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A Cross-National Review of the Studies on the Particulate Nature of Matter and Related Concepts

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Abstract

This study has reviewed the last three decades of students' conception researches on the particulate nature of matter (PNM). To achieve this, criteria were developed to summarize and present the findings by focusing on insights derived from the related studies. The criteria incorporated the following themes: year, type (students' understanding, comparative, experimental, or review), aim, sample and data collection tools. Seventy nine papers were examined in the study. These papers were related to students' understanding and alternative conceptions of the PNM and the effects of different methods on students' learning. The results of the studies reports that traditional teaching strategies are ineffective in helping students to develop a complete understanding of the matter, phase changes and the PNM, to alleviate alternative conceptions, and to promote conceptual change. And also, most of the new methods have positive effect on students' conceptual understanding and alternative conceptions. This study intends to provide useful knowledge for teachers, researchers, curriculum developers and textbook writers.

Keywords: Chemistry education, the particulate nature of matter (PNM), students' understanding, review

Introduction

Chemistry has been regarded as difficult subject for young students by teachers, researchers and educators (Kirkwood & Symington, 1996; Lorenzo, 2005; Nakhleh, 1992). The reasons for students' difficulties may be related to abstract nature of many chemistry concepts, students' lack of formal operational development, students' poor visualization ability (Gabel et al., 1987) or language of chemistry. Firstly, chemistry commonly includes many abstract (Ben-Zvi et al., 1988) and counter-intuitive concepts (Gabel, 1998), which are central to further learning in both chemistry and other sciences (Taber, 2002). Secondly, several educators have identified another reason for students' difficulties (Johnstone, 1999; Nelson, 1999; Tsaparlis, 1997). This is that chemists describe chemistry at three levels, only one of which can be readily observed. These levels are macroscopic, submicroscopic and symbolic and conceptual understanding in chemistry includes the ability to represent and translate chemical problems using these levels (Harrison & Treagust, 2000; Johnstone, 1991; 1993; Raviola, 2001). Johnstone (1991; 1999) has pointed out that at the present time most chemistry courses teach at the symbolic level with little emphasis on the submicroscopic and the macroscopic levels. Numerous studies support the idea that the interplay between macroscopic and submicroscopic phenomena is a source of difficulty for many chemistry students. According to Sirhan (2007), the interactions and distinctions between them are important characteristics of chemistry learning and necessary for achievement in

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comprehending chemical concepts. And also, Hinton and Nakhleh (1999) report that students must use representations characteristic of these three levels for a full understanding of chemistry. Similarly, in the literature it is phrased that the ability of students to understand the role of each level of chemical representation and to transfer from one level to another are an important aspect of generating understandable explanations (Rahayu & Kita, 2010; Treagust et al, 2003). Therefore, if students possess difficulties at one of these levels, it may influence the others. And also, Johnstone (1991) indicated that these three levels of chemistry make it difficult to learn. Thirdly, most of the abstract concepts in chemistry require the three-dimensional thinking and visualization ability to understand and conceptualize them adequately. Therefore, Gabel et al (1987) phrased that students' poor visualization ability is another source of difficulty in chemistry. And fourthly, the language of chemistry may be both difficult and confusing for students. Especially, difference between the scientific and daily usage of some concepts such as melting and dissolution may be a problem for students sometimes.

The concept of matter is essential to chemistry since chemistry is a science of matter and its transformations. It is well known that appropriate understanding of the matter determines the students' understanding of principles and theories of physical and chemical changes (Adbo & Taber, 2009; Liu & Lesniak, 2005). According to Gabel et al (1987), the ability to represent matter at the particulate level is important in explaining phenomena or chemical reactions, changes in state and the gas laws, stoichiometric relationships, and solution chemistry. Similarly, Snir et al (2003) and Treagust et al (2010) define the particle theory of matter the key component of several science education curricula from upper primary school to various stages of secondary school. Because of this importance, educators, science education researchers, and teachers would agree that the particulate nature of matter (PNM) is part of the heart of theoretical chemistry and a central subject in the middle and high school science curriculum. And also, the PNM underpins student understanding of many chemistry concepts (Haidar, 1997; Snir et al., 2003; Tsai, 1999). The structure of matter and phase changes (Bar, 1989; de Vos & Verdonk, 1996; Gabel et al., 1987; Osborne & Cosgrove, 1983), diffusion, dissolution process, and solution chemistry (de Vos & Verdonk, 1996; Lee et al., 1993), chemical reactions, the effects of pressure, volume, and temperature on gases (Nakhleh, 1992) is some of them. In addition, researchers have concluded that the PNM is vital for students' understanding of the physical, life, and earth sciences (Benson et al., 1993; Bouwma-Gearhart et al., 2009; Lee et al., 1993; Noh & Scharmann, 1997). All of the studies in the literature suggest that understanding of the PNM concept progress toward understanding the structural theory of matter and applying the theory in describing and explaining various matter forms and phase changes (Liu & Lesniak, 2005).

