Essays in Education

Volume 24 | Article 9

Summer 8-1-2008

A Cross-Cultural Study: Middle School Students' Beliefs about Matter

Mary B. Nakhleh
Purdue University

Ala Samarapungavan
Purdue University

Yilmaz Saglam
University of Gaziantep

Erdine Duru
Pamukkale University

A Cross-Cultural Study: Middle School Students' Beliefs about Matter

Mary B. Nakhleh
Ala Samarapungavan
Purdue University

Yilmaz Saglam
University of Gaziantep

Erdinc Duru
Pamukkale University

Abstract

Turkish middle school students' understanding of the nature of matter was examined and compared to those of US counterparts. Sixteen Turkish middle school students were interviewed using a semi-structured interview guide. The interview explored students' understanding of the particulate nature of matter in three areas: (1) the composition of the substances; (2) the relationship between particulate structure and macroscopic properties; (3) the relationship between particulate structure and processes. The results indicated that many of the middle school students interviewed could state that matter was composed of atoms. However, the majority of them were not able to use this understanding to explain macroproperties or processes of matter. Compared to the US students, the Turkish students could use terms more appropriately in describing the microparticulate nature of matter. However, when students tried to explain the macroproperties or processes of matter, the US students offered more complex and detailed explanations.

Significance of the Study

In this study, Turkish students' ideas about the nature of matter were investigated. The conceptual content of the students' ideas was analyzed and these ideas were examined for accuracy, coherence and internal consistency. One purpose of the current study was to provide data for a cross cultural comparison of Turkish and US middle school students in order to see what were the similarities and differences in their understanding. In our prior research with US elementary and middle school students, we found that students had significant misconceptions about the nature of matter (Nakhleh & Samarapungavan, 1999; Nakhleh, Samarapungavan, & Saglam, 2005).

For example, US elementary schools students typically did not recognize that all states of matter were particulate (composed of atoms and molecules) and did not explain phenomena at the particulate level (Nakhleh & Samarapungavan, 1999). The US middle school students were more likely to recognize that matter was particulate, but they had difficulty in providing acceptable microscopic explanations for such macroscopic properties as rigidity, fluidity and malleability. The US middle school students in particular, seemed to invoke many ad hoc and inconsistent explanations for such phenomena as dissolving and phase transition.

By comparing the results of the US middle school study with the current study of Turkish middle school students, we hope to increase our understanding of students' chemistry learning across cultures. As Carey and Spelke (1994) suggested, cross-cultural comparisons of conceptual development can inform theories of conceptual change by providing data on universal and culture specific aspects of development in students' knowledge representations. Second, this study provides important information about the challenges that all students face in building their conceptual understanding of matter and what alternative conceptions they commonly hold. Ultimately, this research will help teachers in all cultures develop appropriate instructional strategies to facilitate student learning.

In this study, macro refers to observable and micro refers to invisible characteristics of matter. For example, when students described the properties of matter by statements such as 'it is sweet', 'round', 'white', 'a big piece' and 'made of small particles but can be seen by the naked eye', we categorized these statements as describing macroproperties of matter. In contrast, when students talked about 'invisible particles' or use the terms 'atom' or 'molecule', we categorized those statements as describing microproperties or molecular level properties of matter.

Theoretical Perspective

The process of acquiring knowledge about the natural world is viewed as one in which even before the onset of formal instruction, students construct initial understandings of the observed world based on their everyday experience. This everyday experience is not merely direct or 'sensory' in nature and is itself culturally mediated, especially by everyday language, and lay or folk models both explicit and implicit or enacted, of the natural world (Cole, 1990; Vygotsky, 1978; Wertsch, 1985a, 1985b) With the onset of formal education, students are exposed to the adult culture's formal or scientific theories of the natural world and must restructure their naive beliefs in ways that take the new information into consideration. This general approach is supported by a variety of studies on naive beliefs about the physical world (McKloskey & Kargon, 1988; Samarapungavan, Vosniadou, & Brewer, 1996; Wiser, 1988; Vosniadou & Brewer, 1992, 1994).

Prior Research on Students' Understanding of the Nature of Matter

Some studies have examined young children's beliefs about matter (Au et al., 1993; Rosen & Rozin 1993). Both these studies indicated that children ranging from 3 to 5 years of age believed that dissolved substances continue to exist as tiny invisible particles that influenced the macro properties of the solution, such as taste.

In an earlier study, our research group examined US elementary school students' understanding of the particulate nature of matter (Nakhleh and Samarapungavan, 1999). This research investigated a wider spectrum of substances by including substances in all three states of matter and by including such world examples of matter as granular sugar, solid wood, solid copper wire, liquid water, and a helium-filled balloon. We probed students' understanding of several concepts related to the particulate nature of matter, including their understanding of the solid, liquid, and gas states of matter, phase changes, and their understanding of the dissolving process. It is found that the US elementary school students tended to use descriptive rather than explanatory frameworks. In other words, they often described phenomena rather than explained them. However, these frameworks did tend to cohere at an ontological level, in that when explanations were provided for phenomena, they tended to be in terms of external forces, such as 'pushing' and 'crushing', that operated on matter. Further, we found that many students seemed to have macroparticulate frameworks. In other words, they believed that matter could be broken down into tiny, even invisible particles by human action. However, they believed that the smallest particles of a substance, such as sugar, still possessed all its macroscopic qualities, such as taste and color.

A follow-up study with US middle school students (Nakhleh, Samarapungavan, and Saglam, 2005) showed that while 67% of the students believed that all matter was made up of atoms and molecules, 33% of the middle school students had not completed the conceptual transition from macroparticulate to microparticulate frameworks. Additionally, even the 67% of students who believed that matter was comprised of atoms and molecules could not provide microparticulate explanations for a wide range of macroscopic phenomena. For example, while these students typically provided microparticulate explanations of phase transition and dissolving, they treated macroscopic material properties such as fluidity and rigidity as intrinsic properties of matter and did not explain them at the microparticulate level.

Gable (1998) has noted that coordinating macroscopic (observable properties and behavior of substances) and microscopic (atomic and molecular) levels of representation and explanation in chemistry is a challenge even at the college level. McRobbie and his associates (McRobbie, 1998; Thomas & McRobbie, 2002) have also found that secondary school students frequently explain material phenomena at a macroscopic rather than a microscopic level. By 8th grade, students have typically been introduced to the concepts of atoms and molecules that constitute the microscopic level. They have also been taught to explain the states of matter and phase transitions in terms of the microscopic level.

