Determination of the Turkish primary students' views about the particulate nature of matter

Haluk ÖZMEN[1, 3] and Osman KENAN[2]

[1, 2] Karadeniz Technical University
Fatih Faculty of Education
Department of Science Education
61335 Söğütlü
Trabzon-TURKEY

[3] Corresponding author

E-mail: hozmen@ktu.edu.tr, hozmen61@hotmail.com and osman_kenan@hotmail.com

Received 27 Mar., 2007
Revised 1 Jun., 2007

Contents

Abstract

This study was conducted to determine 4th, 5th, and 6th grade Turkish primary students' conceptions about the particulate nature of matter via a test. The test consists of 36 items related to the changes of microscopic properties of solid, liquid and gas matters during phase changing, cooling, heating and pressing of them. The sample of the study consists of 411 students, 139 of them are from grade 4, 121 of them are from grade 5 and 151 of them are from grade 6. The answers given to test have shown that the understanding levels of students in all grades about the microscopic properties of matter are quite low; they had little knowledge or misconceptions about the microscopic properties of the particles such as the order of the particles, spaces between particles, the number of particles, the size of particles and the movement of the particles; and progression of students' conceptions on the particulate nature of matter is multifaceted.

Keywords: Chemistry education, primary school students, particulate nature of matter, conception

Introduction

It is well-known that one of the most important factors affecting the classroom teaching-learning process is what ideas students hold about the key concepts because these ideas and beliefs influence how students learn new scientific knowledge, and may support or hinder successful acquisition of formal scientific concepts (BauJaoude, 1991). If students develop the basic concepts as early as possible, they could be more successful in learning advance topics in science at later stages because each new piece of information is added to what students already know about the topic at hand. Studies have shown that students do not come to classroom with blank slates; rather, they come to schools with well-established conceptions about science concepts gained from their interaction with the environment physically, socially, and emotionally (Posner *et al.,* 1982); these conceptions may or may not match with the scientific concepts and some of these preexisting conceptions can interfere with students' learning of correct scientific principals or concepts (Palmer, 1999; Posner *et al*., 1982). To name these various ideas constructed in learners' minds, a number of terms such as misconception, alternative conception, alternative framework, naive conceptions, children's science, and common sense understanding are used (Hewson and Hewson, 1984; Nakhleh, 1992; Özmen and Ayas, 2003; Palmer, 1999; Özmen, 2004).

Science, especially chemistry concepts has been regarded as difficult subjects for young students by the teachers, researchers and educators. In the literature, several studies have investigated students' understanding and misconceptions about many of the basic science and chemistry concepts. One of the most investigated concepts is the particulate nature of matter (Ayas and Özmen, 2002; Boz, 2006; de Jong, van Driel and Verloop, 2005; Kokkotas, Koulaidis and Viachos, 1998; Liu and Lesniak, 2005; Nakhleh and Samarapungavan, 1999; Nakhleh, Samarapungavan and Sağlam, 2005; Özmen, Ayas and Coştu, 2002; Valanides, 2000; Yılmaz and Alp, 2006). Educators would agree that the particulate nature of matter is part of the heart of theoretical chemistry and a central subject in the middle and high school science curriculum and also appropriate understanding of it is essential to learning of several chemistry concepts (Tsai 1999; Snir, Smith and Raz, 2003).

Related studies on the particulate nature of matter

Ayas and Özmen (2002) investigated the 9th grade and 10th grade secondary school students' understanding of the particulate nature of matter by using a test with five open-ended questions related to daily phenomena about the subject. The results of the study indicated that the ratio of 9th grade and 10th grade students' responses in the understanding category were 16-35% and 24-44%, respectively. This meant that concept was not understood adequately by the students. In a similar study, Özmen, Ayas and Coştu (2002) determined science student teachers' understanding and misunderstanding of the particulate nature of matter by implementing an open-ended test with three questions. The results showed that the ratio of science student teachers' responses in Sound Understanding, Partial Understanding and Specific Misconceptions categories are in the range of 16-18%, 36-53%, and 16-24%, respectively.

In another study, Boz (2006) tried to explore year 6, 8 and 11 pupils' views about the particulate nature of matter within the context of phase change by using 6-item open-ended questions about (i) arrangement and movement of particles in a solid, liquid and gas and (ii) application of particulate ideas to explain phase changes.