There have been made numerous studies related to the PNM in last three decades. In fact, Talanquer (2009) expresses that structure of matter and its changes may be one of the topics in which the description of students' ideas at different levels may be best characterized. These studies generally examine the understanding and alternative conceptions of the students in all grades (e. g. Adbo & Taber, 2009; Boz, 2006; Flores-Camacho et al., 2007; Hatzinikita et al., 2005; Löfgren & Hellden, 2008; Nakhleh & Samarapungavan, 1999; Othman et al., 2008; Paik et al., 2004; Pozo & Gomez Crespo, 2005; Singer et al., 2003; Taber & Garcia-Franco, 2010). On the other hand, some of the researchers prefer to examine the effect of different teaching approaches on students' learning of the PNM and related concepts (Adadan et al., 2009; Bunce & Gabel, 2002; Johnson & Papageorgiou, 2010; Kokkotas et al., 1998; Meheut, 2004; Noh & Scharmann, 1997; Papageorgiou et al., 2008; Pierri et al., 2008; Stern et al., 2008).

Significance of the study

It is well known that the PNM is problematic and students develop a wide range of alternative conceptions related to this concept. Moving from this commonly known problem, researchers have carried out numerous studies related to this concept, as mentioned above. Newly, Tsaparlis and Sevian (2013) published a book which deals extensively with the particulate concepts of matter. And also, the PNM is still the most attractive concept for researchers to investigate. From this point of view, a review of the PNM related studies is important for researchers, chemistry educators, teachers, and curriculum developers. Although it is possible for researchers to tracking the related literature, it may be difficult for them to obtain whole PNM related studies because there have been numerously. This study aims to be one of the main sources for researchers to see the whole PNM related literature and to take steps for new researches. On the other hand, teachers may lack of tracking the PNM related studies because of their heavy schedule. They will be informed about the PNM related studies and may translate the methodologies and approaches used in the literature into their classroom applications. When we look at the related literature, we can see that there are a few review studies related to the PNM and related concepts (Harrison & Treagust, 2002; Talanquer, 2009). And also, in these studies, authors generally summarized the students' alternative conceptions in different levels and/or different countries and compared them each other rather than present a detailed content analyses. This study tried to analyze the PNM literature using different parameters such as sample, type of study, aim, etc. It is also important to say that this study is a general overview and primarily intends to catalogue the PNM related studies instead of an in-depth analysis and/or discussing the content of them. But, some of the results of the studies and some students' alternative conceptions determined in different studies were summarized to see the progression and changes year by year.

Methodology

This review includes researches addressing the particulate nature of matter and related concepts, published between 1981 and early 2012. All papers published in refereed science education journals were attempted to be included in this period. The list of the searched journals is given in Table 1. To ensure that relevant articles were not missed, it was tried to follow up databases such as Elsevier, Springer, ERIC, etc. And also, the reference lists of all articles were reviewed and cross-checked. In all, seventy nine PNM related research papers covering students' understanding of the PNM and related concepts, alternative conceptions of the PNM and related concepts, and the effects of different strategies on students' learning, involving students at the elementary, secondary, college, and university levels.

In this context, studies related to matter, microscopic properties of matters, particle theory, changes of states, phase changes, the PNM, and etc. were selected and defined. So, the study is limited for the research papers to be reached related to the PNM and related concepts. Papers were classified in three sub-categories which are "s*tudies related to understanding levels and alternative conceptions", "studies related to effects of different teaching methods on students' learning"* and "*review studies".* The author developed criteria with the following headings to review the papers. The criteria includes 6 sub-heading and these are; i) author(s), ii) year of the study, iii) type of the study (students' understanding, comparative, experimental, or review), iv) the aim of the study, v) sample of the study, and vi) data collection tools of the study. Each of the PNM related studies was investigated based on these categories.

Table 1. Journal search results

Journal	Number of studies
Journal of Research in Science Teaching	17
International Journal of Science Education	17
Chemistry Education Research and Practice	7
Science Education	7
International Journal of Science and Mathematics Education	6
Journal of Science Education and Technology	4
Dissertation	3
Journal of Chemical Education	3
European Journal of Science Education	2
International Journal of Environmental and Science Education	2
Research in Science Education	2
Asia Pacific Forum on Science Learning and Teaching	1
Boğaziçi University Journal of Education	1
Canadian Journal of Science, Mathematics and Technology Education	1
Chemical Education: Towards Research-Based Practice	1
Computers & Education	1
Educational Sciences: Theory and Practice	1
Journal of Science Teacher Education	1
Research in Science & Technological Education	1
School Science and Mathematics	1
Total	**79**

Results and Discussion

Seventy nine studies were analyzed in this study. The detailed analysis of the research papers are given in appendix 1. The results of the study show that the target populations of the studies related to the PNM has included a broad range of students from primary school to university. In addition, a few studies have also been conducted with pre-service teachers. Most of these studies aimed to determine and compare students' and/or pre-service teachers' understanding while the others investigated the effect of different teaching techniques on learning of the PNM and related concepts.

