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Author: Orquiza de Carvalho, Lizete M.; Carvalho, Washington; Alvarado, Tawny & Gallagher, James

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Nurturing scientific understanding in a multicultural classroom: observations of interactions

Lizete M.Orquiza de Carvalho, FEIS/UNESP, Brazil, Supported by FAPESP, Visiting Scholar at Michigan State University,
e-mail: msucoe1@pilot.msu.edu;
Washington Carvalho, FEIS/UNESP, Brazil, Visiting Scholar at Michigan State University, e-mail: washcar@pilot.msu.edu;,
Tawny Alvarado, Otto Middle School, Lansing -MI;
James Gallagher, Michigan State University, College of Education, Department of Teacher Education, e-mail: gallaghr@msu.edu.
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ABSTRACT

In this paper we analyzed data from studying a multicultural sixth grade classroom taught by an experienced science teacher. The data were taken from video-tapes of the classes, students' worksheets, and interviews with the teacher. An analysis of the students' mental representation of scientific concepts is presented. We focused on how much students got out of the activities and how the outcomes were intertwined. One of our results is that after students became familiarized with experiments and key ideas, many of them started to relate the experiments to other experiments using the key ideas and to extend those key ideas to different experiments. It seems that if students have greater opportunities to become familiarized with a manageable number of experiments and manageable number of scientific ideas, they can gradually begin to make sense of their own experience with thinking about and using scientific ideas.

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Lizete M.Orquiza de Carvalho, FEIS/UNESP, Brazil, Supported by FAPESP, Visiting Scholar at Michigan State University,
e-mail: msucoe1@pilot.msu.edu;
Washington Carvalho, FEIS/UNESP, Brazil, Visiting Scholar at Michigan State University, e-mail: washcar@pilot.msu.edu;,
Tawny Alvarado, Otto Middle School, Lansing -MI;
James Gallagher, Michigan State University, College of Education, Department of Teacher Education, e-mail: gallaghr@msu.edu.

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INTRODUCTION

Scientific understanding is an elusive goal of teaching. It is especially difficult when we consider understanding of complex constructs like kinetic molecular theory which is commonly part of the middle school curriculum in science. According to J. Osborne (1996), constructivist research has been seminal in exploring learning outcomes resulting from the first of the two sources of human learning (knowledge that is acquired by acting and intervening on the world. Constructivists are only now beginning to explore the learning outcomes of the second (knowledge that is acquired through cultural transmission. The present research focused on the second of these learning outcomes. We aimed at the learning experience needed to enable students to understand the standard scientific world. In order to evaluate the impact of embedded assessment employed by the teacher on the students, we analyzed the student's mental representation of scientific concepts (Villani & Orquiza de Carvalho,1997; Orquiza de Carvalho & Villani, 1996; Scott, 1992) that we were able to recognize on their explanations of experiments.

Over the past few years, members of our research team have been working with science teachers in culturally diverse middle schools to find ways of improving teachers' effectiveness and the quality of students' learning. One direction our work has taken involves the use of classroom-based, embedded assessment as a vehicle for helping teachers become more attuned to students' learning and understanding of scientific ideas that are part of the curriculum. Through a project supported by NSF and Michigan State University, we have been able to work intensively with more than a dozen teachers over a four year period to formulate resource materials and approaches to aid teachers in incorporating assessment as an integral part of instruction.

To support teachers with this transformation of their teaching, we have worked with scientists and teachers to develop teaching and assessment resources for six topics that are common to most middle school science curricula. One of these topics is entitled Structure of Matter which corresponds to the subject content of this investigation.

For each topic we have assembled the following resources, based on research, advice from teachers, guidance from scientists, and recent statements from the agendas for reform such as Benchmarks for Science Literacy and National Science Education Standards: five to seven key ideas that represent the domain of the middle school curriculum on the topic; a list of difficulties students often encounter when attempting to learn this subject matter, based on research findings and teachers' practical knowledge; a sample set of teaching and assessment activities that address and assess students' learning of the content comprising middle school curriculum for the particular topic; assessment criteria for each activity that are consistent with contemporary goals for middle school students in science; examples of students' work pertaining to these activities, along with teachers' interpretations of them and suggestions for the next actions to improve teaching and learning.

In this investigation we worked with one of the teachers who collaborated in the development of the assessment resources (who also is a co-author of this paper) to study how she employed embedded assessment in her teaching and its impact on students' learning and motivation.

SOURCES OF DATA

We analyzed data obtained over several weeks of studying a multicultural sixth grade class of a public middle school in a low social-economic district of Lansing, Michigan. Among the twenty students in this class, there were three African-American, four of Asian descendent, three of Hispanic descendent, and ten Caucasian-American.

The data were taken from video-tapes of the classes, students' worksheets, tests and journals, and conversations and interviews with the teacher. During the period of research, the students were engaged in an instructional unit called 'Matter and Molecules'.

