenomena, such as states of matter, phase changes, and properties. As such, we designed a unit in which learning the particle model of matter is contextualized through the use of a driving question. The development of a driving question (Krajcik & Blumenfeld, 2006) serves to produce a context for students to learn about scientific phenomena. The development of the driving question also serves to anchor students learning within a context. This context plays a vital role in situated cognition in that it "shows students the legitimacy of their implicit knowledge and its availability as scaffolding in apparently unfamiliar tasks" (Brown et al., 1989, p. 38). The anchoring context is revisited throughout the completed curriculum as students gain greater knowledge and understanding of concepts related to the phenomena studied.

The driving question "How can I smell things from a distance?" provides the anchoring context for all of the lessons and is revisited throughout the unit (Krajcik & Blumenfeld, 2006). Second, the unit involves the creation of student artifacts, the models that students create. Students experience various phenomena throughout this eight-week unit to help them to gain knowledge and understanding of the different aspects of the particle nature of matter. Peer-to-peer and whole class discussions are utilized to help students discuss and critique their models and understand scientific concepts.

A foundational piece for the development of this unit was the 1978 Novick and Nussbaum study. This study found that students least internalized aspects of the particle nature of matter that opposed their sensory perception of matter. The aspects relevant to our study are: that matter exists as tiny particles, empty space (the vacuum concept) and intrinsic motion (particle kinetics). These aspects tend to lead students to forming a continuous-particle model. In particular, students cannot conceive of empty space in ordinary matter, including gases.

Based on the findings of the Novick and Nussbaum study, the first learning set of the unit includes focuses on the following:

- Bulk properties of gases that may make it difficult for students to accept the idea of empty space (addition, subtraction, compression and expansion; air has mass and volume).
- Relationship between heat and speed of motion to get at the intrinsic motion of particles.

- Exposure to more phenomena that are dissonant with their sensory perception of matter would lead to greater accommodation of the particle conception of matter

The unit contains three learning sets. The first learning set (lessons 1-5) aims at helping students understand what matter is (anything that has mass and volume and exists in one of three states) and a consensus model of matter: matter is composed of particles, there is empty space between the particles and the particles are constantly moving. Learning Set 2 (lessons 6-9) helps students understand properties and that properties are a result of the arrangement of atoms in a substance. Learning Set 3 (lessons 10-15) involves students using their models of matter to explain phase changes.

The anchoring activity of the unit has students create models (student models are defined as their drawing plus explanation) to explain why they think they can smell an object from a distance. The initial pilot study of the unit identified the modeling activity of lesson 1 as not only a way for teachers to elucidate students' initial notions of the particle nature of matter, but also as an activity that could be repeated throughout the unit to assess students' understanding (See Appendix A). Thus, this modeling activity is repeated in lessons 5 and 15 of the curriculum and serves as a means to monitor students' learning.

Methods

This study reports our findings from one teacher's classes in a large Midwest college town who enacted the *Smell* unit. The students were from various ethnic and socioeconomic backgrounds and differing academic abilities. The teacher has had previous experience in piloting reform-based curricula. In total, there were 57 students who participated in the study. The required lessons for this study were completed in 8 weeks.

Data Collection and Analysis

Student Artifacts

All students completed pre- and posttests that included 18 multiple-choice questions and 3 open-ended items. Multiple-choice questions were scored and tallied with a maximum possible score of 18. The multiple-choice items covered the key learning goals of the unit: particle nature of matter, matter, phase change, and properties.

To analyze student artifacts, rubrics were created for the pre/posttest open-ended questions (see Appendix B). The maximum score for the open-ended items was also 18. There were two scorers for the open-ended items. We randomly sampled 20% of the open-ended test items, which were scored by a third independent rater. Percent agreements were used to estimate inter-rater reliability for each open-ended item. Inter-rater agreement was above 90% for each component of each question.

In addition, a rubric was created for the activity sheets (see Appendix C), based on those developed for the open-ended test items. Originally, students were allowed to take home their work. Therefore, some students' worksheets were lost. These missing artifacts resulted in the analysis of only 43 students' worksheets.

The scoring of student artifacts takes into account the different types of models students generate based on prior research (Novick & Nussbaum, 1978, Johnson, 1998). In addition, the scoring of the drawings reflects the different aspects important to students' developing a particle view of matter: (1) matter is made up of particles, (2) there is empty space between the particles and, (3) movement of the particles. The five model types (see Figure 1) have been classified as (Merritt, Rogat, & George, 2006):

- Type 1: Continuous (no space)
- Type 2: Continuous with empty space
- Type 3: Mixed, particles and clouds or particles and lines
- Type 4: Particles, including everyday ideas (germs, water in air)
- Type 5: Particle

Thus, the scoring rubrics for students' models would need to incorporate these different types of drawings (C= continuous, M = mixed, and P = particle). These different model types are similar to those found by Johnson (1998).