Studies related to understanding levels and alternative conceptions

Fifty two of the seventy eight studies examined in this study aimed to identify students' and/or teachers' understanding levels and alternative conceptions related to the PNM. When the samples of these studies are examined, it is seen that there are students in each grade level from primary to university and in each age from 3-4 to 18-19 years old. In addition to students, understanding levels and alternative conceptions of pre-service and in-service teachers were also investigated. Most commonly data collection tools used in these studies are open-ended questions, multiple-choice questions and interviews. When these studies are examined, it is seen that most focus on nature of matter, states of matter, phase changes and particulate properties of matter. And also, whether students can use the PNM while explaining some daily life situations are examined. While, on one hand, these studies investigate how students understand the matter, its properties and its changes, on the other hand, they try to elicit students' alternative conceptions related to the PNM. Although matter and its properties is a major research area in science and chemistry education and the history of the researches related to this concept go long way back, the oldest paper investigated in this study is Novick and Nussbaum's (1981) study. They tried to determine students' understanding of the PNM in a broad range of sample from grade 5 to 12 and university. The other studies between the years of 1980 and 1989 are generally related to the PNM, states of matter, properties of solid, liquid and gases. For example, Shepherd and Renner (1982), Stavy and Stachel (1985) and Sere (1986) investigated the students' conceptions of states of matter, solid, liquid and gaseous states. They also determined the students' alternative conceptions in their studies. In this period, the study by Gabel et al. (1987) is the only study to be reached which investigates the pre-service teachers' understanding of the PNM.

There are 17 papers to be reached between 1990 and 1999 time interval in the study (see appendix 1). 14 of these are related to students' views and alternative conceptions of state of matter, phase changes and the PNM. While 13 of them focused on students in different grades from primary to university, one of them investigated prospective teachers' views (Kokkotas et al., 1998). In some of these studies, researchers focused on the same grade level students while some of them were cross-age studies. For example, Griffiths and Preston's (1992) studies with grade 12 students while Lee et al (1993) studied with grade 6 students. In cross-age studies, researchers can observe the improvement in students' conceptual understanding in different age groups. Such an approach gives an opportunity for the researcher to see and compare the reaction of the students in different ages in explaining the similar scientific phenomena. On the other hand, Stavy (1990), Bar and Travis (1991), Nakhleh and Samarapungavan (1999) studied with the students in different range of ages. There is only one study which compares pupils' ideas about the PNM in different countries (Maskill et al., 1997). In three studies, Johnson (1998a; 1998b; 1998c) investigated the progression in children's understanding of the particle ideas, longitudinally. Longitudinal studies take a long time but they are important to see the improvement in students' performance and conceptual understanding during the years. In other words, researchers can compare the effect of age and cognitive development in students' performance by using the longitudinal researches.

As seen from the appendix, there are 54 studies related to matter, states of matter, phase changes and the PNM between 2000-2012 time intervals and 34 of them are related to students' views and alternative conceptions. Four of these studies focused on student teachers' views (de Jong et al., 2005; Miller, 2008; Özmen et al., 2002; Valanides, 2000) while the others studied with the students in different grades. Most of these 35 studies compare the students' views in different grades and ages (e. g. Ayas & Özmen, 2002; Boz, 2006; Johnson & Papageorgiou, 2010; Krnel et al., 2003; Löfgren & Hellden, 2008; Othman et al., 2008; Özmen, 2011b; Yezierski, 2003) while the others focus on the same grade level students (e. g. Chang et al., 2010; Nakhleh & Samarapungavan, 1999; Papageorgiou & Johnson, 2005; Stern et al., 2008). In addition, 3 of these studies compared students' views on matter, states of matter and the PNM a cross-national approach (Onwu & Randall, 2006; Rahayu & Kita, 2010; Treagust et al., 2010). On the other hand, 7 of the studies investigated the progression in children's understanding of the particle ideas, longitudinally (Adbo & Taber, 2009; Eskilsson & Hellden, 2003; Holgersson & Löfgren, 2004; Löfgren & Hellden, 2008; Margel et al., 2008; Özmen, 2011b).