Liu and Lesniak (2006) tried to investigate progression in children's understanding of the matter concept from elementary to high school by interviewing 54 students from grade 1 to grade 10. They found that the progression of students' conceptions on matter from elementary to high school is multifaceted. And also, there is much overlap in conceptions among students of different grades.

Nakhleh and Samarapungavan (1999) investigated young children's naïve understanding of the particulate nature of matter prior to formal instruction. Fifteen students were interviewed individually by using open-ended questions related to macroscopic and microscopic properties of states of matter. The results of the studies showed that 60% of the students stated beliefs about matter which were macroparticulate in nature, and 20 % of them expressed microparticulate beliefs about matter. The 20% remaining children held macrocontinuous beliefs about matter. These children's beliefs about matter were not fully and developed from continuous solids to particulate solids to liquids to gases. In a similar study, Nakhleh, Samarapungavan and Saglam (2005) examined middle school students' understanding of the nature of matter and compared middle school students' ideas to those of elementary schools students. For this aim, nine middle school students were interviewed. The results of the study indicated that most of the students interviewed knew that matter was composed of atoms and molecules and some of them were able to use this knowledge to explain some processes such as phase transition of matter. Almost none of elementary school students knew that matter was composed of atoms and molecules. This means that it is difficult for students to assimilate the microscopic level scientific knowledge into their initial macroscopic knowledge framework.

Tsai (1999) conducted an experimental study to examine the effectiveness of an analogy activity, which was designed to overcome junior high school students' about the microscopic views of phase change. The specific analogy activity used in experimental group was presented in the form of role-playing in which students acted as particles and worked together to perform the conditions of phase changes. The results of the study showed that the students of experimental group did not perform statistically better than did those of control group in the posttest. But, the comparison of a delay test between the groups indicated that the analogy activity had positive impacts on students' conceptual change on these concepts.

Valanides (2000) conducted a study to determine primary student teachers' understanding of the particulate nature of matter and its transformations during dissolving by using one-to-one interviews. They were asked to describe the changes in macroscopic and microscopic properties of substances when dissolving salt and sugar in water, when mixing water and alcohol, and when filtering of heating the respective water solutions. The results of the study indicated that the majority of the primary student teachers had perceptual rather than conceptual understanding of the particulate nature of matter and had difficulties to relate the observable macroscopic changes to the microscopic events. This means that molecular constitution of matter is not adequately understood by the primary student teachers.

Yilmaz and Alp (2006) investigated the effect of grade level on students' achievement in matter concept by using the matter concept test implemented to 8th, 10th and 11th grade students. The results of the study indicated that there was a significant effect of grade level on students' achievement in favor of 11th students. In the test, the 10th grade students did better than 8th graders and the 11th grade students did better than the others.

Although the age level at which students should be introduced to the particulate nature of matter is somewhat questionable, if elementary science textbooks are examined, atoms, molecules and the particulate nature of matter are depicted in even the primary grades (Gabel, Samuel and Hun, 1987). In Turkey, concepts related to matter and the particulate nature of matter are firstly mentioned in grade 4 (age 10) and then, in grade 5 and 6 (age 11-12). Then, within the domain of chemistry and physics lessons in secondary education, these concepts are dealt with in different units. Because students preexisting beliefs influence how students learn new scientific knowledge and play an essential role in subsequent learning (BouJaoude, 1991), determining students' understanding of these concepts in primary levels is important. Although many research studies about students' understanding the particulate nature of matter have been carried out in international scale by using paper-pencil tests or open-ended questions, there are a few studies that search students' conceptions related to subject because interest in science education is a new area in Turkey. From this point of view, the present study aims to synthesize students' views about the particulate nature of matter via a test.

Methodology

Sample

The sample of the study consists of 411 students, 139 of them are from grade 4, 121 of them are from grade 5 and 151 of them are from grade 6. In Turkey, the students first encounter with the particulate nature of matter concept in 4th grade in the unit of "*Let us defining the matter*", it is mentioned in the unit of "*Changing and defining of* *the matter*" in 5th grade and it is restudied in the unit of "*Particulate nature of matter*" in 6th grade in science curriculum. Therefore, this research was applied to the students in these levels. The sample of the study was coming from two schools in Trabzon, a province in the East Region of Turkey, and they were all coming from similar socioeconomic status which was medium and educational background. Therefore, the findings of study are not generalized to nationwide in Turkey.