We video-recorded nineteen consecutive classes. In each class there were two researchers: one operated the camera and the other took notes. Besides the videos and the notes, we had access to the students' journals, assignments, and lab worksheets. Also, we had conversations and an interview with the teacher.

The students did ten main activities and experiments which are described below. The data for this study related to the students' learning were taken from these activities. The essence of the *sand, water, and marbles* activity was to get students to make an analogy between macroscopic bodies (in this case marbles, sand, and water (and molecules of different sizes. The analogical relation which this activity is aimed at eliciting has to do with geometrical characteristics, e.g., the size of and the space between things. The teacher filled a beaker with marbles, then she poured sand into it, filling it again. She then showed that it could be filled yet again by filling it with water. Finally, she made a comparison between this experiment and the behavior of molecules. Two days later, the students took a test related to his activity. Their answers, which are analyzed in the next section, refer to the following test questions: (1) Why could the container that was already filled with marbles still hold more sand and water? (2) Describe how molecules compare to other molecules in sizes.

In the *concept-map* activity, students received a list of statements about the topic 'Matter and Molecules'. They were told that the information was scrambled, and they were asked to organize them in the form of a concept map. The maps and the writings were then analyzed.

During the *role-play* activity, the teacher asked for some students to go to the front of the classroom and act like molecules in the different states (liquid, solid and gases. The day before and the day after the activity, the students took pre- and post-tests related to this activity. In those tests they were asked to draw pictures representing the three states of matter and comment on them. Their drawings were then analyzed.

In the *food-coloring* activity (laboratory), students were asked to predict what would happen when food coloring was dropped into a beaker of cold water, and into a beaker with hot water. Then the experiment was done by the teacher. The students were asked to compare their initial predictions with their observations. For this study the lab sheets from this experiment were analyzed.

In the *matching (I, II, and III* activities, students were given a list of key ideas, and a list of thought experiments (see appendix, page 29) that they were familiar with according to the teacher. They had to choose one experiment and one key idea they considered to be related, and then they had to explain the reason for the matching. This activity was done as homework. The lists were prepared based on the Assessment Resources Material (Gallagher et al., 1997).

In the *distillation* activity (laboratory), an apparatus for water distillation was placed in front of the students. After the distillation process began, the teacher invited the students, in groups of five, to come closer to the experimental device in order to observe and discuss about what was happening in the different stages of the process. For this study the students' lab sheets were analyzed.

In the *vanilla* activity (laboratory), the teacher put some drops of vanilla into a balloon then blew it up and tied it. After shaking the balloon, the teacher asked them if they could smell the vanilla. The balloon was passed around all the students in order to have each one them getting a conclusion. The day before the experiment, the teacher had explained it to the students, and asked the students to predict whether or not they would be able to smell the vanilla. The students' lab sheets were analyzed.

In addition to the written material related to the activities described above, we also analyzed three questions of the final test. The answers to the following questions were analyzed for this study:

(a) A bottle of nail-polish remover was opened in front of the classroom. A student seated in the rear part of the room smells it only after some minutes. Why?

(b) Why do drops of food coloring spread more quickly in hot water than in cold water?

(c) Draw a picture of the behavior of molecules in each of the following states: solid, liquid and gas. Also include in your picture your explanation of what you have drawn.

DESCRIPTION AND ANALYSIS OF THE DATA

a) Video analysis of teacher's actions

The video analysis was based on the instrument STAM[1]*. We observed that the teacher used a student-centered approach to teaching. Generally, she opened the class by writing a list of the main ideas on the board. Then she would explain what was expected of the students. Then students would begin their activities. Student activities comprised 60% of the total time spent in the eighteen classes we recorded.

The most notable characteristics of this teacher were: she showed concern about getting all the students to participate in the activities she gave, individual assistance to the students while they were working, she carefully explained all the objectives of each class; and she demonstrated that she was teaching for understanding.

The teacher worked to teach students to have scientific attitudes towards their data by commenting on their answers on the lab sheets, showing her concern for teaching the scientific process. On the lab sheets she discussed the students' answers by commenting on how they fit with the research question, hypothesis, description of experimental apparatus and procedure, conclusion, and evidence for the conclusion. Regarding content, she worked to teach students the particulate model of matter, properties of matter and matter measurement by implementing a set of laboratory activities. She also made some connections between the subject she was teaching and the world outside the school.

b) Students' mental representations of scientific concepts

Below, an analysis of the students' mental representation of scientific concepts is presented under the perspective of the assessment, i.e., we focused on how much students got out of each activity and how the outcomes were intertwined. It was important for us to observe how much

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[1]• The Secondary Teaching Analysis Matrix is an instrument addressed to be used by researchers and teachers educators in the analysis of video-recorded classes. It was developed by J. Gallagher and J. Parker(Michigan State University.

of the activities appear through the following activities. In addition to the representation of scientific ideas, alternative ideas that the students came up with were taken into account. Our results are summarized in two tables.