As seen above, there are several studies addressed students' understanding and/or alternative conceptions of one or more of the phenomena on the PNM and related concept, across a wide range of ages. When the content of the papers are examined, it is seen that students in all levels do not have an adequate understanding of matter, its transformations, and the PNM. Although students may understand the main point of the scientifically accepted theory that matter is made of discrete particles within constant motion and has empty space between the particles, research suggests that they find it difficult to apply to novel situations (Haidar & Abraham, 1991; Novick & Nussbaum, 1981; Tsai, 1999). Results of studies indicate that the nature and characteristics of particles, the nature of space between particles, behavior of particles in different states of matter, the size of molecules, and change in the arrangement of the particles during the phase change and chemical processes are the main problematic issues for the students (Boz & Boz, 2008; de Vos & Verdonk, 1996; Harrison & Treagust, 1996; Tsai, 1999; Harrison & Treagust, 2002). It is possible to say that abstract and submicroscopic nature of the particles and particulate level phenomena cause difficulties in understanding.

In addition to difficulties in understanding of matter, phase changes, and the PNM, both students and prospective teachers and even teachers have several alternative conceptions related to these concepts. Even, researches indicate that the alternative conceptions are generally similar (Benson et al., 1993; Gabel et al., 1987; Kokkotas et al., 1998; Valanides, 2000). Matter is continuous rather than particulate (Ben-Zvi et al., 1986) and macroscopic properties of matter such as hardness, color, and melting may be attributed to its submicroscopic particles (Albanese & Vicentini, 1997; Ben-Zvi et al., 1986; Griffiths & Preston, 1992; Harrison & Treagust, 2002; Kokkotas et al., 1998; Lee et al., 1993; Nakhleh, 1992) are the most common alternative conceptions. For example, Krnel et al (1998) report that students regard particles as small pieces of an object with all its properties. Another alternative conception is related to particle size. Students think that particle size increase when phase change occurs from solid to liquid and gas (Boz, 2006; Griffiths & Preston, 1992; Lee et al., 1993; Özmen et al., 2002; Özmen & Kenan, 2007; Pereira & Pestana, 1991; Valanides, 2000). Similarly, some students believe that the atoms get larger as matter changes from the liquid to the gas state and the numbers of the particles decrease from the solid to liquid and to gas (Gabel et al., 1987; Özmen & Kenan, 2007). These results indicate that students have a tendency to use their perceptions on macroscopic changes of a substance to infer its phase change occurring at the submicroscopic level and the presence of the particles in three states of matter is counter-intuitive to their knowledge.

Although there are several studies determining students' views, progression of the understanding, and the alternative conceptions related to matter, its properties, phase changes and the PNM in the literature, these concepts still are the focus of interest by the researchers. Therefore, it is still possible to see such type of researches in recent science and/or chemistry education literature (e.g. Ayas et al., 2010; Rahayu & Kita, 2010; Treagust et al., 2010). This shows the importance of the matter, its structure and the PNM in science and chemistry education. Table 2 summarizes some of the results of different studies and students' alternative conceptions determined from different levels and cultures.

Table 2 shows that students' alternative conceptions related to the PNM are generally similar all over the world and for almost all of the students. On the other hand, there is a fact that the studies in the literature are very similar to each other based on their results. Especially, some of the studies cannot go one step further except for repeating and confirming the results of the older studies by using different sample. Table 2 reflects this clearly. As seen from the table, the results of most of the studies are similar or the same with each other although they cover a wide range of years. These results also confirm the view that alternative conceptions are encountered in different ages, nations and levels. On the other hand, these results show that students' conceptions of the particulate nature of matter are far from desirable and there is much overlap in conceptions among students of different grades. In addition, students in all levels besides student teachers have similar alternative conceptions and these need to be remedied by instruction.

Table 2. Results of some studies related to students' understanding and alternative conceptions of matter and its particulate and sub-microscopic nature

Aim	Sources	Concepts	Results
To determine students' understanding, and/or alternative conceptions	Data from elementary school students, secondary school students, university students and student teachers	Matter, PNM, states of matter, solid, liquid and gases, phase changes, atoms and molecules, transformation of matter, evaporation and condensation	- Results show that students in all levels have some problems in understanding of matter, its sub-microscopic and particulate nature and its transformations. [1, 3, 8, 9, 22, 25, 30, 32, 33, 39, 44, 47 – 49, 53, 61, 69, 74 (*)] - Students in different countries have some problems in understanding of the matter and its structure [1, 15, 16, 25, 36, 46, 50, 70, 71, 74, 76] - Progression of students' conceptions on matter from elementary to high school is multifaceted [1 – 4, 7, 8, 10, 13, 16, 18, 19, 20, 30 – 36, 43, 44 -51, 53, 54, 56, 65, 69, 70, 71, 74, 75, 77] - Students attribute the bulk macroscopic properties of matters to atoms, molecules or particles [1, 6, 9, 12, 13, 14, 15, 17, 18, 24, 27, 34, 43, 50, 56, 57, 63] - Students in all levels have some alternative conceptions. Some of the most commonly encountered alternative conceptions are listed below: i. Solids are heavy and they remain the same shape. Gases and liquids are light and able to change shapes [2, 7] ii. The bubbles are made of heat [3, 8, 18, 19] iii. The bubbles are made of air **[3, 8, 18, 19, 36, 41, 56]** iv. The bubbles are oxygen and hydrogen [3, 8, 18, 19, 41, 56] v. Water changes into air during the evaporation [3, 12, 24] vi. Water decomposes into oxygen and hydrogen when it evaporates [24, 56] vii. Air and/or gas has no weight [7, 12, 30, 68] viii. The size of particles is smallest in the solid, increases in the liquid and increases even more in the gas [6, 9, 12, 24, 28, 34, 50, 59, 61, 64, 73, 74] ix. Distances between the particles increases, decreases or does not change during the phase changes [3, 10, 24, 50, 73] x. Number of the particles changes during the phase changes [6, 12, 50, 67, 73, 74] xi. Molecules in solids are heavier than those in liquids, and molecules of vapor are the lightest [7, 12, 21, 56, 64, 68] xii. Particles in a solid do not move [3, 12, 24, 43, 52, 60, 64, 79] xiii. Matters are continuous [9, 10, 12, 18, 19, 21, 22, 32, 38, 40, 44, 45, 49, 54, 57, 60, 64, 65, 69, 72]