Therefore, in order to better understand the scope and generalizability of these findings, it is important to collect data on students' understanding of the nature of matter from a variety of cultures. The current research contributes to this endeavor by examining the beliefs of Turkish middle school students.

Design and Procedures

Sample Description

The present study was conducted with 8th graders at an urban middle school in Izmir, Turkey. The fourth author interviewed 16 volunteer students, 10 of whom were female and 6 of whom were male, drawn from four different classes. The semi-structured interviews probed students' understanding of the nature of matter. The school enrolled students with a mix of socioeconomic levels that we found to be similar to the US school. The students were all Turkish.

Methodology

The 4th author individually interviewed the students, using a Turkish-language semi-structured interview guide similar to the one used by Nakhleh and Samarapungavan (1999) with elementary students and in their study of US middle school students (Nakhleh, Samarapungavan, & Saglam, 2005) (see Appendix). The English-language interview guide was translated into Turkish by the 3rd author. Some of the substances were also changed as discussed below. The interview guide consisted of three sections: (1) questions on properties and particulate nature of pure substances; (2) questions on macroproperties of pure substances; and (3) questions on phase changes and dissolving processes. The 4th author asked questions and took notes. The interviews were audio taped and later transcribed and translated. Each interview lasted about 30 to 45 minutes. When required, the interviewer asked further questions to probe students' understanding in more depth.

The questions were open-ended and were designed to explore the student's understanding of matter on both the macroscopic level of observable properties and on the molecular level. The questions were of two types: (1) descriptive and (2) explanatory. In the descriptive questions, each student was asked how he or she would describe a substance. After students' initial response, the interviewer followed up with questions that probed whether a substance was made of small particles or was one continuous piece. We were concerned with both initial spontaneous descriptions and their understanding of the particulate nature of matter. In the explanatory questions, we asked students to explain macroproperties of matter, such as the fluidity of water and the malleability of copper wire. We also had the students watch such common phenomena as ice melting or dissolving salt in a glass and asked them to explain what they thought was happening in each process.

The questions were designed to find out the students' understanding of matter in the solid, liquid and gas states. Furthermore, the substances selected for this study were common objects with which students might be familiar and which gave them the opportunity to use their prior knowledge or experiences. We asked them to describe six substances: a sugar cube, liquid water, a wooden toothpick, a metal hinge, a piece of copper wire, and a clear balloon filled with air. For phase transitions and the dissolving process, we used ice cubes and table salt. The original English version used a sugar cube, liquid water, a wooden toothpick, a piece of copper wire and a clear balloon filled with helium gas. For phase transition and the dissolving process, similar substances were used such as ice cubes and table salt. However, in some cases, the Turkish students were asked to explain melting process of common substances, such as a metal hinge and a piece of copper wire.

Based on our previous studies of matter with US students (Nakhleh, 1994; Nakhleh & Samarapungavan, 1999; Nakhleh, Samarapungavan, & Saglam, 2005), we conjectured that these Turkish students might also still be engaged in the process of transitioning from continuous to particulate to microparticulate understandings of matter. We also thought that the Turkish students might articulate views on the nature of matter that were similar to the views of the US students.

Data Analysis and Results

The interview tapes were transcribed and translated into English. The students' responses were then coded based on the categories and operational definitions shown in Table 1. These categories initially emerged from the US elementary and middle school students' data. However, the additional category of 'microquantity' emerged from the data of this study. This additional category is shown in italics on Table 1. The names used are pseudonyms. The third author used the decision rules in Table 1 to code the transcripts. Two additional coders also used table 1 to code transcripts, and an inter-rater reliability of 95% was calculated. Disagreements were resolved by discussion.

Table 1
Operational definitions for coding categories

I. Categories arising from initial, spontaneous description	
1. Macroproperties	
1.1 Visual	Attributes detected by the visual system, such as color, visible, invisible, clear, colorless
1.2 Shape	Attributes pertaining to geometric shape, such as pointy, square, round, irregular
1.3 Composition	Attributes pertaining to the name/ nature of the substance, such as made of wood, made of sugar, etc.
1.4 Texture	Attributes detected by the sense of touch, such as cold, hot, smooth, rough, wet, dry
1.5 Function	Human use of the substance/ object, such as put on cereal, used to clean teeth, used to pick up things
1.6 Other property	Miscellaneous properties mentioned by the children, such as 'strong', 'does not bend easily', 'light'
1.7 State of matter	Mention of the state of matter of the substance, i.e., solid, liquid, or gas
1.8 Size	Indication of the size of the visible particles, such as sugar crystals
1.9 Taste	Refers to the taste sensation of the bulk substances, such as 'sugar tastes sweet'
1.10 Human action	Refers to phenomena created by human action, such as breaking a toothpick into pieces or bending a copper wire
1.11 Quantity	Attributes pertaining to the amount of the substance, such as 'it is heavy if there is more'
1.12 Source	Mention of the resource of the substance, such as 'it comes from ground', 'it comes from ocean'
2. Microproperties	
2.1 Composition	Attributes pertaining to the structure of the substance, such as 'made of molecules' or 'made of atoms'
2.2 *Microquantity*	Attributes pertaining to the amount of the substance on microlevel, such as 'molecular mass of iron atoms is heavier than the atoms in the wood'

II. Categories arising from interviewer-constrained description of composition

3. Macrocontinuous	Statements which indicate a continuous view of matter such as 'made of one piece,' 'a solid piece' cannot be divide or broken down
4. Macroparticulate	Statements which indicate a particulate (but not molecular) view of matter, such as 'made of little pieces', can be broken into little pieces by human action. Usually states that the little pieces are of different shapes and sizes, like broken fragments of a whole. Often children will indicate that the particles are small but can be seen, like sugar crystals or wood splinters
5. Macrodescription	Describes substances/ objects in terms of their bulk properties, such as color, texture, shape, size (see Category 1 above)
6. Microparticulate	Statements that indicate a molecular view of matter, such as 'made of molecules,' 'made of atoms' Usually indicates that the molecules or atoms are more uniform in shape and size than broken fragments and that the molecules or atoms are very, very tiny and invisible. Sometimes confusion with the microbe scale of size (see Category 2 above)