The written portion of the model reflects the type of understanding students attain as a result of experiencing the unit. The scoring of these explanations mirrors the desired growth in understanding from description to mechanism (Minstrell, 2001). Therefore, we expect that as students' drawings move towards a particle view, the level of sophistication of their explanations will also increase.

Video Analysis

Students are learning about the particle nature of matter within the context of their classroom. Classroom discussion plays a pivotal role in student learning. Thus, the context of the classroom must be taken into consideration. Analysis of teacher questioning patterns and response to students' answers allow us to see the how these interactions affect student learning. In particular, what points of emphasis that were made by the teacher are reflected in students' models during in class modeling activities in lessons 1, 5 and 15.

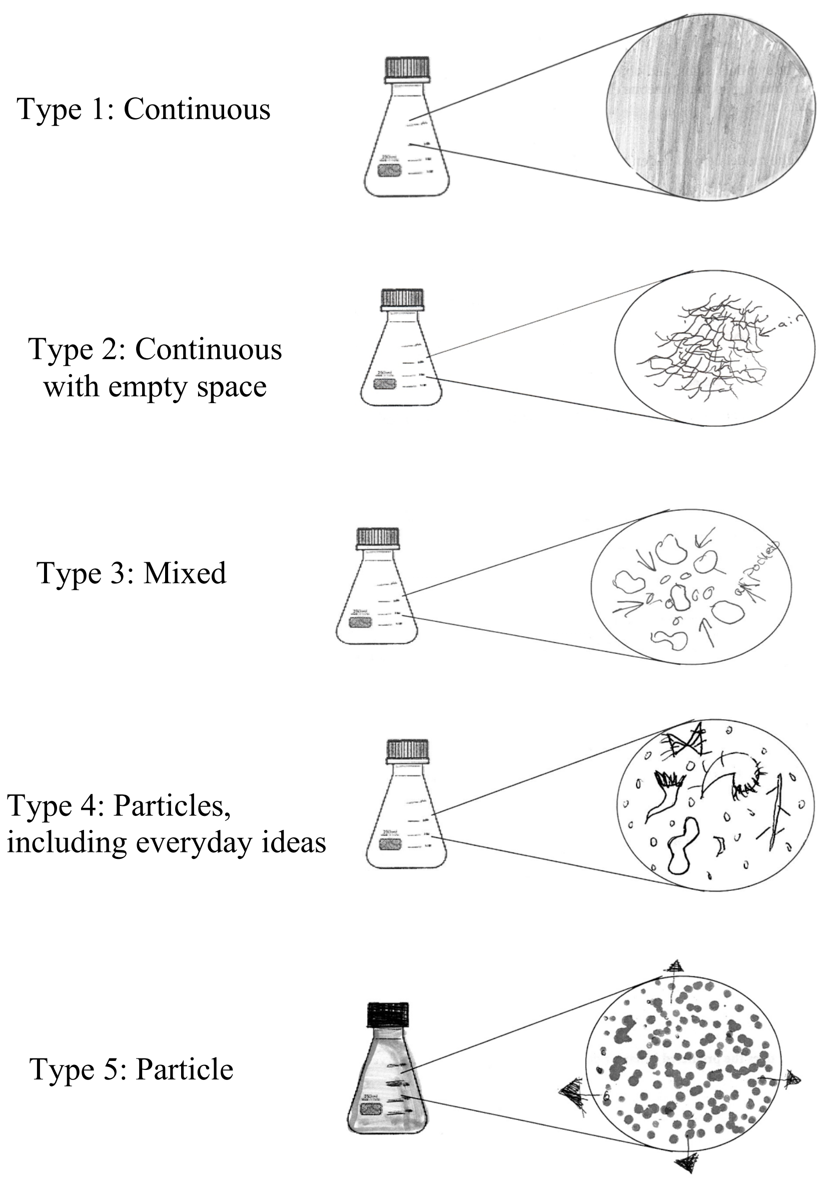


Figure 1. Examples of the five types of drawings generated by students

Results and Discussion

Overall Student Learning Gains

We first examined what students' learning of key learning goals was using a paired samples t-test. Table 3 provides the learning gains for students, including total score, open-ended items, and multiple-choice items as well as key content items. Process items are both multiple-choice and open-ended items that include models or modeling. Overall, students achieved significant learning gains from pre to posttest.

Table 3: Overall Student Learning Gains (n = 57)

Items (Max Score)	**Pretest Mean (SD)**	**Posttest Mean (SD)**	**Gain (SD)**	**Effect Size[a]**
Total (36)	16.87 (4.09)	28.18 (5.17)	11.26 (4.97)	2.77***
Multiple Choice (18)	8.75 (2.98)	14.19 (2.87)	5.44 (2.98)	1.83***
Open Ended (18)	8.41 (2.14)	13.99 (3.11)	5.52 (3.27)	2.58***
Process Items (23)	10.25 (2.90)	18.26 (3.52)	8.10 (4.02)	2.81***
Content Items				
Phase Change (13)	5.42 (1.98)	10.16 (2.36)	4.74 (2.68)	2.39***
Particulate Nat. (18)	7.64 (2.43)	14.61 (2.91)	6.97 (3.24)	2.87***
Properties (4)	2.02 (1.13)	2.84 (1.19)	0.82 (1.28)	0.73***
Matter (5)	3.43 (0.84)	3.96 (0.66)	0.53 (1.00)	0.63***

*** $p < .001$

[a]Effect size: Calculated by dividing the difference between pre and posttest mean scores by the pretest standard deviation

An item analysis revealed that students reached a ceiling on the pre-test with the multiple-choice questions related to matter and properties. The matter items also included one of the open-ended items. Most students' score improvement is related to their answer to this question.