Asterisk (*) represents the code number of the study in appendix 1

Studies related to effects of different teaching methods on students' learning

Because students' alternative conceptions are well known, preventing and overcoming of them by using different methods are also important and the number of such studies increases day by day in recent years. Twenty two of the examined studies in this paper aimed to determine the effect of different teaching methods on students' learning and alternative conceptions related to the PNM. When the teaching methods used in these studies are examined, it is seen that different methods such as analogy, computer-based instruction, multi-representational instruction, microcomputer-based laboratory, conceptual change texts, and etc. are most commonly used. Most of these studies are quasi-experimental in nature and are condensed between 2000-2012 time intervals. For example, while there is no experimental study in 1980-1989 intervals, there are three studies in 1990-1999 periods (see appendix 1) (Gabel, 1993; Lee et al., 1993; Tsai, 1999). On the other hand, there are 18 studies in 2000-2012 intervals (e. g. Adadan, 2006; Chang et al., 2010; Özmen, 2011a; Pierri et al., 2008; Snir et al., 2003; Stern et al., 2008). The samples of the studies show that each grade students from primary to university were studied. Most commonly data collection tools used in these studies are open-ended questions, multiple-choice questions and interviews.

When the content of the studies is examined, it is seen that computer software, animations, analogies, multiple representations, and conceptual change texts are the most frequently used instructional techniques. Among them, computer-based technologies (software, animations and simulations) and multiple representations have been extensively used. For example, Papageorgiou et al (2008), Snir et al (2003) and Stern et al (2008) investigated the effectiveness of software for introducing students to the PNM and related concepts. Similarly, Yezierski and Birk (2006) and Chang et al (2010) investigated the effectiveness of animations on students' understanding of the PNM, phases of matter and phase changes. On the other hand, there are a number of studies investigating the effect of multiple representations on students' understanding of the PNM and related concepts. For example, Adadan (2006), Adadan et al (2009), Adadan et al (2010), Adadan (in press) and Bunce and Gabel (2002) investigated the efficacy of the multi-representational instruction on students' understanding of the PNM. In recent years, conceptual change texts-based studies are also reported. For example, Beerenwinkel et al (2011) were tried to explore the effect of a conceptual change text on students' awareness of common misconceptions on the particle model of matter on grades 7 and 8. Similarly, Özmen (2011a) aimed to determine the effect of animation enhanced conceptual change texts on grade 6 students' understanding of the particulate nature of matter and transformations during the phase changes.

The results of all these studies show that different methods that focus on the particle level representations are more successful than the traditional ones. In traditional classrooms, the PNM is generally taught by using two-dimensional drawings of dots and circles to represent atoms, ions, and molecules and the traditional approach to teaching of chemistry and/or science does not include the particulate diagrams that stress the interaction of atoms, molecule, and ions (Bunce & Gabel, 2002). For this reason, traditional classroom environment and methods may not match the learning style of most learners as students play a passive role in the learning process. On the other hand, understanding of the particulate world requires students to bridge their conceptual understanding among macroscopic, microscopic, and the symbolic representations (Hinton & Nakhleh, 1999). Several researchers have expressed that computer-based technologies are useful to show particulate interactions which are necessary to explain observed chemical phenomena (Bunce & Gabel, 2002) and help students to understand chemistry by increasing their ability to visualize particle-level processes take place at sub-microscopic level (Kelly & Jones, 2007; Özmen et al., 2009; Yezierski & Birk, 2006). Studies using computer-modeling of sub-microscopic processes in chemistry suggest that, after interventions, students may develop better understanding of the related concepts and may be able to answer conceptual questions about particulate phenomena in a more scientifically accurate (Ardac & Akaygun, 2004; Jones, Jordan & Stillings, 2005; Kelly & Jones, 2007; Madden, Jones & Rahm, 2011).