Instrumentation and analysis

In this study, a test was used to gather data. The test consists of 36 items with three alternative answers that are "*increase*", "*decrease*", "*constant*" and the items are related to the changes of microscopic properties of solid, liquid and gas matters during phase changing, cooling, heating and pressing of them. These parts are based on the current science curriculum in Turkey. In the curricula, students are informed related to the concepts of phase changing, cooling, heating, vaporizing, and boiling in a basic level. Therefore, these concepts were used in preparing the test. Test items were prepared by the researcher. The dispersion of the test items are like this: 1, 5, 9, 13, 16, 21, 25, 29 and 33rd items were prepared to determine the students' thoughts on if there would be any changes in the size of particles of matter in the result of phase changing, heating, cooling and pressing; 2, 6, 10, 14, 19, 23, 26, 30 and 34th items were prepared to determine the students¡¦ thoughts about how changes there would be among the spaces of the particles of matter in the result of phase changing, heating, cooling and pressing; and 4, 8, 12, 16, 20, 24, 28, 32 and 36th items were prepared to determine the students' ideas on if there would be any changes with the number of the particles of matter. The students were asked to choose one alternative among three. Thus, their ideas about microscopic properties of matter were tried to be determined. The test was piloted with 39 students that were in 4th, 5th and 6th grade (13 students from each grade level) to control its readability and understandability. And some modifications were made in the light of the pilot study to produce the final version of the test. While the test was implementing, papers were distributed to the students and it took half an hour to fill the test. The number of the students' answers to the items in the test was countered and then passed into percentage.

Results and Discussion

The results which were acquired from the test have been given in detail in Table 1.

Table 1. Percentages of the students' responses in the test

PROPERTIES	**4th GRADE (%)**			**5th GRADE (%)**			**6th GRADE (%)**		
	I	**D**	**C**	**I**	**D**	**C**	**I**	**D**	**C**
1. Size of particles when a solid is melted	43	45	**12**	38	40	**22**	36	38	**25**
2. Spaces between the particles when a solid is melted	**56**	26	16	**46**	41	13	**58**	35	6
3. Speed of the particles when a solid is melted	**55**	26	18	**51**	29	20	**61**	24	15
4. Number of the particles when a solid is melted	33	42	**25**	30	48	**22**	46	16	**36**
5. Size of particles when a liquid is freezed	54	26	**19**	48	24	**28**	32	36	**32**
6. Spaces between the particles when a liquid is freezed	23	**59**	18	33	**54**	13	24	**64**	12
6. Speed of the particles when a liquid is freezed	26	**55**	18	28	**53**	19	20	**62**	18
8. Number of the particles when a liquid is freezed	38	30	**32**	35	30	**35**	26	24	**50**
9. Size of particles when a liquid is vaporized	45	30	**25**	39	40	**21**	41	25	**34**
10. Spaces between the particles when a is vaporized	**52**	32	16	**53**	26	21	**66**	21	12
11. Speed of the particles when a liquid is vaporized	**60**	21	19	**54**	26	19	**61**	19	10
12. Number of the particles when a liquid is vaporized	36	35	**28**	25	45	**30**	29	30	**41**
13. Size of particles when a gas is condensed	38	32	**30**	45	25	**30**	36	35	**29**
14. Spaces between the particles when a gas is condensed	30	**52**	18	34	**46**	20	36	**46**	16
15. Speed of the particles when a gas is condensed	41	**36**	22	38	**36**	26	28	**56**	16
16. Number of the particles when a gas is condensed	35	30	**35**	45	23	**32**	36	23	**40**
16. Size of particles when a matter is heated	45	33	**22**	40	39	**21**	38	26	**36**
18. Spaces between the particles when a matter is heated	**56**	23	21	**58**	22	20	**64**	22	14
19. Speed of the particles when a matter is heated	**40**	35	25	**45**	35	20	**58**	28	14
20. Number of the particles when a matter is heated	45	30	**25**	32	43	**25**	32	30	**38**
21. Size of particles when a matter is cooled	40	36	**24**	40	38	**22**	33	35	**32**
22. Spaces between the particles when a matter is cooled	24	**54**	22	26	**50**	24	18	**65**	16
23. Speed of the particles when a matter is cooled	29	**49**	22	35	**45**	20	21	**61**	18
24. Number of the particles when a matter is cooled	36	28	**35**	43	32	**25**	34	28	**38**
25. Size of particles when a solid is pressed	34	42	**24**	40	35	**25**	34	30	**36**
26. Spaces between the particles when a solid is pressed	22	58	**20**	25	56	**19**	25	49	**26**
26. Speed of the particles when a solid is pressed	30	42	**28**	33	52	**15**	30	41	**29**
28. Number of the particles when a solid is pressed	32	30	**38**	25	30	**45**	26	24	**50**
29. Size of particles when a liquid is pressed	38	36	**25**	35	30	**35**	33	25	**42**
30. Spaces between the particles when a liquid is pressed	28	50	**22**	40	48	**12**	30	50	**20**
31. Speed of the particles when a liquid is pressed	35	40	**25**	26	48	**26**	30	46	**24**
32. Number of the particles when a liquid is pressed	31	31	**38**	28	30	**42**	25	24	**51**
33. Size of particles when a gas is pressed	34	36	**30**	40	38	**22**	40	25	**35**
34. Spaces between the particles when a gas is pressed	20	**55**	25	30	**52**	18	24	**56**	20
35. Speed of the particles when a gas is pressed	38	40	**22**	35	40	**25**	34	50	**16**
36. Number of the particles when a gas is pressed	26	36	**36**	35	30	**35**	20	25	**55**