Table 1 (pages 10 and 11) contains the students' mental representations of scientific ideas that were recognized as being the best or the most scientific. They did not necessarily indicate the scientific concepts which the teacher intended to get across, but rather what the teacher's actions made it possible for the students to construct. They are presented in the order in which they appeared. When the same idea appeared two or more times, the order of appearance is denoted with the appropriate number. This makes it possible to follow the characteristics of many ideas through the sequence of the activities.

Table 2 (page 12) contains the categorization of students' representations of the scientific ideas presented in table 1. Each row number in table 2 corresponds to the same row number in table 1, hereafter referred to as 'lines'. The dashes indicate that the student did not answer that particular question. All the As in table 2 mean that the students' explanations of experiments indicate that the students' mental representation of scientific concepts are those that appear in table 1.

Line 1 refers to the ideas conveyed in the water-sand-and-marbles activity. The A students related size to space and made the comparison between the macroscopic bodies and molecules explicit. For example, Tracey[2*] wrote, *There were holes through the marbles where the sand and water could get through. . . .All molecules are different sizes and*

[2*] Names listed are pseudonyms.

Table 1 (Students' mental representations of scientific concepts

	Student's representations of scientific ideas	**Activity**
1	molecules have different sizes and there are spaces between them(I	sand,watr,and mrbl
2	the topic 'Matter and Molecules' is comprised of four great ideas: properties of matter, changes in matter, particles of matter, and states of matter	concept map
3	there are three states of matter that exist at ordinary temperatures: solid, in which the molecules are in a fixed position; liquid, in which the molecules change position and move past each other; and gas, in which the molecules spread apart.	concept map
4	chemical change is a change in matter in which one substance changes into another (I	concept map
5	the states of matter differ by the arrangement of molecules and the space between them	role-play (pre-test)
6	states of matter differ by the speed of molecules	role-play (post-t)
7	hot water differs from cold water by the space and/or speed of molecules (I	food coloring (anticipation
8	hot water differs from cold water by the space and/or speed of molecules (II	food coloring
9	different molecules interact with one another (I	food coloring
10	air is matter (I	matching (I
11	molecules cannot be seen but their behavior can	matching (I
12	speed is an important concept needed to describe molecules (I	matching (I
13	in chemical changes one substance changes into another (II	matching (I
14	during a chemical reaction atoms are rearranging to form new molecules	matching (I
15	heat is responsible for the speeding up of water molecules	distillation
16	cold is responsible for the slowing down of water molecules	distillation
17	phase changes affect the rearrangement of molecules	distillation
18	molecules cannot be seen but their behavior can	matching (II
19	space, and speed are important concepts needed to describe molecules	matching (II
20	molecules change phase at temperatures at which the speed of the molecules affects their arrangement	matching (II
21	when a material is heated its molecules move faster and faster; when it is cooled, the particles move more slowly	matching (II
22	chemical change is a change in matter when one substance changes into another (II	matching (II
23	molecules have different sizes and there are spaces in between (II	vanilla(anticipation
24	molecules have different sizes and there are spaces in between (III	vanilla (after exp.
25	water can change from a liquid to a gas and back to a liquid	matching (III
26	different molecules interact with one another (II	matching (III

Table 1 (continuation

27	air is matter (II	matching (III
28	all matter is made up of molecules that are in constant motion	matching (III
29	molecules cannot be seen but their behavior can	matching (III
30	heat is responsible for the speeding up of water molecules (II	matching (III
31	speed is an important concept needed to describe molecules (II	matching (III
32	different molecules interact with one another (III: when molecules are moving faster they bump against each other harder	matching (III
33	different molecules interact with one another (IV; speed is an important concept needed to describe molecules (III	nail-polish (final test
34	hot water differs from cold water by the space and/or speed of molecules (III	food coloring (final test
35	different molecules interact with one another (V	food col. (final test
36	the states of matter differ by the arrangement of molecules, the speed of molecules and the space between them	drawing molecules (final test

for example alcohol went through the holes of the water molecules because they are smaller.

Lines 2-4 refer to the ideas conveyed in the concept map activity. The concept-map activity, unlike the others, did not contain many assessable elements because in this activity the students had to organize a set of statements. From this, we were not be able to evaluate how much and which of these statements had been truly grasped by the students. It was necessary to wait for the following activities to verify which ideas were meaningful. Therefore, from the concept map activity only those ideas that had some repercussions on the following activities were selected for this study. In these lines all students were categorized as A students because all of them used the representations 2, 3, and 4 (see table 1) in their concept maps.