The literature also suggests multiple visual representations as a teaching pedagogy to improve students' ability to visualize the submicroscopic occurrences of the phenomena (Adadan et al., 2009; Adadan, in press; Bunce & Gabel, 2002; Snir et al., 2003). For example, Yezierski (2003) suggests that the dynamic nature of phase of matter and phase changes on a particle level lends itself well to animations as a descriptive tool. Similarly, a number of studies report that animations increase the conceptual understanding of particle behavior (Sanger et al., 2000; Stieff & Wilensky, 2003; Tasker & Dalton, 2006; Wu et al., 2001). These properties of the computer-based technologies make them important in-class activities and investigation of the literature show that the numbers of studies that intend to determine the effect of computer-based instruction and/or multiple representations increase day by day.

Review studies

In the literature, there is a limited amount of studies reviewing the studies of the PNM. As seen from Appendix 1, five of the seventy eight examined studies aimed to review the literature. Among them, Harrison and Treagust's (2002) study is the most detailed one. They investigated and summarized several numbers of studies. Recently, Talanquer (2009) reviewed the literature, similarly. On the other hand, any of these review studies did not develop criteria similar to this study. And also, when the content of these studies are examined, it is seen that while almost all of the investigated studies are related to determining students' alternative conceptions of the PNM, there are no studies investigating the effect of different methods on students' learning. Although there have been made 17 studies in 2000-2011 interval to see the effect of alternative instructional techniques, none of them has been included in the review studies. It is of course important to review the students' alternative conceptions related to the PNM. But, on the other hand, it is not considered that the effect of different methods on students' conceptual understanding of the PNM is also important. As a matter of fact, in recent years, researchers prefer to investigate the effect of different methods on students' conceptual understanding and alternative conceptions rather than determining the alternative conceptions. For this reason, reviewing the literature that examines the different methods on students' conceptual understanding becomes important day by day.

It is important to review the literature to determine students' alternative conceptions and to develop new and original instructional techniques different from the literature. In fact, researchers can easily follow the related literature through the review studies. Although it is possible to overview the literature by making the most of technological opportunities in this day and time, review studies can easily inform the researchers about the studies. This study is a review and intends to provide useful knowledge for teachers, researchers, curriculum developers and textbook writers for this manner as a source of published papers.

Conclusion and Implications

The particle theory of matter is a corner stone in science education curricula from as early as upper primary school to various stages of secondary school (Snir et al., 2003; Treagust et al., 2010). Educators, science education researchers, and teachers would agree that the PNM is a central topic in chemistry and a central subject in the primary and high school science curricula. In addition, the literature suggests that after understanding the PNM, students are able to progress toward understanding the structural theory of matter and using it to describe and explain the characteristics of the various forms of matter and phase changes

(Liu & Lesniak 2005). Because of this importance, several studies related to the pedagogical treatment of the PNM are already present in the literature.

We know from the literature that students rarely perceive matters as made up of discrete particles called atoms, molecules and ions before they are introduced to this idea in school (Adadan et al., 2009). On the other hand, students' understanding of the PNM in all grades from elementary to high school is multifaceted, there is no significant conceptual difference between grades in conceptual progression (Liu & Lesniak, 2006) and students in primary school to university develop either spontaneous or instruction-based alternative conceptions on this concept (Liu & Lesniak, 2005; Nakhleh & Samarapungavan, 1999; Nakhleh et al., 2005). All these results emerge the question "at which age should students be introduced to the PNM?". The PNM is included in even primary curriculum of most countries (Gabel et al., 1987). But, literature also suggests that the particle theory should be moved to later in the curriculum (Fensham, 1994; Harrison & Treagust, 2002). The reasons for this are that it is too difficult, cognitive requirements of such an abstract model are too great for most primary school students (Johnson & Papageorgiou, 2010) and progression in students' understanding is influenced by maturation by age (Rahayu & Kita, 2010). Based on this view, National Curriculum for England and Wales stated that particle ideas need not to be taught in primary schools up to age 11. Similarly, Papageorgiou and Johnson (2005) state that particle ideas do not feature at primary levels in Greece. This is also consistent with Piaget theory which states that older students have more developed their formal thinking ability. On the other hand, Johnson (1998a) advocates that children's difficulties with the particle model could be due to the widespread inadvertently teaching practices and children do not have a meaningful macroscopic conception related to a gas without particle ideas. And also, Liu and Lesniak (2006) assume that "*children's matter concept development is attributable to not only maturation by age but also school context, such as curriculum and instruction* (p. 322)". If we come back to the question "at which age should students be introduced to the PNM?", the response is still somewhat questionable. But, one thing is not questionable that students in various grades do not learn the particulate interaction necessary to explain observed phenomena through traditional chemistry or science teaching (Nakhleh & Mitchell, 1993). The picture emerged from the researches shows a widespread failure of students to grasp the PNM concept. In other words, traditional methods are ineffective in helping students to develop a complete understanding of the matter, phase changes and the PNM, to alleviate alternative conceptions, and to promote conceptual change (Tsai, 1999). For this reason, methods designed for improving students' conceptual understanding and overcoming their alternative conceptions on the PNM has become important in last decade. To promote change in students' conceptions of the PNM, researchers have designed different methods such as conceptual change texts (Beerenwinkel et al., 2011; Durmuş & Bayraktar, 2010), animation-enhanced conceptual change texts (Özmen, 2011a), molecular animations (Chang et al., 2010), multi-representational instruction (Adadan et al., 2009; Adadan et al., 2010), microcomputer-based lab (Pierri et al., 2008) and analogies and role-modeling (Tsai, 1999). These methods have also positive effect on students' alternative conceptions. For this manner, literature suggests that teachers should be more receptive in seeking alternative methods if they find that their present teaching methods are inadequate (Tan & Treagust, 1999). These results show that researchers should develop and implement new, original and enriched alternative teaching methods to improve students' conceptual understanding.