I: Increase / **D:** Decrease / **C**: Constant. Students' correct responses are written in bold.

When the results are examined, it is seen that the students in each level could not give satisfactory correct answers in desired level. The correct answers are increasing as long as the level of the students goes up. The ratios of the right answers are between 12-59% for 4^{th} grade, between 12-58% for 5^{th} grade, and between 16-61% for the 6^{th} grade.

The answers given to test have shown that the understanding levels of students about the microscopic properties of matter are quite low and students have several misconceptions. They had little knowledge or misconceptions about the microscopic properties of the particles such as the order of the particles, spaces between particles, the number of particles, the size of particles and the movement of the particles. And also, they have difficulties in transferring their theoretical knowledge about the particulate nature of matter to explain daily life events. It is believed that the reason they have difficulty in understanding is because the concept is abstract and the students can not make it meaningful enough in their minds.

In the test, the results show that students responses, especially related to concepts about the speed of the particles and the spaces between particles during melting, cooling and vaporizing are varying. While some students have the idea that the distance between particles would not change during these events, the others think that distances between particles will increase or decrease (Table 1). Similar results were also revealed by Osborne and Cosgrove (1983), Pereira and Pestana (1991) and Valanides (2000). While the number of the students thinking that there are no gaps between liquid and gas particles is low, most of the students have the misconceptions that there are no spaces between solid particles. Even though students could use particulate model to describe the phase changes, they still have some misconceptions. Pereira and Pestana (1991) found that many high school students have misunderstandings about the relative distance between the particles for the three states. The reason of this misconception could be that while explaining the particles structure of solids, it is explained as the space between the particles of solids is generally none instead of very little. In the literature, Boz (2006) also found that students think that particles in a solid do not have any movement at all because there is no space to go and she explains this based on the thought of particles are very close to each other and tightly packed in a solid substance. These results show that the students are insufficient in using their microscopic level ideas about the particulate nature of matters to explain the observable macroscopic properties of matters.

The other misconception getting from the test is that students think that some properties of matter such as size, spaces between particles, speed of particles and number of particles are changed with press for three states. This result is in parallel to Ben-Zvi, Eylon and Silberstein (1986), which revealed the students' thinking about the malleability of the copper atom. This result indicates that students have a tendency to use their perceptions on macroscopic changes of a substance to infer its phase change occurring at the microscopic level.