Next, we examined students' learning gains related to the modeling open-ended test items (see Appendix B for actual items). For each modeling question, the model was assessed for its content, type and explanation. The content refers to the aspects included in the model. For example, the highest scored model includes air and odor molecules, movement, empty space and indicates the effect that temperature has on the movement of the particles. The type refers to whether the model is continuous, mixed or particle, with particle model receiving the highest score. Table 4 shows that for each modeling item, students showed significant learning gains.

Table 4: Learning Gains for Modeling Items

Items (Max Score)	**Pretest Mean (SD)**	**Posttest Mean (SD)**	**Gain (SD)**	**Effect Size**[a]
Question 2 (9)	4.19 (1.31)	7.01 (2.05)	2.82 (2.34)	2.15***
Room Choice (1)	0.64 (.49)	0.96 (.19)	0.33 (.51)	0.67***
Content (4)	1.40 (0.79)	3.08 (0.92)	1.68 (1.15)	2.13***
Type (0.6)	0.12 (.22)	0.50 (0.21)	.38 (0.30)	1.73***
Explanation (4)	1.27 (.655)	2.52 (1.14)	1.25 (1.28)	1.91***
Question 4 (6)	2.26 (1.28)	4.81 (1.59)	2.56 (1.87)	2.00***
Content (4)	1.37 (0.81)	2.84 (1.06)	1.47 (1.28)	1.81***
Type (0.8)	0.15 (0.30)	0.64 (0.31)	0.49 (0.39)	1.63***
Explanation (2)	0.76 (0.53)	1.34 (0.63)	0.58 (0.68)	1.09***

*** $p < .001$

[a]Effect size: Calculated by dividing the difference between pre and posttest mean scores by the pretest standard deviation

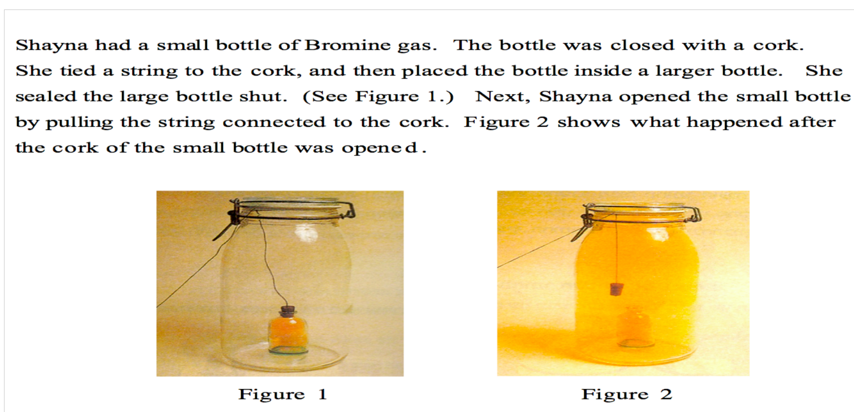


Figure 2. Open-ended question 4

For example, open-ended item number 4 asked students to create a model to explain what happened when the small bottle was opened (see Figure 2). On the pretest, Mark created a continuous model of the bromine gas escaping into the larger bottle (see Figure 3a). The written portion of his model describes exactly what Mark drew. In contrast, Mark's posttest answer is a particle model that includes both bromine and air. It includes more sophisticated movement in that the air and bromine molecules are colliding into each other or the bottle. The written portion of his model does not fully reflect a particle view, in that Mark switches from using a macro level description of what is going on to a micro level description when he is describing the movement of the particles. This was a common feature of many students' posttest models.