III. Categories arising from explanation of fluidity, rigidity and malleability

7. Macrodescription	Explanation of a phenomenon based on another, noncausal property, other property such as 'it bends because it's not hard.' Does not invoke the molecular level of explanation
8. Macrointrinsic	Explanation of a phenomenon based on a property perceived as inherent to the substance, such as 'wood is stiff,' 'metals bend'
9. Macrostate	Explanation of a phenomenon based on the state of the substance, such as 'because it is a liquid'
10. Macroforce	Explanation of a phenomenon based on the action of an external force, such as gravity
11. Macrocomposition	Explanation based on the composition of the substance, such as 'toothpick is made from wood, but water is made from chemicals'
12. Macrocompression	Explanation based on the perceived compressed state of the substance, such as 'wire is denser, less breakable'

13. Nonexplanation	Explanation based on attributes that do not distinguish between the substances, such as ‘both are solids’ for the copper wire and the toothpick
14. Macroparticulate	Explanation of a phenomenon based on a particulate (nonmolecular) view of matter, such as ‘water has pieces but wood does not’
15. Macrocontinuous	Explanation of a phenomenon based on a continuous view of matter, such as ‘wood is hard because it’s compacted tightly, but water is not’
16. Macroquantity	Explanation of a phenomenon based on the amount of the substance, such as ‘the more you have, the tougher it will be’
17. Microparticulate	Explanation of a phenomenon based on a molecular view description of matter, description such as ‘water is freer because it is made of molecules and wood has none’
18. Microstate	Explanation of a phenomenon based on the molecular state of the substance, such as ‘water flows because it is a molecule or an atom’
19. Microcomposition	Explanation of a phenomenon based on the composition of the substance, such as ‘they have different properties because there are different molecules or atoms in them’

IV. Categories arising from explanation of phase transitions and dissolving

20. Macroprocess	Explanation based on a perception of a process occurring, such as ‘water freezes and turns into ice’
21. Macroprocess-heat	Explanation based on a perception of a process involving heat, such as ‘ice melts when it gets warm’ or ‘ water freezes and turns into ice’
22. Microprocess	Explanation based on a molecular level process, such as ‘salt molecules join water molecules, fit together with others to become more compact’
23. Microprocess-heat	Explanation based on a molecular level process involving heat, such as ‘atoms spread out when you warm something’

Note. Words enclosed in single quotes are paraphrased, not direct quotes. Words written in italics are new categories that emerged from data.

As the third author translated the transcripts, he encountered some challenges in translating some expressions used by the students. To illustrate, when asking students what happened to the salt when it was added to water, some students used the term ‘eridi’. This was the past tense of the verb ‘erimek’, which literally means ‘to melt’. In Turkish, the scientific term ‘to dissolve’ refers to ‘çözmek’, but people do not use this term in daily life. Instead, the term ‘erimek’ is used to refer to both melting and dissolving in everyday conversation. Accordingly, we had to assume that the students using this term meant that the salt dissolved in water. Students' responses fell into five major categories: (1) an initial spontaneous description of six substances (sugar cube, toothpick, metal hinge, copper wire, water, and balloon filled with air), (2) composition of these substances, (3) explanation of fluidity (water vs. toothpick vs. gas), explanation of malleability (metal hinge, copper wire vs. water vs. sugar cube), and (4) explanation of phase transitions (liquid water and ice), and (5) explanation of the dissolving process (table salt and water).

Initial Spontaneous Descriptions

In this section of the interview, the students were asked to describe each substance. It is found that the spontaneous descriptions ranged from (a) macroscopic (macro) properties, such as taste, function, visual properties, texture, shape and size, to (b) microscopic (micro) properties, such as 'made of molecules'. All sixteen students gave at least one macrolevel description in their initial spontaneous descriptions. Erkan, Deniz, Sevim, Mustafa, Ilknur, Derya, Emin, Aynur, Sila, Ibrahim, Turkan, and Hulya did not give any microlevel descriptions in their initial-spontaneous descriptions. Only four students (Sezer, Sener, Melise and Berrin) invoked at least one description for the microproperties of matter. Sezer described the toothpick, metal hinge and copper wire using a molecular understanding of matter. Sener portrayed the sugar cube and metal hinge as being composed of atoms. Melise viewed the metal hinge as consisting of small molecules, but Berrin described the metal hinge and copper wire as being composed of atoms.

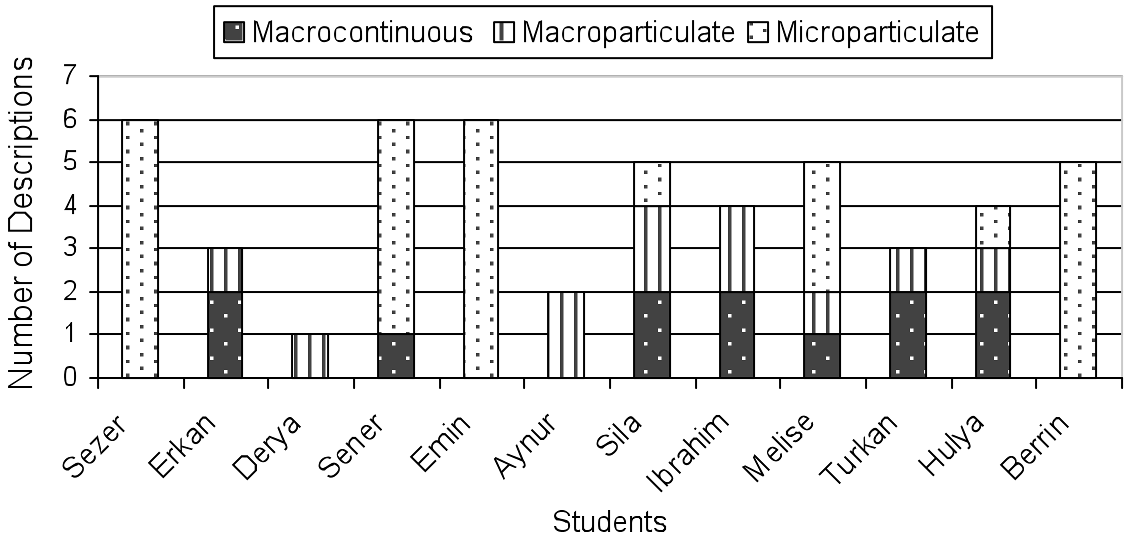
The following dialog taken from Sezer's interview transcript (p. 1) illustrates both a macro and microlevel view of matter. In this and in all subsequent data clips, the interviewer is represented by R and the student by S.