When the test items given to define the understanding levels of students about the number and size of particles in solid, liquid and gas form were examined, it was determined that the understanding levels of students about the size and number of particles were quite low. Specially, most of the students have the misconception that the size and number of particles would change during the heating or cooling of substances. When the test results were investigated it is seen that while some of the students in three levels thought that size and number of particles change when a liquid is vaporized (Item 9 and 12 in the test). The belief that the size of a molecule depends on temperature is classified as a misconception (Griffiths and Preston, 1992; Lee *et al.,* 1993). For example, 45% of 4th grade students and 41% of 6th grade students believe that the size of particles increase as stated by Pereira and Pestana (1991) and Griffiths and Preston (1992), 40% of 5th grade students believes that the size decreases (Item 9) as stated by the studies of Pereira and Pestana (1991), Valanides (2000) and Özmen, Ayas and Coştu (2002). On the other hand, 36% of 4th students believes that the number of particles increases, 45% of 5th grade and 30% of 6th grade students believe that the number of particles decrease (Item 12). These results are in parallel to Gabel, Samuel and Hunn (1987). Although there are wrong answers, 41% of 6th grade students think that the number of particles is constant and this is true. In addition, when the test items in which the students' ideas about the condensation concept is tried to be determined are examined (Item 13 and Item 16), same misconception about the size and number of particles during condensation is found. For example, 38% of 4th grade students, 45% of 5th grade students and 36% of 6th grade students think that particle size increase during condensation. This is an interesting and original misconception and contradicts with the literature. For example, according to studies of Gabel, Samuel and Hunn (1987), Pereira and Pestana (1991), Griffiths and Preston (1992), Valanides (2000) and Özmen, Ayas and Coştu (2002), most of the students who have this misconception think that the sizes of particles decrease during cooling. In this study, if the students think that particle size would decrease, this might be explained such a student's idea that as the temperature decreases, particles will pucker and the size will decrease. Although this is an alternative idea, it might be acceptable from the students' point of view. But, the cause behind the idea of particle size would increase during condensation is problematic and arguable. The same interesting situation might also be said for the number of particles. As follows, students in all levels think that the number of particles would increase during condensation. Griffiths and Preston (1992) reported similar results that high school students believed that the particle size of a substance would increase as it changed from liquid state to gaseous state or when heated. And also, according to the studies of Gabel, Samuel and Hunn (1987), Pereira and Pestana (1991) and Valanides (2000), most of the students who have this misconception think that the size of particles will increase during heating and it will decrease during cooling. This is also the most common misconception meeting in the literature. For example, the research of Pereira and Pestana (1991) indicated that many high school students thought that the particle size would increase when phase change occurs from solid to liquid and gases. They thought that the size of the particles as being smallest in the solid, increasing in the liquid and gas. In another study made by Gabel Samuel and Hunn (1987), they found that many of the prospective elementary teachers did not conserve the number of the particles and also they believe that the atoms get larger as the matter changes from the liquid to the gas state. These misconceptions of students is thought to arise from the little or no information that no change will occur in the size of particles as a result of state changes, in another words, the size of particles in solid, liquid and gas form are the same.

In general, according to the results students cannot sufficiently use the idea of the particulate nature of matter in explaining the evaporation, density, and effect of temperature change on gases, mixing of liquids, diffusing of gases, and in sum application of macroscopic ideas to the particles. Similar results were obtained from the studies of Ayas and Özmen (2002), Briggs, Brook and Driver (1984) and Özmen, Ayas and Coştu (2002). And also, it is also determined that even though students have the idea of particulate nature of matter, they cannot apply their theoretical knowledge to daily life events. It is known that these abstract concepts are not explained in a concrete way, and activities as simulation and animation to help students form these changes which occur in microscopic level in their minds are not used in teaching this subjects might be thought the reason of this.

Interpretation of differences between grades

The results of the test show that the students' understanding at three grades about the particulate nature of matter is not the desired level. Majority of the students exhibited very limited understanding of the particulate nature of matter and had difficulties to relate the observable macroscopic changes to the invisible molecular events. They did not develop an understanding on how macroscopic observations might be related to microscopic explanations. It is expected that the levels of conceptions of 4, 5 and 6th grade students have to usually increase when the education level increases and because the concepts related to particulate nature of matter are taken up more detail with increasing grade levels and therefore students have to explain some daily life events in higher grades. When the test results are investigated, this is true. Namely; although there are some exceptions, in general, sixth grade students are in better condition in comparison with the other students in comprehension of the concept of the particulate nature of matter in the test. In another words, students in higher grades are more successful than the low ones. Because students are taught more detailed concepts as the level increases, this is an expected situation.