Lines 5 and 6 refer to the ideas conveyed in the role-play activity (drawing molecules). Line 36 refers to ideas conveyed in the

Table 2

Categorization of the students' representations of scientific concepts

	Ninh	Tracey	Lyn	Ray	Pilar	Jonathan	Anita	Stacy	Jeff	Antonio	Shari	Wei	Allison	Julie	Jose	Yang	Wayne	Randy	David	George
1	A	A	B	A	B	A	B	B	B	B	B	D	A	C	B	B	C	C	B	D
2	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
3	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
4	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
5	A	A	A	B	B	A	A	A	B	A	B	A	B	B	B	A	B	B	B	B
6	B	B	A	B	A	A	A	C	A	A	C	A	C	C	A	B	C	A	B	B
7	A	A	B	D	D	-	B	B	A	C	A	C	D	D	D	D	C	D	D	D
8	A	A	A	D	A	-	B	A	A	A	A	A	C	C	D	C	C	C	D	D
9	C	B	B	C	C	C	C	C	C	B	C	C	C	C	C	C	C	C	C	C
10		A	A																	
11	A																			
12					A															
13				A																
14													A							
15	A	A	C	-	C	-	-	B	A	-	-	D	C	C	C	B	B	D	-	-
16	A	A	B	-	D	-	-	D	B	-	-	D	A	B	D	D	B	D	-	-
17	C	C	B	-	B	-	-	D	C	-	-	B	C	C	C	D	D	D	-	-
18			A																	
19			A		A	A														
20	A					A														
21							A	A												
22		A																		
23	C	A	D	B	C	B	D	B	D	-	-	C	-	D	B	D	-	-	C	D
24	A	A	A	A	A	A	A	B	B	-	-	A	-	D	D	C	-	-	D	D
25	A																			
26	A																			
27				A																
28				A																
29													A							
30										A										
31			A																	
32											A			A						
33	C	C	B	A	A	C	A	C	C	C	C	C	-	A	C	C	C	C	C	D
34	A	A	A	A	A	A	A	A	A	C	A	A	-	A	D	A	A	C	C	D
35	B	B	B	D	D	D	D	D	B	B	B	D	D	D	D	D	B	D	D	D
36	A	A	A	A	A	A	B	B	A	A	A	A	A	A	A	A	A	D	A	A

answers to the final test question about drawing molecules. Line 5 categorizes the pictures that students drew in the pre-test, and line 6 categorizes the pictures that students drew in the post-test. In line 5 each A indicates that the student was able to recognize two elements which distinguished the states of matter, e.g., the *arrangement* of molecules and *space* between them. In the post-test (line 6) all the students recognized that *arrangement* and *space* were important elements in distinguishing states of matter. In lines 6 and 36, each A indicates that the students also recognized the *speed* of molecules as an element of distinction.

Lines 7-9 refer to ideas conveyed in the food coloring experiment. Lines 34 and 35 refer to ideas conveyed in final test question about the food coloring. Line 7 categorizes what students were thinking of in anticipation of the experiment, and line 8 categorizes what students were thinking of after the experiment. Each A in lines 7 and 8 means that the student explained his/her anticipation or observation using the ideas of the *speed* of water molecules and/or *space* between molecules to differentiate hot and cold water. For example, Ninh wrote, *the hot water has more space and it moves quicker than cold water because of the heat*. Had there been an A student in lines 9 and 35, it would have meant that he/she had referred to the food coloring molecules in addition to the water molecules.

Lines 10-14 refer to ideas that were conveyed in the Matching (I activity sheet. Line 10 refers to the key idea that air is matter. Both Tracey and Lynn appropriately matched this idea to the beaker-and-container-of-water experiment (thought experiment). For example, Lynn explained*, I think it goes together because air molecules take up space so that there won't be any room for the water to come in*. Line 11 refers to the key idea that molecules cannot be seen but their behavior can. Ninh matched this idea to the egg-in-vinegar experiment. By choosing this matching she showed that she recognized the changes in the egg as having been an evidence of the "reality" of molecules. Line 12 refers to the idea that speed is an important characteristic of molecules. Pillar tried to apply the idea of the speed of molecules to explain the egg-in-vinegar experiment. She wrote, *When the egg get in, the vinegar's molecules would be faster and that made the calcium comes out of the egg shell.* The idea of the speed of molecules was the core of her conclusion for the food coloring experiment, which was the last experiment for the class. By trying to apply this idea to another context, Pillar showed that the idea was already available to her as a tool for interpretation. Line 13 refers to the idea that chemical change is a change in matter when one substance changes into another. Ray compared two cases (baking soda/vinegar reaction, and the volcano (and associated them to the general idea of chemical changes. Line 14 refers to the key idea that during a reaction atoms are rearranging to form new molecules. Julie associated this key idea with the egg-in-vinegar experiment.

Lines 15-17 refer to the ideas conveyed in the distillation lab sheet. The A students in line 15 referred to heat as being responsible for the speed up of the molecules. For example, Ninh said, *heat is making the molecules to speed up and bubbling…the bubble helps make the molecules to speed up and it turn into a gas*. The A students in line 16 mentioned the cold water as being responsible for the slow down of the molecules. If there had been an A students in line 17, he/she would have made reference to the rearrangement of molecules.