> R- This is a sugar cube, can you describe the properties of it?
>
> S- It is a solid material. It has a volume and mass. Since it occupies space, we can define it as matter.
>
> R- This is a piece of wood, can you describe the qualities of it?
>
> S- The wood is made of wood atoms. Since the wood atoms, via gathering together in the space, have a volume and mass, this is matter.

Interviewer-Constrained Descriptions of Composition

After their initial, spontaneous descriptions, the students were then asked whether each substance was made up of little bits or of one big piece. Figure 1 displays how these interviewer-constrained descriptions were coded. As shown in figure 1, students gave a variety of descriptions, ranging from the macrocontinuous to the microparticulate. Seven of the students gave at least one macrocontinuous description. Four students (Deniz, Sevim, Mustafa, and Ilknur) did not receive the question of composition. Three students (Sezer, Emin and Berrin) invoked microparticulate description of all objects. Four students gave mixed micro/macro descriptions.

Figure 1. Interviewer-constrained descriptions of composition made by each individual. Four students did not receive this question.



The students used statements such as 'made of one piece' or 'it is a big piece' to indicate that the substance was not made of little pieces; rather, it was made by cutting and shaping a larger piece. The following transcript taken from Sila's interview illustrates this viewpoint.

Note that in the following transcripts, you will notice that sometimes in the transcripts we used the term 'Play Doh:', which refers to the figures students made using play dough when they were asked to demonstrate the small particles of the substance.

R- What is a piece of wood made of? What makes it up?

S- What do you mean?

R- What comes together and makes up the wood?

S- It is a part of a tree. It is comes from a body or a branch of a tree.

R- Is this piece of wood a big piece of material? Or it is made by bringing small particles together.

S- It is made from a big piece.

On the macroparticulate level, they made such statements as 'made of little bits' to point out that the material was made of small, tiny particles. For example, they generally described sugar cube as made of small particles. When further asked how these small particles looked like, the students mostly made small empty circles with a range of sizes. The next quote, taken from Turkan's transcript, highlights this view of matter.

R- Is this sugar cube a big piece, or does bringing small particles make it up?

S- Bringing small particles makes it up.

R- Can you show me these small particles using Play Doh?
Play Doh: little empty circles with a range of sizes.

R- Sugar particles make it up. Are these particles very small?

S- Yes, they are very small.

R- Can we see them by the eyes?

S- Yes, we can.

On the microparticulate level, the students used molecular descriptions such as ‘made of atoms’ or ‘made of molecules.’ Some of the students modeled the structure of atoms using Play Doh and some said matter was made of particles too small to be seen by the eyes. These explanations were categorized as ‘microparticulate’. When students mentioned the terms ‘atoms’ or ‘molecules,’ we probed their understanding by asking what shapes these atoms or molecules could be and whether or not they could be seen. The students generally viewed atoms and molecules as being circles that were too small to be seen by the naked eye, and were similar to each other. Seven students (Sezer, Sener, Emin, Sila, Melise, Hulya and Berrin) invoked at least one microparticulate description for the substances. Only three students (Sezer, Emin and Berrin) viewed all substances as made of atoms. However, Berrin could not provide a description for the composition of water. The following quote taken from Sezer’s transcript illustrates this molecular view of matter.

R- Is the sugar cube one big piece of material? Or is it the part of a material?

S- The smallest unit of the sugar is the atom. The sugar atoms, by coming together, make up the sugar.

However, it is detected that Sezer and Sener had some misconceptions about atoms. Possibly, they confused atoms with cells or microbes. The following excerpts illustrate this alternative conception.

Sezer’s excerpt:

R- This is a piece of wood, can you describe the qualities of it?

S- The wood is made of wood atoms. Since the wood atoms, via gathering together in the space, have a volume and mass, this is a matter.

R- What are the differences and similarities between this piece of wood and a tree?

S- The atoms in the tree can be alive; however, since this piece of wood no longer has a connection with the soil, it is not alive.

R- Can you give me some details about the wood atoms? What do you mean by saying 'atom'?

S- The wood atoms by gathering together make the wood and it occupies a certain amount of area in the space.

Sener's excerpt:

R- What can you say about atoms?

S- Atom is the smallest particle of matter. Atom is made of some components. These are protons, neutrons and electrons. That is it.

R- Can you show me how an atom looks like using this Play Doh.
Play Doh: Two small circles in the center, other empty circles surrounding them

R- What can you say about the size of an atom?

S- Since atom is the smallest particle of matter, it is too small to see by bare eyes. It is likely to see them under microscope.

Figure 2 displays students' responses by each substance. All students described sugar as being made of small particles on either micro or macroparticulate. Most of them described these bits as being circles with a range of sizes. They further stated that these tiny bits were compacted together to make up the cube. The following quote taken from Hulya's transcript illustrates this macroparticulate view of matter.

R- This is a sugar cube, can you describe the properties of it?

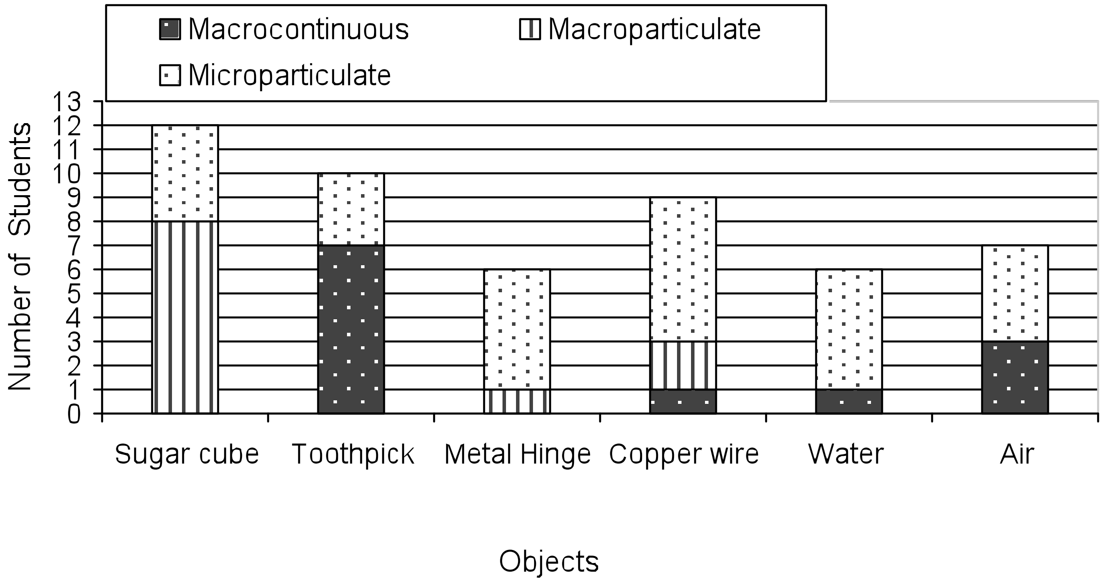
S- It is made of small particles. In other words, they are sugar. In the water, it turns to powder and dissolves.