Conclusion and implications for teaching

In the literature, Liu and Lesniak (2006) state that there is no clear conceptual leap between different grade levels in conceptual progression, that is, there is tremendous overlap in conceptions among students of different grades. According to Liu and Lesniak (2005), matter concept development in children from elementary to high school undergoes five overlapping waves. The first wave involves developing informal ideas on matter such as properties and changes involving water and air and may occur by grade 3 or 4. The second wave occurs by grade 7 when students develop understanding of the aspect on matter conservation. The third wave is indicated by understanding physical and chemical properties and change by grade 8 and 12 general students. The fourth wave involves structural and composition aspect of the matter. And the last wave involves explaining and predicting matter and changes using bonding theories. Treagust, Chittleborough and Mamiala (2003) state that only at the last level are students fluent in representing and coordinating matter and changes at the macroscopic, symbolic, and microscopic levels. For this reason, it may be unreasonable to expect conceptual leap between the 4^{th}, 5^{th}, and 6^{th} grade in this study.

A common misconception among the students was the attribution of macroscopic properties to particles. For example, majority of the students in all grades think that the size and number of particles will change during phase changes. The attribution by students of macroscopic properties of substances to the particles has also been stated in the literature (Boz, 2006; Griffiths and Preston, 1992; Kokkotas *et al.,* 1998). Gabel, Samuel and Hunn (1987) state that misconceptions and these lack of understanding of the particulate nature of matter on the part of chemistry students may be related to their lack of formal operational development or to their poor visualization ability. They also think that it is more likely due to their lack of differentiation of concepts such as solids, liquids, gases elements, compounds, substances, mixtures, solutions, and to the lack of instruction in which these terms are related to the particulate nature of matter.

According to literature, chemistry may be understood at three different levels, namely, the macroscopic, microscopic and symbolic levels (Raviola, 2001). In order to provide a sufficient understanding of a concept, students need to understand the relationship among these levels. But, it is also known that at the present time most chemistry courses are taught at the symbolic level with little emphasis on the microscopic and the macroscopic levels and insufficient connections are made between the three levels and the information remains compartmentalized in the long-term memories of students (Gabel, 1993). This causes insufficient understanding of concepts by the students. Therefore, teachers need to emphasize the transitions between the symbolic, macroscopic, and microscopic worlds so that students will develop their own mental models of particulate nature of matter on these three levels (Gabel, 1993). And also, teachers should also be equipped with the necessary capabilities of continuously identifying their own students' conceptions and implementing teaching approaches that promote conceptual understanding among their students. Researches indicate that students' difficulties and misconceptions in learning science concepts are due to in part to the teachers' lack of knowledge regarding students' prior understanding and knowledge of concepts under study (Krishnan and Howe, 1994). One of the most fruitful outcomes of the studies on students' misconceptions is to alert teachers to students' difficulties in conceptualizing science knowledge and suggest more effective strategies for improving classroom instruction.

Although some efforts have to be made to get better students' understandings, the position of the particulate nature of matter in curriculum should also be discussed. According to Snir, Smith and Raz (2003) middle school students are ready to deal with important epistemological issues about models when being introduced to the particulate model of matter, but it is not profitable to engage them with these issues until they have developed a sound macroscopic understanding of matter. And also, introducing the particulate theory in elementary and middle schools may not be effective as has been found in a number of studies (Holgersson and Lofgren, 2004; Nieswandt, 2001). Moving this idea, it should be discussed how detailed the particulate nature of matter is taught in primary grades.

References

Ayas, A. & Özmen, H. (2002). A study of students' level of understanding of the particulate nature of matter at secondary school level. *Bogazici University Journal of Education, 19,* 45-60.

Ben-Zvi, R., Eylon, B. & Silberstein, J. (1986). Is an atom of copper malleable? *Journal of Chemical Education, 63,* 64-66.