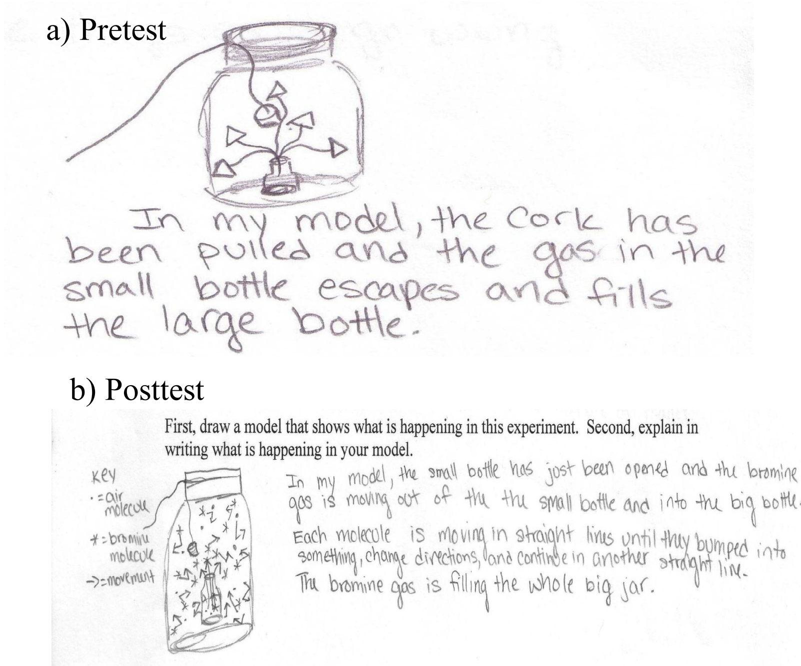
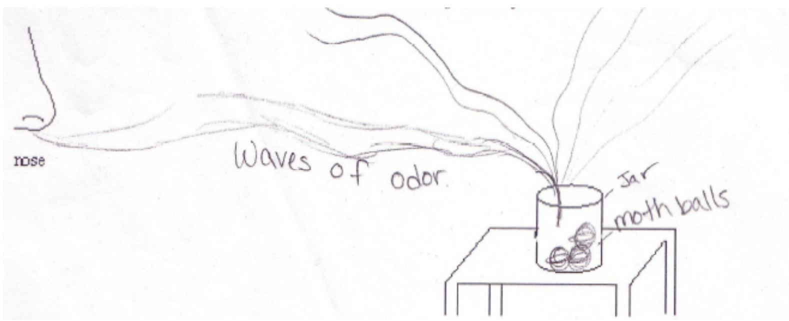


Figure 3. Mark's pretest (a) and posttest (b) models, open-ended item 4.

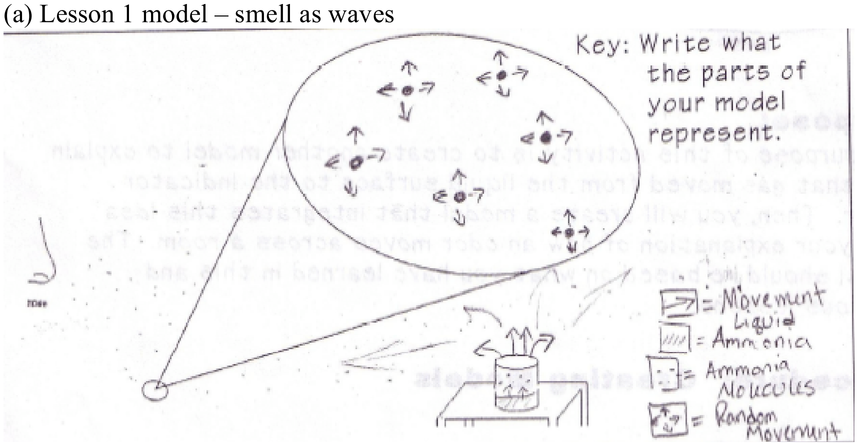
Embedded assessment: Modeling the same phenomena

The lesson 1 anchoring activity of the Smell unit involves students creating models (student models are defined as their drawing plus explanation) to explain why they think they can smell an object from a distance (see Appendix A). This modeling activity is repeated in lessons 5 and 15 of the curriculum and serves as a means to monitor students' learning. Analysis of students' artifacts indicates that in general, students produce more accurate models, with more accurate explanations as they progress through the unit. For example, figure 3 shows the changes of one student's model as he progressed through the unit. The model in figure 4(a) is a continuous model, which over 45% of students created in the first lesson. Half the students only included odor in their models and 87% gave descriptions of their models, such as "The odor is coming out of the source".