R- You said it is made of small particles. Are these small particles the same or different?

S- They are similar to each other.

R- In this box is Play Doh. Can you show me these small particles using Play Doh? Using Play Doh.
Play Doh: Small empty circles stuck together. Like letter 'O'.

Figure 2. Interviewer-constrained description of composition by object.



There was no substance that was viewed as solely made of atoms by all students. However, all substances were viewed as being made of atoms or molecules by at least three students. The students had mixed views on copper wire, ranging from macrocontinuous to macroparticulate to microparticulate. The toothpick was also seen as being made of one big piece (macrocontinuous) by seven out of ten students. Therefore, we speculate that it was very difficult for students to describe solid matter with no visible granularity as being made of particulate or molecular matter. These students seemed to rely on what they saw rather than what they have learned at school. Another explanation could be that the students had difficulty in expanding or transferring their understanding of the particulate nature of matter to substances that they had never studied at school. For example, the students could easily see that sugar was particulate and therefore had no difficulty in describing sugar as particulate on either the macro or microlevel. However, it was more difficult for them to view the wood with no visible granularity as being composed of small particles. The following excerpt taken from Melise's transcript illustrates this macrocontinuous view of matter.

R- Is this piece of wood a big piece or does bringing small particles make it up?

S- This is a big piece because it is broken off a tree.

Explanations of Fluidity, Rigidity and Malleability

In order to explore students' beliefs about how the composition of a substance might influence its macroscopic characteristics, we asked each student to explain why water flows, but wood holds its shape, and air escapes when we open the balloon. In doing this, we probed their understanding of fluidity versus rigidity. We further asked them why we could break the sugar cube, separate the water and bend the copper wire. This probed the students' understanding of the properties of malleability and fluidity.

Fluidity, rigidity and malleability were purposely selected because the students had many opportunities to experience them in everyday life. Moreover, these properties could be explained on either macro- or microlevels of understanding of matter. The property of fluidity applied to gases and liquids; malleability and rigidity applied to solids.

As shown in Table 1, our coding framework for fluidity, rigidity and malleability had nine categories on the macrolevel and three categories on the microlevel. These categories had emerged from the data on the US elementary and middle school students (Nakhleh & Samarapungavan, 1999; Nakhleh, Samarapungavan, and Saglam, 2005). However, the Turkish students' explanations fell into only five categories: macrodescription, macrointrinsic, macrostate, macroparticulate, and macroforce. Interestingly, no explanation given by the students was on the microlevel. Even Sezer, Emin and Berrin who had viewed almost all substances as composed of atoms did not use this micropariculate understanding in explaining the macroproperties of matter. All of the Turkish students' explanations were on the macrolevel. We speculate that it might have been very demanding for these students to explain the properties of fluidity, rigidity and malleability from a molecular level of understanding.

Fluidity and rigidity. In order to explore students' understanding of the macroproperties of matter, such as fluidity and rigidity, the students were asked why the wood held its shape, the water flowed, and the air in the balloon escaped when we opened the balloon. Their explanations were coded into four categories: macrointrinsic, macrostate, macroforce, and macrodescription. No student gave a microlevel explanation. For example, Sila's explanation as to why some substances flow while others hold their shapes was coded as macrostate and macrointrinsic. The following quote taken from her transcript illustrates this understanding of matter.

> R- Do you think why the wood holds its shape, but water flows, and when I open the balloon the gas escapes?
>
> S- Because water is a liquid substance. It can take only the shape of the container. However, the wood stays as it is. That is, breaking, unless you hit it, it stays as it is. However, when the water, regardless whether it gets hit or not, is poured into another container, the shape of it changes. It takes the shape of the container.
>
> R- How about the gas in the balloon?
>
> S- It depends on the breath we blow into balloon. The air with which we filled the balloon causes the plastic to get inflated. When you tie the opening of the balloon, it stays with no change in shape. When you open the balloon, in other words, since the opening is not sticky, the air gets out of the opening.

Fluidity and malleability. In order to probe students' understanding of the properties of fluidity and malleability, the students were asked why we could break the sugar cube, separate the water and bend the copper wire. Students' explanations of fluidity and malleability were coded into five categories: macrodescription, macrointrinsic, macrostate, macroparticulate, and macroforce. The students most frequently used the macrointrinsic, macrodescription and macroparticulate categories. For example, Ilknur's explanations fell into the macrointrinsic category. The following quote taken from her transcript demonstrates this macro-level understanding.

> R- You can break the sugar cube, bend the metal, by pouring water into two different containers, you can separate it. Do you think why these happen? Why these substances act in these ways?
>
> S- Due to the nature of substances, when we hit the sugar cube with a heavy material, we can change it to a different shape. Regarding iron or metal, this is valid for only some of them. Some can be bent. Thick substances can be bent with the help of some kinds of devices. By pouring water into different containers we are able to give any shape we want to it.

Compared to the US students (Nakhleh, Samarapungavan, and Saglam, 2005), who gave twelve different explanations for the macroproperties of matter, the Turkish students' explanations fell into only five categories. Moreover, three US students invoked microparticulate explanations, but no Turkish students provided a microlevel explanation. We found this to be an interesting result because the Turkish students had expressed more microparticulate descriptions of the particulate nature of matter; therefore they should have given more elaborated and microparticulate explanations for fluidity, rigidity, and malleability. In addition, their explanations not only fell into fewer categories but they were also more basic and less complex than those of the US students.

The Turkish students' explanations were mostly coded as macrointrinsic, macrostate and macrodescription. This finding made us reexamine the interview transcripts. It is realized that when Sezer, Emin and Berrin were asked to describe the composition of matter, they repeatedly gave similar definitions that were directly derived from textbooks. We speculate that these students may have simply memorized the scientific fact that 'all matter is made of atoms' without internalizing it. This would explain why they could not apply this knowledge in their explanations of the macroproperties of matter.