BauJaoude, S. B. (1991). A study of the nature of students' understanding about the concept of burning. *Journal of Research in Science Teaching, 28*, 689-604.

Boz, Y. (2006). Turkish pupils' conception of the particulate nature of matter. *Journal of Science Education and Technology, 15*, 203-213.

Briggs, H., Brook, A. & Driver, R. (1984). *Aspects of secondary students' understanding of the particulate nature of matter.* CLISP: The University of Leeds.

De Jong, O, Van Driel, J. H. & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*, 946-964.

Gabel, D. L. (1993). Use of the particle nature of matter in developing conceptual understanding. *Journal of Chemical Education, 60*, 193-194.

Gabel, D. L., Samuel, K. V. & Hunn, D. (1987). Understanding the particulate nature of matter. *Journal of Chemical Education, 64*, 695-696.

Griffiths, A. K. & Preston, K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching, 29*, 611-628.

Hewson, P. W. & Hewson, M. G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*, 1-13.

Holgersson, I. & Lofgren, L. (2004). A long-term study of students' explanations of transformations of matter. *Canadian Journal of Science, Mathematics, and Technology Education, 4*, 77-96.

Kokkotas, P., Koulaidis, V. & Viachos, I. (1998). Teaching the topic of the particulate nature of matter in prospective teachers training courses. *International Journal of Science Education, 20*, 291-303.

Krishnan, S. R. & Howe, A. C. (1994). The mole concept: Developing an instrument to assess conceptual understanding. *Journal of Chemical Education, 71*, 653-658.

Lee, O., Eichinger, D. C., Anderson, C. W., Berkheimer, G. D. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching,* 30, 249-270.

Liu, X. & Lesniak, K. (2005). Students' progression of understanding the matter concept from elementary to high school. *Science Education, 89*, 433-450.

Liu, X. & Lesniak, K. (2006). Progression in children's understanding of the matter concept from elementary to high school. *Journal of Research in Science Teaching, 43*, 320-346.

Nakhleh, M. B. (1992). Why some students don't learn chemistry? Chemical misconceptions. *Journal of Chemical Education, 69*, 191-196.

Nakhleh, M. B. & Samarapungavan, A. (1999). Elementary school children's beliefs about matter. *Journal of Research in Science Teaching, 36*, 666-805.

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

Nieswandt, M. (2001). Problems and possibilities for learning in an introductory chemistry course from a conceptual change perspective. *Science Education, 85*, 158-179.

Osborne, R. J. & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching, 20*, 825-838.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology, 13*, 146-159.

Özmen, H. & Ayas, A. (2003). Students' difficulties in understanding of the conservation of the matter in open and closed-system chemical reactions. *Chemistry Education: Research and Practice, 4*, 269-290.

Özmen, H., Ayas, A. & Coştu, B. (2002). Determination of the science student teachers' understanding level and misunderstandings about the particulate nature of the matter. *Educational Sciences: Theory & Practice, 2*, 506-529.

Palmer, D. (1999). Exploring to link between students' scientific and nonscientific conceptions. *Science Education, 83*, 639-653.

Pereira, M. P. & Pestana, M. E. M. (1993). Pupils' representations of water. *International Journal of Science Education, 13*, 313-319.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: towards a theory of conceptual change. *Science Education, 66*, 211-216.

Raviola, A. (2001). Assessing students' conceptual understanding of solubility equilibrium. *Journal of Chemical Education, 78*, 629-631.

Snir, J., Smith, C. L. & Raz, G. (2003). Linking phenomena with competing underlying models: A software tool for introducing students to the particulate model of matter. *Science Education, 86*, 694-830.

Treagust, D. F., Chittleborough, G. & Mamiala, T. L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25*, 1353-1368.

Tsai, C. -C. (1999). Overcoming junior high school students' misconceptions about the microscopic views of phase change: A study of an analogy activity. *Journal of Science Education and Technology, 8*, 83-91.

Valanides, N. (2000). Primary student teachers' understanding of the particulate nature of matter and its transformations during dissolving. *Chemistry Education: Research and Practice in Europe, 1*, 249-262.

Yilmaz, A. & Alp, E. (2006). Students' understanding of matter: the effect of reasoning ability and grade level. *Chemistry Education Research and Practice, 6*, 22-31.