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APPENDIX:

Appendix 1. Studies related to the PNM and related concepts

Studies in chronological sequence	Date	Type of the study				Aim of the study	Sample	Data collection tools					
		SU	C	E	R			OEQ	MCQ	I	Q	D	DA
1. Novick and Nussbaum	1981	X	X			To determine students' understanding of the PNM (cross-age study)	576 students (from grade 5-12 and university)	X	X			X	
2. Shepherd and Renner	1982	X	X			To determine student understandings and misunderstandings of states of matter	135 students (grade 10 and 12)	X					
3. Osborne and Cosgrove	1983	X				To determine children's conceptions of the changes of state of water	43 students (ages 8-17)			X			
4. Stavy and Stachel	1985	X	X			To determine children's ideas about solid and liquid	200 students (ages 5-13)			X			
5. Sere	1986	X				To determine children's conceptions of the gaseous state prior to teaching	600 children at first year of secondary education			X	X		
6. Gabel, Samuel and Hunn	1987	X				To determine pre-service teachers' understanding of the PNM	90 pre-service teachers		X				
7. Stavy	1990	X	X			To determine students' conceptions of changes in the state of matter from liquid or solid to gas	120 students (ages 9-15)			X			

8. Bar and Travis	1991	X	X		To determine children's views concerning phase changes	83 students (ages 6-12) + 152 students (ages 10-14) + 266 students (ages 11-15)	X	X	X		
9. Griffiths and Preston	1992	X			To determine grade 12 students' alternative conceptions related to atoms and molecules	30 grade-12 students			X		
10. Benson, Wittrock and Baur	1993	X			To determine students' preconceptions of the nature of gases	1098 students (from second graders to university)					X
11. Gabel	1993			X	To determine the effect of using the PNM in developing students' conceptual understanding	66 students		X			
12. Lee, Eichinger, Anderson, Berkheimer and Blakeslee	1993			X	To determine the conceptual frameworks that sixth-grade students use to explain the nature of matter and to assess the effectiveness of two alternative curriculum units in promoting students' understanding	15 sixth grade science classes		X	X		
13. Abraham, Williamson and Westbrook	1994	X	X		To determine students understanding of five chemistry concepts (including phase change) (cross-age study)	100 students (junior high school physical science, high school and college	X				

							chemistry)						
14. De Vos and Verdonk	1996				X	To address correct or acceptable ideas about the PNM in science education and studies of children's alternative conceptions	Related literature						X
15. Albanese and Vicentini	1997	X				To determine Italian students' ideas of properties of atoms and molecules	30 secondary school students				X		
16. Maskill, Cachapuz and Koulaidis	1997	X	X			To determine pupils' ideas about the PNM (cross-national study, Greece, Portugal and UK)	1000 children (age 11 to 12 in each country)				X		
17. Kokkotas, Vlachos and Koulaidis	1998	X				To teach the topic of the PNM in prospective teachers' training course and determine their ideas	70 prospective teachers	X			X		
18. Johnson	1998 (a)	X				To determine progression in children's understanding of a basic particle theory (longitudinal study)	147 secondary school students (year 7 to 9)			X			
19. Johnson	1998 (b)	X				To investigate students' understanding of boiling water and particle ideas (longitudinal study)	147 secondary school students (year 7 to 9)			X			
20. Johnson	1998 (c)	X				To investigate students' understanding of evaporation and condensation below boiling point and particle ideas (longitudinal study)	147 secondary school students (year 7 to 9)			X			