Explanations of Phase Transition and Dissolving

In the final part of the interview, the students were asked to explain phase transition and dissolving. These processes were selected because melting, freezing and dissolving were readily observable and students had very likely experienced these processes in daily life. In the case of phase transition, we asked students what ice was made of, and we further asked what would happen to the ice if we left it on the table. In the case of dissolving process, we asked the students what would happen to table salt if we add some of it to a glass of water and stirred.

The students' responses were coded into only two categories: macroprocess-heat and microprocess. Fourteen out of 15 students invoked explanations that fell into the macroprocess-heat category. These students said that freezing water makes ice and if they place water in a refrigerator, it forms ice back again. They did not mention the atoms or molecules that make up the water. The following excerpt taken from Ibrahim's transcript illustrates this understanding.

> R- Tell me how ice is made?

S- First, you pour water into a bottle or an ice tray. Then, you put it into a refrigerator. Ice starts forming slowly.

R- When we leave the same ice on a table, what happens to it after a while?
S- It changes to water.

R- It changes to water, it turns back to former state, does it?

S- Yes.

Only Sezer gave microlevel explanation for the phase transition process. The following quote taken from his transcript illustrated this view.

R- What happens if I place water into a refrigerator?

S- It undergoes a physical reaction; then, it changes to solid.

R- What happens to the structure of it?

S- There will be no much difference in the structure of it. The density of it gets smaller; the volume of it enlarges.

R- Why does the volume increase?

S- It turns into solid phase. Since it is fluid, the atoms in it are closer to each other. However, this is not true for the solid materials.

R- Are the water and the ice cube similar to each other? Or are they different?

S- In fact, they are similar. Even though they have different shapes, with respect to their atomic structure, they are alike.

R- When we leave this ice cube on the table, what happens after a long time?

S- Over zero degree, it can melt.

R- Is there any change in the structure of it?

S- No change happens in the structure but its appearance does change.

Interestingly, although Melise viewed water as being made of small molecules, she did not use this understanding when she explained the phase transition.

R- Tell me how ice is made?

S- Ice is made of water. When water freezes, it forms ice.

R- When we leave the same ice on a table, what happens to it after a while?

S- It changes to water.
R- It turns back to ice again?

S- Uh-huh.

R- What do you think makes up the ice cube?

S- The water particles form the ice cube. Water has its own molecules; that is, it's specific material that makes it up.

R- Can we see those water particles by bare eyes?
S- When we turn the tap on, it looks it has pieces. However, indeed it is not like that. It has too small molecules to be seen by the eyes as well.

Compared to the US students, who gave 6 macro and 3 microlevel explanations, the Turkish students, who invoked 14 macro and 1 microlevel explanations, were more macrolevel.

For the dissolving process, we asked the students what happened if we added some salt to the water and followed up with questions as to whether the salt could be retrieved and whether the salt was still there. 13 out of 16 students gave macrolevel explanations, which fell into the category of macroprocess. Only three students invoked microlevel explanations. Even though these three students (Sezer, Sener, and Emin) did not give accurate explanations for dissolving process, their explanations were on microlevel. The following excerpt taken from Emin's interview illustrates this microlevel understanding.

R- In this container is some water. I am adding some salt to water and then I am stirring. Do you think what has happened to the salt in the water?

S- It has mixed with water. It has made a compound with the water.

R- Is it possible to get the salt back?

S- It is possible.

R- How?

S- We can evaporate water. The salt will be left over in the container, water evaporates so that we can separate them.

Even though he used neither atom nor molecule in his explanation, we categorized this explanation as microprocess because he had invoked microparticulate views in his descriptions for the composition of matter; therefore, we assumed that he used the term 'compound' properly.

We further asked the students whether there was a way to get the salt back. 9 out of 16 students (Erkan, Deniz, Sevim, Mustafa, Ilknur, Sener, Aynur, Ibrahim, and Turkan) thought that there was no way to get it back. Seven students (Sezer, Derya, Emin, Sila, Melise, Hulya, Berrin) thought that it was possible to get the salt back. They mostly stated that if the water were evaporated, the salt would be left over.

Student Frameworks

No student had a fully macrocontinuous framework. All 12 students demonstrated a particulate understanding at least one time in their descriptions of the composition of matter. Most of the students held a range of beliefs that varied with the identity of the substance. Only Sezer and Emin demonstrated microparticulate view on all six substances. They viewed matter as being made of atoms. Berrin also described all substances except for water as being composed of atoms or small particles that cannot be seen by the eyes.

Characteristics of Macroparticulate Students

When describing the composition of each substance, five students (Erkan, Derya, Aynur, Ibrahim, and Turkan) exhibited some characteristics of a macroparticulate framework, but some also demonstrated continuous views of matter. For example, Erkan described sugar as being made of small bits, but he viewed toothpick and copper wire as macrocontinuous. The following excerpt taken from his transcript illustrates this view.

> R- On the table is a sugar cube, can you describe the properties of it?
>
> S- It is square. It is used as a sweetener. It sweetens.
>
> R- What is it made of?
> S- It is made of sugar particles. It has gone through a manufacturing process and been turned into cubic shape.
>
> R- This is a piece of wood. Can you describe the properties of this wood?
>
> S- Tree. This is a small piece that is cut out of a tree.
>
> R- On the table is a copper wire. Can you describe the properties of it?
>
> S- It is very thin and short.
>
> R- What is this copper wire made of?
>
> S- It is made by melting and then, shaping the iron.

When explaining the macroproperties of fluidity, rigidity and malleability and the phase transition and dissolving processes, these students gave macrolevel explanations. No explanation was on the microlevel. Their explanations regarding the macroproperties of matter fell into macrostate, macrointrinsic, macroparticulate, macrodescription, macroforce. For phase transition and dissolving processes, the students' explanations were coded into macroprocess-heat.

Characteristics of Microparticulate Students

Seven students (Sezer, Sener, Emin, Sila, Melise, Hulya, and Berrin) were identified as having some of the elements of a microparticulate view of matter. Only Sezer and Emin demonstrated a microparticulate view on all six substances. Berrin also described all substances except for water as microparticulate. The rest of the students (Sener, Sila, Melise, and Hulya) held mixed views of matter on both the macro- and microlevels. These students described matter as being made of small particles or one big piece and, in some of their descriptions they viewed matter as made of atoms or molecules.