Lines 18-22 refer to ideas that were conveyed in the Matching (II activity sheet. Line 18 refers to the key idea that molecules cannot be seen but their behavior can. In matching this key idea to the food coloring experiment, Lynn revealed that she recognized the results of food coloring experiment as an evidence of the "reality" of molecules. Line 19 refers to the idea that important characteristics of molecules are the speed of molecules and the space between them. Lynn used these ideas appropriately to explain the food coloring experiment. Jonathan used the same ideas to explain the metal ball-ring experiment. He wrote, *the ball heated expands making the molecules move faster, makes them move with more space in between.* Pillar used this idea to explain the experiment in which heated air inflates a balloon (thought experiment). Line 20 refers to the key idea that molecules change phase at temperatures at which the speed of the molecules affects the arrangement of the molecules. Jonathan matched appropriately this key idea to the distillation experiment. When Ninh saw the distillation experiment in the class, she wrote that *the cold water helps molecules to slow down.* On the same day, she chose this key idea to be associated with the glass-with-ice-and-water experiment (thought experiment), which she did as a homework. She explained, *the water is cold so it cool it and slow the molecules and changed it back to liquid.* She focused on the change of state from vapor to liquid, relating this experiment to the previously seen in classroom. Line 21 refers to the key idea that when a material is heated, its molecules move faster and faster; when it is cooled, the particles move more slowly. Anita matched this key idea to the food coloring experiment in an appropriate way. Line 22 refers to the idea that chemical change is a change in matter when one substance changes into another. Tracey wrote, *the vinegar is a chemical and when it reacts with the egg shell made of calcium it eats away at the shell and the egg feels like rubber*.

Lines 23 and 24 were conveyed in the vanilla-in-balloon experiment lab sheet. Line 23 categorizes what students were thinking of in anticipation of the experiment, and line 24 categorizes what students were thinking of after the experiment. The A student in lines 23 and 24 made reference to the idea of space between the molecules to explain her expectation or observation that the vanilla scent would be detected outside the balloon. There was only one A student in line 23, Tracey, and she was also the only one who made reference to molecules prior to the experiment. She wrote that *vanilla molecules scent go through the balloon (because) the molecules move and the balloon is thin when blown, so the scent go through the balloon molecules*. Ninh and Tracey offered the most sophisticated explanations in line 24 because they also compared the balloon molecules to the vanilla molecules.

Lines 25-32 refer to ideas that were conveyed in the Matching (III activity sheet. Line 25 refers to the idea of a liquid changing state to a gas. Even though Ninh had appropriately matched the key idea that water can change from a liquid to a gas and back to a liquid to the nail-polish remover experiment, from her explanation, she appeared to have been focusing only on the change of state from liquid to a gas and not to the reverse. In fact, she was putting the idea of a change of state into a new context, something she had already done during the distillation experiment. She wrote, *I think the light in our classroom help evaporates the smell*. Line 26 refers to the idea of interaction between molecules. Ninh compared the nail-polish remover experiment to the food coloring. She wrote, *When you open the remover its smell spread like the drop of the red coloring into water*. Ninh is one of the A students in lines 7 and 8, and one of the B student in line 9. By putting together her explanations concerning lines 7, 8, 9, and 26, we concluded that she probably considered the interaction between molecules. By spontaneously comparing two experiments, she showed her acquaintance with the experiments. Line 27 refers to the key idea that air is matter. Ray appropriately matched this idea to the heated-air-inflates-a-balloon experiment. Line 28 refers to the key idea all matter is made up of molecules that are in constant motion. Ray matched appropriately this key idea to the heated-air-inflates-a-balloon experiment. Line 29 refers to the key idea that molecules cannot be seen but their behavior can. In matching that idea to the egg-in-vinegar experiment, Allison revealed that she recognized this experiment as an evidence of the "reality" of molecules. She wrote, *the calcium on the egg acts with the vinegar and dissolve so slowly that you can barely see the tiny bit of behavior from the tiny molecules, but it make it.* Line 30 refers to the idea that heat makes molecules move faster. Antonio used this idea to explain the heated-air-inflates-a-balloon experiment. He wrote, *the heated air is like helium, so then the heat makes the molecules move very fast. The air is circulating and inflates the balloon.* Line 31 refers to the idea that speed is an important characteristic of molecules. Lynn used this idea to explain the nail-polish remover experiment. She explained that, *because the nail polish has a strong smell and when you pour it, it spreads quickly in the front, but it takes time for it to spread around*. Her explanation contained a potential conflict between the high speed of the molecules and the slow speed of the nail-polish remover displacement. She seemed to have recognized the conflict but did not try to solve it. Line 32 refers to the key idea that when molecules are moving faster they bump against each other harder. Shari and Julie matched this idea to the heated-air-inflates-a-balloon experiment. Shari explained, *When it is cooled, the particles move more slowly. When the molecules are moving faster they bump up against each other harder and that is how we get air in the balloon.*

Line 33 refers to ideas that were conveyed in the answers to the final test question about the nail-polish remover. The A students in line 33 made reference to the interaction between the nail-polish remover and the air. For example, Ray wrote, *the* (nail-polish remover) *molecules are drifting in the air*. Also, Anita explained the experiment by writing that *the air in the classroom have bubbles of molecules and the molecules fills up with the scent and the molecules move around the room*. Interestingly, she considered only the air to be made up of molecules. For the polish remover, she kept her old idea that scent is something fluid and non-particulate. It is interesting to note that Anita's explanations for both the food-coloring and the nail-polish remover cases were coherent. In the first case she only considered the water to be made up of molecules and not the food coloring, and in the second, she only considered the air, and not the polish remover.