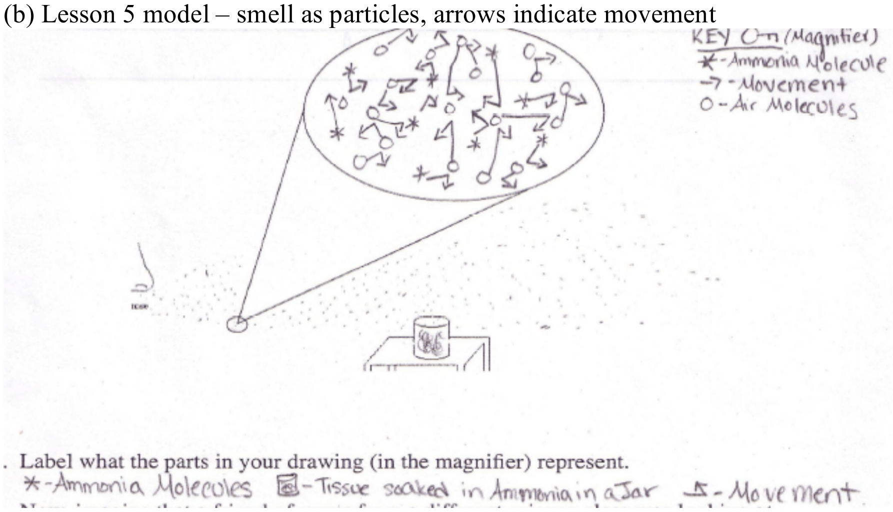
The lesson 5 model (see Figure 4(b)) now represents odors as particles and that the particles are moving in all directions. In fact, 52.3% of students created a particle model at this stage of the curriculum. Other students created a mixed model (45.5%). A key feature of student models at this point is that 70.5% now include particles with some indication of movement. In addition, students written descriptions of their models now are trying to explain the phenomena, albeit with the incorrect mechanism. Mark describes what is happening as follows: " Molecules in the liquid come off the surface of the liquid and become a gas. They move around and change direction when they come in contact with another object."



(a) Lesson 1 model – smell as waves



(b) Lesson 5 model – smell as particles, arrows indicate movement



(c) Lesson 15 model: air and ammonia molecules, movement includes molecules bouncing off one another.

Figure 4. *Changes in Mark's models of the same phenomena*

The lesson 15 model (see Figure 4(c)) represents odor and air molecules that are moving in straight lines until they collide with another air or odor molecule. At this last lesson in the unit, 75% of students create a particle model of matter, while 25% create a mixed model of matter. Moreover, 68% of students include odor particles that are moving in straight lines until they collide into each other. The remaining 32% of students include both odor and air in their models. Finally, most students have moved from a written description of their model, to writing about how their models explain how an odor can move across a distance.

Overall, a majority of students move to a particle model of matter throughout the curriculum. Students' models also indicate that they also include the motion of particles. The motion of particles included in students' models becomes more sophisticated as they add notions of particles in the gaseous state move in straight lines until they bump into each other. In addition, there are students who include empty space as a labeled concept in their model. However, students' written portions of their models do not always reflect the same level of understanding. Thus, we were also interested in how the teacher's instructional practices influenced students' models.

Teacher Influence on Student Models

Analysis of video collected from enactment of the curriculum provided us with the opportunity to see how instructional practices influenced students' models. We again focused on lessons 1, 5 and 15 because they provided us an opportunity to see how students' ideas changed while modeling the same phenomena. From this analysis, we were able to recognize what influences of the teacher's practice influenced students' models.

An emphasis for all three lessons was that of labeling as an important part of creating models. In lesson 1, students create their initial models of smell. From the beginning of this activity, the teacher emphasizes that students need to make sure they labeled the parts of their drawing. For example, when the teacher walked around the classroom to help students in putting their ideas on paper the following conversation occurred:

T: Label any parts. Like what are those waves? (Uses a hand motion to indicate waves) What are they?

S: Uh, smell waves

In yet another conversation with a student in a different group, the teacher again emphasized the importance of labeling through question students about their models:

> Oh excellent, what are they? Odors are things and molecules are things. I want to know. Oh, no, no, no, no. Don't, don't go erasing anything because those are your models. The important part is you tell me what it is to you. And if you label it something like, um, I don't know, argon gas, then you find out later its not argon gas, but the model works. Its still fine with me okay. So, tell me what you think it is. If you don't have the right word, go with it. If you have the idea that these are things, I want to you to tell me what they are.

Thus, starting from the anchoring modeling activity through the entire unit, the teacher emphasized the importance of labeling when communicating ideas through their models. Moreover, this was reflected in that students included labels for their different parts of their models (see Figure 4a).

In addition to labeling, lesson one introduces students to models and modeling. The teacher lead students in a discussion about models not being the real thing, but as "close to the real thing as you can get"

> S: Well I think that like all models, like you can't really like make a model that's perfect just because the world is always changing, so whenever you make a model, there's always going to be something wrong with it. Something new might come up, and then your model is wrong, but your model was right at that point in history, so
>
> T: Alright, so I think that is one of those huge ideas. I'm going to put it down under good, if you don't mind, and that is that models change over time. The whole idea behind a model is that it's NOT the real thing. It's as close to the real thing as you can get. And its accurate as you can get, but its really not the real thing. And so there's always going to be some little thing that isn't quite right and good science is making that model better and better over time.

This point of emphasis seemed to be a hindrance for some students in moving completely to a particle view. Many of those students who did not move to a completely particle view seemed to have a mixed model view, in which they keep some things as they would appear in the macro view, while emphasizing the magnified portion of their drawing as particles.

During the lesson 5 modeling activity, the teacher again emphasized the importance of labeling the parts of the model. In addition to labeling, the teacher emphasized the idea of motion and discussed with students how they thought the odor particles were moving. In this example, a student named Samuel is creating a model on the board to explain why indicator paper changes color without dipping the indicator paper in color. The teacher has had a side conversation with the student about what knowledge he is using to create his model. The teacher shares with the class that Samuel is using the evidence from this experiment as well as his previous knowledge about solids, liquids and gases to create his models.