When explaining the macroproperties of fluidity, rigidity and malleability and the phase transition and dissolving processes, three students (Sezer, Sener, Emin) gave both macro and microlevel explanations. Sila, Melise, Hulya, and Berrin invoked only macrolevel views. Their explanations regarding the macroproperties of matter fell into macrostate, macrointrinsic, macroparticulate, macrodescription, macroforce. For phase transition and dissolving processes, the students' explanations were coded into microprocess, macroprocess, and macroprocess-heat. However, in the case of the phase transition, only 1 out of 15 students' explanations were microlevel and for dissolving process 3 out of 16 students' responses were microprocess. It seems that it was hard for them to apply molecular understanding to the explanations of macroproperties and of the processes.

Discussion and Conclusions

The present study provides valuable insight with regard to how students' acquire knowledge about the nature of matter. To begin with, it informs us about the content knowledge of middle school students' ideas and to what degree this knowledge corresponds to the current scientific beliefs about matter. Second, by providing data on the structure and quality (organization, coherence, and explanatory scope) of middle school students' ideas about the nature of matter, it informs the current discussion about the systematicity of student knowledge. Third, by comparing the ideas of middle school students to those of the US students (Nakhleh, Samarapungavan, & Saglam, 2005) we can see the similarities and differences.

Content and Scientific Accuracy of Middle School Students' Ideas

The study pointed out that the middle school students are in transition from naïve to a more scientifically accurate view regarding the composition of matter. However, we also see that the ideas of macroparticulate and even the microparticulate students showed significant misconceptions about matter.

For example, all of the five macroparticulate students did not view the matter as made of atoms and molecules. Correspondingly, even the seven microparticulate students (except for Sezer and Emin) did not invoke a molecular view for all substances. More interestingly, although Sezer described matter as made of atoms, he believed that the atoms in trees could be alive but the wood atoms could not be alive since they had no connection with soil. It seems he confused atoms with cells. Similarly, Emin believed that atoms could be seen under microscope. He apparently confused atoms with microbes. We speculate that since in school the concepts atoms, cells, and microbes are taught to be too tiny units to be seen by bare eyes, these students may have constructed these misconceptions from formal instruction.

Second, even though most of the students' descriptions regarding the composition of matter corresponded with the current scientific beliefs, almost none of their explanations were scientifically accurate for the macroproperties of fluidity, rigidity, and malleability or for the processes of phase transition and dissolving. We conjecture that it must be very hard for the students to apply their molecular view to macroproperties of matter or to the processes that matter undergoes.

Structure and Quality of Middle School Students' Ideas

We found that the students did not have a consistent, widely applicable framework that they could use to describe and explain a range of physical phenomena related to the nature of matter. Rather, it seems that the students used several frameworks to describe and explain the happenings around them. For example, many students who successfully described the composition of matter could not explain fluidity, rigidity and malleability. Instead, they invoked a range of unscientific explanations. It appears that they had a fragmentation in their ideas. Explaining the properties of fluidity, rigidity and malleability on the molecular level seems to have been very challenging for the students.

Our data also show that it was difficult for the macroparticulate students to view solid, nongranular substances like wood and invisible substances like air as being composed of particulate matter. The students still relied on what they saw rather than what they have learned at school. Another explanation can be these students had difficulty in expanding their macroparticulate view to all substances. For example, even though the students could easily see that sugar was particulate, it was more difficult for them to view invisible air or wood with no visible granularity, as being composed of small particles.

Comparison of the Turkish and the US Students

The data gathered through interviews were all context-dependent (Greenwood & Levin, 2005, p. 54-55) and therefore could not be generalized in a quantitative sense. In qualitative studies, the primary goal of qualitative research is not the generalization of the findings to other contexts or subjects. Rather, it is the transfer of the findings to other comparable contexts or subjects (Patton, 2002, p. 581-84). Therefore, the findings of this study cannot be generalized to all classroom settings; however, the results can be applicable to comparable students or classroom settings. In this case, we compared two settings that we thought are similar.

Regarding the composition of matter, the Turkish students' descriptions seemed to be more microparticulate than those of the US middle school students. Of the Turkish students' descriptions, 54% were microparticulate, 22% macroparticulate and 24% were macrocontinuous. On the other hand, the descriptions of the US students were 22% microparticulate, 44% macroparticulate and 33% were macrocontinuous. Therefore, the Turkish students used more microparticulate and less macroparticulate and macrocontinuous descriptions. However, concerning the macroproperties of fluidity, rigidity and malleability, the Turkish students' explanations were coded into only five categories: macrodescription, macrointrinsic, macrostate, macroparticulate, and macroforce. In contrast, the US students invoked 12 categories: macrodescription, macrointrinsic, macrostate, macroforce, macrocomposition, macrocompression, macroparticulate, macrocontinuous, macroquantity, microparticulate, microstate, and microcomposition.

The Turkish students' explanations were fewer and less complex than those of the US students. This was interesting as the Turkish students had invoked more particulate views on the composition of matter; therefore they might be expected to give more and better explanations for the macroproperties of matter. However, they could not do so. We conjecture that this is because the Turkish students had received more theory-based instruction and fewer hands-on activities than the US students. We further speculate that hands-on activities might facilitate the transfer of the students' microparticulate understanding to their explanations of macroproperties of the matter. Therefore, hands-on activities may have helped US students use their particulate understanding to explain macroproperties of matter. Another explanation could be that hands-on activities might be a rich resource and basis for the construction of theoretical thought. That is, unlike teacher-led instruction, in which students are mostly instructed orally, through experiences, students form knowledge about reality, called empirical thought and within the mind empirical thought becomes the sources of mental activities in order to discover the essence or the generality of the experience, which will be the basis of theoretical thought, idealized or crystallized essences of experiences (Davydov 1990, pp 245-253). Still another explanation could be the cultural differences between Turkish and US students. The Turkish students might have been more nervous or timid in expressing their beliefs and feelings than their US counterparts.

References

Au, T.K., Sidle, A., & Rollins, K. (1993). Developing an intuitive understanding of conservation and contamination: Invisible particles as a plausible mechanism. *Developmental Psychology, 29*, 286-299.