The Bs mean that the explanations the students gave did not exactly correspond to the students' mental representation that appear on table 1, but they did indicate the presence of the particulate model of matter. For example, in line 23 some of the B students explicitly used the idea of molecules but also used other models. Stacy's explanation juxtaposed some old view and some new ones. After the experiment she wrote, *it smells really good and all the molecules inside are all around. You know there is no vanilla on the outside but it still smells*. She explained her reasoning by saying that *the vanilla inside the balloon you can smell easily*. Stacy solved the cognitive conflict (Chinn & Brewer, 1993; Villani & Orquiza de Carvalho, 1995) that she recognized between her anticipation and the experimental result without substantially changing her old models; she simply attributed more strength to the smell.

Other interesting fact related to B students refers to line 33. The nail-polish remover case presented a potential cognitive conflict to students because of the high speed of the gas molecules and the low speed of the nail-polish remover spreading: Why does the nail-polish remover take so long to spread if the gas molecules move fast? We verified that many students considered this conflict. For example, Lynn had already revealed the conflict in the matching activity III (see line 31). Now she developed a sort of solution for it. She wrote, *the nail-polish is a liquid so the molecules moves kind of slow and kind of fast, so when you open it the molecules start to spread in the front of the classroom and takes time for it to get to the rear end of the classroom.* Her solution considered the nail-polish remover to be both a liquid and a gas at the same time. In order to implement her solution, she needed to misapply the idea that the speed of molecules is higher in gases than in liquids. As a liquid, the nail-polish remover could move slowly; as a gas its molecules should move more quickly.

In general, the Cs mean that the student did not consider the substances to be made up of molecules. For example, Yang chose the path of minimum change in line 24. In his observation he explained, *I think it got some hole on the balloon*.

The Ds indicate that students did not give any explanation, except in lines 1, 9, and 33. For example, the D student in line 33 solved the cognitive conflict he also recognized in the nail-polish experiment by denying that gas molecules move so fast. George wrote, *it has not that strong and the molecules don't move as fast*.

The sand, water, and marbles activity turned out to have a very powerful effect on the students' understanding of molecules because it introduced the idea of space between molecules that would be applied to future study. From line 5, we conclude that the sequence of activities coming before the role-play pre-test provided students with the framework for distinguishing among the states of matter in terms of the space between the molecules. The analogy between macroscopic bodies and molecules enabled the students to understand that space between molecules was a fundamental characteristic of matter. The concept-map activity enabled them to use their new idea of space to construct a distinction among the three states of matter.

From lines 5 and 6, it can be concluded that the novel element introduced by the role-play activity was *speed*, since most of the students started to mention this element after that activity. This activity also reinforced the recognition of the elements which the students already knew at the time of the pre-test. From line 7 it is concluded that for three students at least, the idea of the water molecule had already become available to be used as an intellectual tool to explain new data. For three others, it seems that this idea was close to becoming available. In comparing lines 7 and 8 it can be concluded that the food coloring activity was an opportunity for at least three students (Antonio, Pillar, and Wei) to construct the idea of the difference between hot and cold water in terms of molecules. For four other students (Tracey, Ninh, Jeff, and Shari) this difference was simply confirmed, since they had constructed that idea earlier. For two other students (Lynn and Stacy) the idea became more precise as a result of this activity. From line 9, we can conclude that nobody explicitly made reference to food coloring molecules. It seems that just because the activities up to this point had contributed to students' building up an image of water molecules, there is no guarantee that the same activities would contribute to their building up a particulate image of food coloring.

From line 15, we verified that three students (Ninh, Tracey, and Jeff) explicitly linked heat with the speeding up of molecules. Three students (Stacy, Yang, and Wayne) made reference only to molecules and five others (Lynn, Allison, Pillar, Julie, and Randy) made reference only to heat. From line 16 we can conclude that only three students (Ninh, Tracey, and Allison) linked the cold water to the slowing down of the molecules. Four other students made reference to the cold water as being responsible for the water condensation (they did not consider water molecules in their explanations. By comparing lines 15, 16, and 17 it can be concluded that the distillation activity was partially successful at getting students to describe the process of evaporation and condensation using the key ideas of the speeding and slowing down of the molecules. However, none of the students used the idea that a change of state affects the rearrangement of molecules in his/her explanation. This does not mean that students had not noticed the change of state, since some of them (the C students in line 17) gave alternative models to the change of state.