> T: Okay so you smelled the part of it that is coming out. Okay, and so when you draw these little lines (teacher traces lines that Samuel drew on the board). Are you showing me the motion? Are you showing me
>
> Samuel explains to teacher in a muffled voice.
>
> T: You're showing me where the odor. Think back to model one, the first model you drew. You know, back in the day when we opened up the menthol and you drew a picture? How is this different than that?

The teacher is emphasizing both the concept of movement and inclusion of evidence and prior knowledge.

The teacher then discussed with students the previous lesson in which they discussed the movement of air particles in a syringe when it is expanded and compressed.

> T: Did everyone in this class agree that they are all moving? (Class, yes)
>
> T: How are they moving? Do you have any idea?
>
> Class: Molecules bouncing off the side, until it hits something else

This is followed by a brief discussion of evaporation. The inclusion of movement in students' models from lesson 5 is evident in that most students included it in the drawing portion of their model (79%). In addition, 72% of students discussed movement in the written portion of their models, even though some included incorrect notions such as the air was moving the odor molecules. Only one student included evaporation as a part of their written portion of their models.

The final lesson of the unit (15) is a summary lesson, in which the teacher leads a discussion about how key lessons helped to answer the driving question of the unit, "How can I smell things from a distance?". The teacher then completed the anchoring activity again, before students created their models. The teacher read the directions from the activity sheet before again emphasizing the importance of labeling the parts of their drawing. Students' models again reflected this emphasis on labeling (see Figure 4c).

Moreover, most students included notions of movement on a molecular level in the written portion of students' models.

From the beginning of the unit, the teacher emphasized the importance of labeling. This is reflected in the increased level of labeling students included in the drawing portion of their model. The teacher also asked students questions to push their thinking about what parts of their drawing should be labeled. The least mentioned part of the model is the written portion of the model. This is reflected in the following excerpt from lesson 1 in which the teacher is reading the directions for the written portion of the model:

> So imagine that the S kids didn't get to smell anything and they're looking at your drawing. In that space, describe your drawing to an S kid and tell how your drawing explains that odors travel from one place to another.
> (Teacher walks around as students complete the written portion of their model.)
> So write down what you would tell them. Take a look through. Did you describe what happened when I first opened it? How long it took the smell to get to you? Did you draw and label your picture? Flip it over. Did you write a good explanation for another kid?

This pattern of reading the directions and moving on to the next part of the lesson was again done in lessons 5 and 15 in almost the exact same manner.

Conclusion

Most 6th grade students can move from a continuous to a molecular view of matter. This is reflected in students learning gains from pre- to posttest and in the increased sophistication of the models students created during instruction. Analysis of student models also indicates that students take different paths towards developing a particle model of matter. These different pathways are indicated through the different types of models students create, the parts of the drawing that they label as well as the language used (macro versus micro) in the written portion of their models.

Implications for Curriculum

Based on the results of this study, changes were made for the present enactment of the curriculum. Discussion of student models is an important part of students changing conception of matter. Thus, additional emphasis was placed on the different types of discussion that teachers should have with students regarding both content and models.

The supports for these discussions include informing teachers of the purpose of the discussion and what ideas students should come away with at the end of the discussion.

Although it was not a focus of this study, we found that the teacher did a lot of consensus model building. This resulted in the addition of more consensus model building in two key lessons of the curriculum. Consensus model building seemed to be important because it was a part of students sharing and discussing their models after they created their models.

Future Studies

The completion of this study provided us with several opportunities for examining student learning throughout the curriculum. First, it afforded us the opportunity to assess student outcomes after enactment of the entire unit through the use of pre/post-test measures, video analysis and student work. However, it did not provide answers to the question: What are students' learning progressions of the particle nature of matter throughout the unit? Learning progressions provide a framework for gauging how students are moving towards more complex thinking as ideas develop over time.

The particle nature of matter (PNM) is the foundation for understanding a myriad of science concepts including properties, phase change, and chemical reactions. Previous interview studies (Novick & Nussbaum, 1978; Stavy, 1991; Nakhleh, Samarapungavan & Saglam, 2005) have outlined the difficulties students have with understanding PNM and its related concepts. Current large-scale tests that assess students' knowledge of PNM and its related concepts do not provide information to teachers or students that would help to improve teaching or learning. In addition, the large-scale tests tend to ask questions that require rote memorization of facts. As Minstrell (2001) notes:

> Peoples' explanations generally progress from a description of the phenomenon or description of procedures for creating the effect, through identification of relevant concepts, to understanding particular mechanisms of causality, to a more model-like weaving of concepts, mechanisms, and relations among factors. (p. 424)

In addition, future enactments of the curriculum include students experiencing a prior unit that also emphasizes the use of models and modeling. The question that we would like to answer is: How does having a prior unit focused on models and modeling influence students learning of the particle nature of matter?