Carey, S., & Spelke, E., (1994). Domain-specific knowledge and conceptual change. In L. A. Hirschfeld, & S. A. Gelman (Eds.), *Mapping the Mind* (pp. 169 -200). Cambridge, MA: Cambridge University Press.

Cole, M. (1990). Cognitive development and formal schooling: The evidence from cross-cultural research. In L. C. Moll (Ed.*), Vygotsky and education: Instructional implications and applications of sociohistorical psychology* (pp. 89-110). Cambridge: Cambridge University Press.

Davydov, V. V. (1990). *Soviet studies in mathematics education: Vol. 2. Types of generalization in instruction: Logical and psychological problems in the structuring of school curricula* (J. Kilpatrick, Ed., & J. Teller, Trans.). Reston, VA: National Council of Teachers of Mathematics. (Original work published 1972)

Gabel, D. (1998). Complexity of chemistry and implications for teaching. In B.J. Fraser & K. Tobin (Eds.), *International Handbook of Science Education Research.* Dordrecht, The Netherlands: Kluwer.

Greenwood, D. J. & Levin, M. (2005). Reform of the social sciences and of universities through action research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 43-64). Thousands Oaks, CA: Sage.

McCloskey, M., & Kargon, R. (1988). The meaning and use of historical models in the study of intuitive physics. In S. Strauss (Ed.), *Ontogeny, phylogeny and historical development* (pp. 49-67). Norwood, NJ: Ablex.

McRobbie, C. J. (1998). Coordinating theories and evidence in chemistry classrooms. In D. M. Druskovich & G. T. Klease (Eds.), Bridging the gap: Proceedings of the Australian Chemical Institute Chemical Education Conference (pp. 135-140). Rockhampton, Central Queensland: University Publishing Unit.

Nakhleh, M. B. (1994). Students' models of matter in the context of acid-base chemistry. *Journal of Chemical Education, 71,* 494-499.

Nakhleh, M. & Samarapungavan, A. (1999). Elementary school children's beliefs about matter. *Journal of Research in Science Teaching, 36* (7), 777-805.

Nakhleh, B. M., Samarapungavan, A. & Saglam, Y. (2005). Middle school students' beliefs about matter. *Journal of Research in Science Teaching, 42*(5), 581-612.

Patton, M. Q. (2002). Variety in qualitative inquiry: theoretical orientations. In C. D. Laughton, V. Novak, D. E. Axelsen, K. Journey, & K. Peterson (Eds.), *Qualitative research & evaluation methods* (pp. 75-138). Thousands Oaks, London: Sage Publications.

Rosen, A., & Rozin, P. (1993). Now you see it, now you don't: The preschool child's conception of invisible particles in the context of dissolving. *Developmental Psychology, 29*, 300-311.

Samarapungavan, A., Vosniadou, S., & Brewer , W.F. (1996). Thinking about the earth, sun, and moon: Indian children's cosmologies. *Cognitive Development, 11,* 491-521.

Thomas, G. P., & McRobbie, C. J. (2002). Collaborating to enhance student reasoning: Frances' account of her reflections while teaching chemical equilibrium. *International Journal of Science Education, 24,* 405-423.

Vosniadou, S., & Brewer, W.F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24,* 535-585.

Vosniadou, S., & Brewer W.F. (1994). Mental models of the day/night cycle. *Cognitive Science*, *18*(1), 123-183.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wertsch, J. V. (1985a). *Vygotsky and the social formation of mind.* Cambridge, MA: Harvard University Press.

Wertsch, J. V. (Ed.). (1985b*). Culture, communication, and cognition: Vygotskian perspectives.* Cambridge: Cambridge University Press.

Wiser, M.(1988). The differentiation of heat and temperature: History of science and novice-expert shift. In S. Strauss (Ed.), *Ontogeny, phylogeny, and historical development* (pp. 28-48). Norwood, NJ: Ablex.

Appendix

Interview for Children's Beliefs About Matter

Sequence I. Properties of pure substances (elements or compounds).

1. SHOW: A sugar cube.

2. ASK: This is a sugar cube. Please describe the qualities of this sugar cube.

IF macro or continuous description
THEN ASK What is it made of?
Is it just one big piece of material?
Is it made of little bits?

IF particulate description
THEN ASK Think of the smallest bits. Are all of the bits the same or are some different?
Here is some Play Dough. Please use the Play Dough to

help explain what you mean.

IF particulate, but still not specific,
THEN ASK Please tell me what these little bits look like? What shape are they?

IF participant cannot get to micro level but remains continuous or macro, THEN GO ON with interview.

3. REPEAT: Repeat sequence using wood, liquid water, a metal like Cu wire, and a clear balloon filled with He.

Sequence II. Relationships between the particles.

4. ASK: Why does the wood hold its shape, but the water flows, and the gas escapes when you open the balloon?

IF particulate description
THEN ASK What holds these bits together? Please use the Play Dough to help explain what you mean
THEN ASK: Remember you told me [refer to participants' earlier descriptions, such as wood is hard, water soft, etc.] Why to you think that happens? Why do these substances have different properties?

5. ASK: You can (break the sugar cube, separate the water, bend the metal, etc.). Why do you think that happens?

IF particulate description
THEN ASK: What happens to the bits when you do that?

IF macro or continuous description
THEN ASK: What held these parts together?

6. ASK: Does this broken piece still have all of the qualities of sugar? Explain your answer. How are these pieces similar to the original piece of sugar (wood, etc.)? How are these pieces different from the original piece of sugar (wood, etc.)?

7. REPEAT: Ask the same questions for sugar, wood, liquid water, a metal like Cu wire, and a clear balloon filled with He.

Sequence III. Phase changes of pure substances.

8. ASK: Tell me how ice is made.

IF no answer or wrong answer

THEN SAY: If you put a tray of water in the freezer for a few days, what will be in the tray?

9. ASK: This ice cube was made by freezing liquid water. What might this ice cube be made of?

IF particulate description
THEN ASK: If you leave this ice cube on the table, it starts to melt. What do you think might be happening to the bits of water? Please use your Play Dough to help explain your ideas.

IF macro or continuous description
THEN ASK: What's happening to the ice?
Why is [whatever S says] happening?

10. REPEAT: Ask the same questions for sugar, wood, liquid water, a metal like Cu wire, and a clear balloon filled with He.

11. ASK: Dissolve some salt in water (enough to dissolve completely).
What happened to the salt that we added to the water?

Thank you for participating in this interview.
Do you have any questions for me?