By comparing lines 1, 5, 7, 8, 19, 23 and 24 we can follow the student's ideas of 'space' along the path of construction of the concept of molecule. More than half of the students were successful at explaining what happened in the vanilla experiment. Tracey, especially, was able to give a very complete explanation of the vanilla experiment even prior to the experiment. To a great extent, students who were successful at this were those who were well-acquainted with the idea of space, which had been introduced by analogy in the sand, water, and marbles activity, and corroborated by other activities along the path.

By comparing lines 34 and 35 to line 8 and 9 it can be concluded that the food coloring activity was particularly successful at getting students to distinguish hot water from cold water using the idea of speed of molecules. The second time the experiment was done, more students revealed having grasped the idea. As far as the particulate image of the food coloring substance is concerned, no substantial difference can be noticed between the first and the second time they analyzed it. No student ever explicitly made reference to food coloring molecules.

c) Students' actions and the multicultural factor.

Most of the time, the students were fairly well engaged in the activities. Seven or eight of them seemed to be very interested in science. This was believed to be so due to the fact that those students were focused on the teacher's explanations. Also, they performed well on tests, assignments, and in lab activities.

The classroom was disturbed on occasion by behavior problems. In those situations the teacher was firm; she explained her points of view on the necessity of discipline and respect, and demanded a cooperative environment in the classroom. The students seemed to understand the necessity of a 'productive discipline.'

The relationship among the students seemed to be very amiable. Several opportunities were created by the teacher to get them to work together, which is an important factor in reducing avoidance behavior in the classroom (Atwater, 1996).

Judging those sixth grade students by their participation in the eighteen video-recorded classes, there seemed to be no apparent facts which could have related the performance of the students to their ethnic origin. However, the interview with the teacher provided information about each student that eventually led us to a greater insight into the aspect of multiculturalism in that classroom.

The teacher described her classroom as having five top students. This group was comprised of two students of Asian descendent (Lynn and Ninh), one student of Hispanic descendent (Antonio) and two Caucasian-American students (Jonathan and Tracey). The teacher regularly addressed questions to Antonio, and it seemed that he always fulfilled her expectations. According to the teacher, the parents of these students were very concerned about their child's education and were very supportive. Two cases in particular drew our attention: Antonio's parents, and Nihn's mother. Antonio's parents, according to the teacher, had very high expectations for Antonio's future. It seemed that they saw education as a highly important factor in overcoming their present social-economic condition. Ninh's mother, despite the fact that she was dealing with a serious disease, and that she could not speak much English (she was Vietnamese), was very supportive of her daughter, and demanded a good performance of her scholastically.

According to the teacher's description, seven students were low performers in science. In this group there were two Afro-American, two Caucasian-American, one Hispanic and two Asians. If analyzed based on the degree of parental involvement, it can be seen that all students of this group had parents who were concerned about their children's education but did not know how to help them effectively. The teacher described several cases where this problem was evident.

We observed that the teacher understood and dealt well with the ethnic-cultural differences of her students. Throughout the eighteen video-recorded classes, the teacher demonstrated that she cares about all the students. Also, she put a lot of effort into reaching more of the low-performing students. She often would sit with those students to try to get them to talk about their difficulties related to the activities.

CONCLUSIONS

The students can be distinguished by the number of attempts they took to make sense of the scientific ideas. Those who took a high number of attempts were more likely to appropriately match key ideas with experiments that had not been explored much in the classroom. The same students were more likely to compare experiments with other experiments using scientific ideas. It seems that the students who were persistent in trying to understand scientific ideas from one activity to the next gained a familiarity with both key ideas and experiments that made the mental construction of connections between them easier.

Looking at table 2, two groups can be visibly distinguished. The first one, on the right of the table, is composed of Ninh, Tracey, and Lynn. They clearly made many attempts to make sense of the scientific concepts (each of them got a total of eighteen As and Bs. Based on students' participation in the classroom and on the teacher's opinion, Antonio, Ray and Jonathan would likely have been classified in this group if they had done all assignments that the first group did. Another reason to believe that these three students would have been in right group was their performance in the matching activities.

The second, more visible, group is composed by Jose, Yang, Wayne, Randy, David, and George. They appear on the left of table 2. They made few attempts at constructing meaning out of scientific concepts, and, particularly, they did not do well in the matching activities. They were more likely to have a hard time matching key ideas with experiments that had not been explored much in the classroom, mainly because they did not share the same frame of reference of science to describe the experiments.

Most of the students constructed As and Bs mental representations of those basic scientific ideas that had been applied many times in different contexts, as can be verified in lines 1, 5, 6, 8 ,15, 34, and 36. Vos and Verdonk (1996) described these ideas as follows: (a) molecules behave as hard, solid and (except in chemical reactions) immutable objects; (b) in drawing, the molecules may be portrayed as small circles or dots; (c) molecules are too small to be seen; (d) in a gas the empty space between particles is much larger than that occupied by the particles themselves; (e) in solid the particles are much closer together; (f) in solid the particles are arranged in regular patterns, with each particle being able to move only around a fixed position; (g) in liquids the particles are irregularly arranged and move from place to place; (h) s*ome* matter (mainly water and air) consists of entities called particles; (g) there is a direct relation between the temperature of an amount of matter and the average kinetic energy of its particles.