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Appendix A: Lesson 1, 5 and 15 Activity Sheet

The activity sheets for lessons 1, 5 and 15 vary slightly in terms of number of questions, however, questions 3, 4, and 5 from the lesson 1 activity sheet appear on all three sheets.

Lesson 1 Can You Smell What I Smell? Activity Sheet 1.1

ACTIVITY 1.1 CAN YOU SMELL WHAT I SMELL? SW

Purpose

In class, your teacher opened a jar that had an object in it. The object in the jar had an odor to it, and the odor moved across the room. In this activity you will record your ideas of how an odor can go from the object to your nose.

Data Collection/Observation

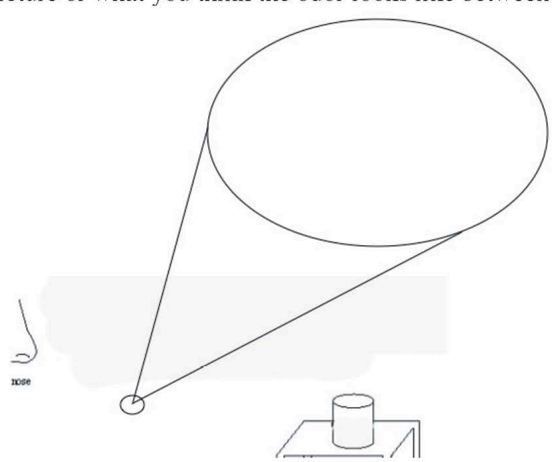
1. Write the odor you smell: ____________________

2. Describe what happens when your teacher opens the jar.

____

____

3. Imagine that you have a very powerful microscope that would allow you to see the odor up really, really close. What would you see? The large circle in the drawing below represents the magnified part of the air between the jar and your nose. In the circle, draw a picture of what you think the odor looks like between the jar and your nose.



4. Label what the parts in your drawing represent.

1

Lesson 1 Can You Smell What I Smell? Activity Sheet 1.1

5. Now, imagine that a friend of yours was looking at your drawing. In the space below, describe for your friend how your drawing helps to explain that odors travel from one place to another.

2

Appendix B: Open-ended Test Item Rubrics

Smell Unit: Open-ended Question Scoring Rubric

2. Bill and Shauna noticed that Bill's room was a lot colder than Shauna's room. They wondered if you could smell an air freshener faster in a cold room or a warm room. They decided to do an experiment: Bill plugged a lemon air freshener into the wall in the cold room. At the same time, Shauna plugged a strawberry air freshener into the wall in the warm room. (The air fresheners were the same distance away from the bedroom doors.) Bill sat by his door and Shauna sat by her door. Which one smelled the air fresheners first? *(9 pts)*

A. First, circle which room Bill and Shauna would smell the odor from first: ***(1 pt)***

Cold Room   Warm Room   Both at the same time   Neither of the rooms

Code	Answer
0	Neither of the rooms
0	Both at the same time
0	Cold Room
1	Warm Room

B. Second, draw models that show why you chose your answer in part A. (Your models should show how the odors moved in the cold room and in the warm room.) (***4 pts)***

Note for drawings: If student does not represent particles = continuous model
Squiggly lines = movement
Particles look like they are spreading out = movement

Code	Content	Sub-Code
0	No drawing	0
1	Drawing is indecipherable	1
2	**Continuous** model of odor *and/or* air, but **no movement** indicated	2C
3	**Continuous** model of *air and/or odor* and **movement** indicated, but **no temperature difference (1), temperature difference is incorrect (2) or temperature difference is irrelevant (3)**	3C1 3C2 3C3
	Mixed model of odor *and/or* air but **NO movement** indicated	M
4	**Continuous** model of air or odor only and **movement,** indicating affect of **temperature difference**	C
	Mixed model of odor and/*or* air, **movement** indicated	M
	Particle model of odor and/or air, but **NO movement** is indicated.	P
5	**Continuous** model of air and odor; **movement**, indicates affect of **temperature difference**	C
	Mixed model of odor or air only, **movement** indicated and affect **of temperature difference**	M
	Particle model of odor *and/or* air and **movement** indicated.	P
6	**Mixed** model of odor and air, **movement** indicates affect of temperature difference	M
	Particle model of *odor only*. **Movement** shows the affect of **temperature difference**.	P
7	**Particle** model. Particles are of odor *and* air. **Movement** shows the affect of **temperature difference**	7

C. Third, explain in writing why you chose your answer in part A. (Your explanation should describe how the odors moved in the cold room and the warm room.) ***(4 pts)***