If some ideas had been introduced sooner, the students would have been more successful at explaining some of the experiments. One of these ideas refers to collisions between molecules. This idea was introduced in the list of key ideas and was used only by Shari in the matching activity III (line32). Before that, all students considered only one of the substances of a mixture (food coloring and water, air and nail-polish remover, vanilla and air) as being made up of molecules. In the case of the nail-polish remover most of the students faced a cognitive conflict (lines 31 and 33) that put an idea that they had already became familiar with at risk. Only few of the students recognized the presence of the air and solved the conflict successfully.

Our results support the idea that the science teachers should be committed to promote greater opportunities for students to become familiarized with a manageable number of experiments and a manageable number of scientific ideas that potentially match each other. This notion of students' going back and forth inside a limited range of experiments and keys ideas seems to be compatible with the idea of objectivity of science. As Ziman (cited in Osborne, 1996) says: "the objectivity of a well established science is thus comparable to that of a well-made map drawn by a great company of surveyors who have worked over the same ground along many different routes."

Regarding to the multicultural context of the classroom that we analyzed, we can say that the students' performance cannot be related to their ethnicity or cultural background, even though in other contexts this relation might exist (Gallard, 1993; Atwater, 1994).

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APPENDIX

Key Ideas

1	All matter is made up of molecules that are in constant motion. (a) Molecules cannot be seen but their behavior can. (b)Air is matter. (c) Water is matter.
2	As a material is heated, its molecules move faster and faster. When it is cooled, the particles move more slowly. When the molecules are moving faster they bump against each other harder.
3	Matter usually exists in one of three phases: solid, liquid, and gas. (a) The phases differ in the speed of the molecules. (b) The phases differ in the space between molecules. (c) The phases differ in the arrangement of molecules: the molecules in a solid remain between the same neighbors but they continue to move; in a liquid, they can move past each other but remain close together; in a gas, they move randomly and independently.
4	Molecules change phase at temperatures in which the speed of the molecules affects the arrangement of the molecules. (a) Phases changes involve changing the speed of the molecules, so that the bonds between molecules change. (b) Phases changes do not changes molecules themselves. (c) It takes energy to break intermolecular bonds. A large amount of energy is absorbed by the substance as the bonds break. (d) Water can change from a liquid to a gas and back to a liquid.
5	During chemical reactions, atoms are rearranged to form new molecules. Bonds between atoms are broken and reformed. (a) Breaking bonds between atoms requires energy. (b) Chemical changes involve rearranging the ways that atoms are combined into molecules.

Thought Experiments

1	You have an empty beaker and a container of water. You press the inverted beaker into the water, and see that the water does not fill the beaker.
2	The egg in the vinegar.
3	A glass that contains ice water appears to "sweat".
4	You put a drop of food coloring in a beaker of water, and the food coloring spreads.
5	We can see chalk dust visible is strong light.
6	If a bottle of nail-polish remover containing acetone into a dish that is at the table classroom, the students who are seated at rear of the classroom will not smell the perfume until some minutes later.
7	A metal ball fits through a ring. The same metal ball is heated and no longer fits through the metal ring.
8	Heated air inflates a balloon.
9	The liquid in a thermometer expand as the surrounding temperature increases.
10	The rate if food coloring spreading in hot water is greater then the rate of food coloring spreading in cold water.
11	Water distillation.

THE AUTHORS:

Lizete M. Orquiza de Carvalho is Assistant Professor of Physics in the Faculdade de Engenharia de Ilha Solteira(SP (Brazil). Since 1980 she has been developing researches in Science Education, especially in the field of alternative concepts and conceptual change. She completed her doctorate at Universidade de Sao Paulo (Brazil) in 1994. Currently, she is Visiting Scholar in the College of Education at Michigan State University.

Washington L. P. Carvalho is Assitant Professor of Physics in the Faculdade de Engenharia de Ilha Solteira(SP (Brazil). For almost two decades he has been developing researches in alternative concepts among students, creativity in science education, and strategies for science teachers' development. He complete his doctorate at Universidade de Campinas (Brazil) in 1991. Currently, he is Visiting Scholar in the College of Education at Michigan State University.

Tawny Alvarado is Science Teacher at Otto Middle School, Lansing(MI. For four years she participated in the Assessment Project at Michigan State University, and collaborated in the development of the "Assessment Resources" that is a set of texts addressed to help science teachers to use embedded assessment in their teaching.

James J. Gallagher is Professor of Science Education at Michigan State University, where he has worked for the last twenty years. He earned his doctoral degree at Harvard University in 1965. His major interests are in the ecology of secondary school science classrooms and in the education of science teachers. Currently, he codirects the Assessment Project at MSU, and is part of a Ministry of Education project in Thailand on environmental education.