Note: Move faster = increased movement

Code	Content	Example
0	No answer	
1	Incorrect answer	In the warm room, the odors would rise, but in the cold room they would stay low, and close to the door, This is why I chose the cold.
2	Identifying warmer room air moves faster or spreads but not both. OR colder room air moves slower or trying to give explanation, but applies incorrect mechanism	The cold room should move slowly because cold places cool down stuff like air and slows them down. But in a warm room air and odors go faster.
3	Warmer room air moves faster and spreads/travels to nose OR Colder room air moves slower and travels/spreads to nose.	I chose my answer because odors expand in warm air and in cold air the odor would stay more together and not spread throughout the room like the warm does.
4	In a warmer room air and odor particles moves faster. Particles have increased movement/energy in a warmer room. OR in a colder room…. For a score of four, student must indicate three of the following: that they are particles, faster, have increased energy/movement or spread/travel /move across room (or vice versa if talking about a cold room)	The reason that I chose the warm room was because gas molecules move faster when there is more heat. Heat is the transfer of energy, and in a hot or warm room, there is more energy to go around. More energy, more movement.
5	In a warmer room air and odor particles moves faster. Particles have increased movement/energy in a warmer room and the odor particles spread/travel to nose. OR in a colder room…. For a score of five, student must indicate all of the following: that they are particles, faster, have increased energy/movement or spread/travel /move across room (or vice versa if talking about a cold room)	In the warm room, there is more energy and more energy means more movement with the molecules and that makes the odors spread quicker. In the cold room there is less energy and less energy means less movement which makes the molecules spread slower so you don't smell the odor as fast as the warm room.

4. Shayna had a small bottle of Bromine gas. The bottle was closed with a cork. She tied a string to the cork, and then placed the bottle inside a larger bottle. She sealed the large bottle shut. (See Figure 1.) Next, Shayna opened the small bottle by pulling the string connected to the cork. Figure 2 shows what happened after the cork of the small bottle was opened. (6 pts)

First, draw a model that shows what is happening in this experiment. Second, explain in writing what is happening in your model. *(4 pts)*

Code	Content	Sub-Code
0	No drawing	0
1	Drawing is indecipherable no key or label of components)	
2	Continuous model of odor *and/or* air, but no movement indicated	2
3	Continuous model with bromine only. Shows the movement from smaller bottle to larger bottle	3C
	Mixed model of bromine only, but no movement indicated.	3M
4	Continuous model with bromine and air. Shows movement from smaller bottle to larger bottle.	4C
	Mixed model of bromine only. Shows movement from smaller bottle to larger bottle	4M
	Particle model of bromine but no movement indicated.	4P
5	Mixed model of bromine and air, Shows movement from smaller bottle to larger bottle	5M
	Particle model of bromine only or particles are indistinguishable. Shows the movement of particles from smaller bottle to larger bottle.	5P
6	Particle model. Particles are of bromine *and* air. Shows the movement of particles from smaller bottle to larger bottle.	6

Explanation ***(2 pts)***

Code	Content	Example
0	No answer or meaningless	
1	Description	The gas is coming out of where the cork used to be.
2	Trying to give explanation, but applies incorrect mechanism	The air molecules are hitting the bromine molecules making the bromine molecules move into the air.

3	Answer related to behaviors of gases: expands, takes the shape/volume of container	In my model the gas is being compressed in the little jar. The little jar is opened so there is space for the gas to expand and move around. OR In my model the gas is expanding to fill the container.
4	Particles of bromine move/spread/bounce/expand and fill the container.	In my model the string is pulling up the cork. As the cork is being pulled up, the bromine molecules are bouncing out and filling the larger jar.

Appendix C: Smell Model Rubric

This table is the scoring rubric for assessing the drawing portion of students' models. The subcode helps to distinguish the type of model the student created: continuous, mixed or particle. The explanation portion of the model is scored separately.

Table X1. Drawing Rubric

Code	Content	Sub-Code
0	No drawing	0
1	Drawing is indecipherable (no key or label of components)	
2	Continuous model of odor *and/or* air, but no movement indicated	C
3	Continuous model with odor only. Shows the movement from source to nose	C
	Mixed model of odor only, but no movement indicated.	M
4	Continuous model with odor and air. Shows movement from source to nose.	C
	Mixed model of odor only. Shows movement from source to nose	M
	Particle model of odor and/or air but no movement indicated.	P
5	Mixed model of odor and air, Shows movement from source to nose	M
	Particle model of odor only or particles are indistinguishable. Shows the movement of particles from source to nose.	P
6	Particle model. Particles are of odor *and* air. Shows the movement of particles from source to nose.	6

Table X2. Explanation Scoring Rubric

Code	Content	Example
0	No answer or meaningless	
1	Description	The odor is coming out of the source
2	Trying to give explanation, but applies incorrect mechanism	The air molecules are hitting the odor molecules making the odor molecules move into the air.
3	Answer related to evaporation of liquids /or movement of odor particles.	In my model the liquid evaporates and becomes a gas. The gas particles then travel in the air from to my nose.
4	Particles of liquid evaporate from the source. The odor particles	In my model the liquid evaporates. The liquid molecules at the surface have enough energy to move into the air. The odor molecules bump into the air molecules until they reach my nose.