21. Krnel, Watson and Glazar	1998				X	To review the researches related to the development of the concept of matter	Related literature						X
22. Nakhleh and Samarapungavan	1999	X				To determine elementary school children's beliefs about the PNM	15 students (ages 7-10)			X			
23. Tsai	1999			X		To examine the effectiveness of an analogy activity designed to overcome junior high school students' misconceptions related to the microscopic views of phase changes	80 eighth grade students					X	
24. Valanides	2000	X				To investigate primary student teachers' understanding of the PNM and its transformations during dissolving	20 primary student teachers			X			
25. Ayas and Özmen	2002	X	X			To determine high school student understandings of the PNM	150 grade 9 students + 100 grade 10 students	X				X	
26. Bunce and Gabel	2002			X		To investigate whether teaching the particulate representations of chemistry increases student achievement and whether there is a differential effect of using the particulate representation of chemistry for males and females	12 teachers and 447 grade 10 and 11 high school chemistry students		X				
27. Harrison and Treagust	2002				X	To review the studies related to the PNM and challenges in	Related literature						X

					understanding the submicroscopic world					
28. Özmen, Ayas and Coştu	2002	X			To determine prospective science teachers' views of the PNM	190 prospective science teachers	X			
29. Edwards and Soyibo	2003	X			To determine whether the subjects' attitudes towards science were favorable or not and whether there were any statistically significant differences in the students' knowledge of matter based on gender, attitudes towards science, school type and socio-economic background	216 grade 9 students		X		X
30. Eskilsson and Hellden	2003	X			To determine how pupils use their mental models of the nature of matter when they talk about everyday phenomena involving transformation of matter (longitudinal study)	40 students (between 10 and 11 years age)			X	
31. Krnel, Glazar and Watson	2003	X	X		To determine development of the concept of matter (cross-age study)	84 students (ages 3-13)			X	
32. Snir, Smith and Raz	2003			X	To design a software for introducing students to the PNM and to explore the effectiveness of the software	9 fifth- and sixth-grade students + 28 seventh grade students	X			X
33. Yezierski	2003			X	To determine students' conceptual understanding of the PNM (Cross-	848 students (middle, high		X		

					age study – doctoral dissertation)	and college students)						
34. Gomez Crespo and Pozo	2004	X			To determine the students' mechanism used for explaining changes in matter in terms of kinetic theory	278 Spanish students of different ages				X		
35. Holgersson and Löfgren	2004	X	X		To investigate the progression in students' explanations of transformations of matter (a long-term study)	60 students (from age 6 to 16)				X		
36. Paik, Kim, Cho and Park	2004	X	X		To investigate K-8th grade Korean students' conceptions of changes of state and conditions for changes of state	25 students (from kindergarten, second grade, fourth grade, sixth grade and eight grade)				X		
37. De Jong, Van Driel and Verloop	2005	X			To determine preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry	12 preservice teachers	X					X
38. Hatzinikita, Koulaidis and Hatzinikitas	2005	X			To determine pupils' understanding and explanations concerning changes in matter	30 primary students (fifth and sixth grade)			X			
39. Liu and Lesniak	2005	X			To determine students' progression of understanding the matter concept from elementary to high school	Grade 3, 4, 7, 8 and 12 students (TIMMS datasets)	X	X				

40. Nakhleh, Samarapungavan and Saglam	2005	X			To determine middle school students' views about matter	9 middle school students			X			
41. Papageorgiou and Johnson	2005			X	To determine whether particle idea help or hinder students' understanding of phenomena	39 fifth-grade students			X			
42. Adadan	2006			X	To determine the effect of multiple representations on high school students' conceptual understandings of the PNM (doctoral dissertation)	42 high school students	X		X			X
43. Boz	2006	X			To explore grade 8, 9 and 11 Turkish students' views about the PNM within the context of phase changes	300 students	X		X			
44. Jimenez Gomez, Benarroch and Marin	2006	X			To evaluate degree of coherence found in students' conceptions concerning the PNM	43 students (ages 9 – 22)			X			
45. Liu and Lesniak	2006	X	X		To identify students' conceptual progression on matter from elementary to high school	54 students (from grade 1 to 10)				X		
46. Onwu and Randall	2006	X	X		To investigate students' understanding of a particulate model used for relating submicroscopic entities and processes to macroscopic events in chemistry (cross-national study)	333 students (224 grade 10 students from Nigeria + 72 grade 12 students from Japan + 27 first		X				

						year pre-service science teachers from South Africa)					
47. Yezierski and Birk	2006			X	To investigate the effectiveness of animations on student' PNM misconceptions related to phases of matter and phase changes	719 students (from 8-grade middle school; 10-, 11-, and 12-grade and college chemistry students)	X				
48. Yılmaz and Alp	2006	X	X		To determine the effect of reasoning ability and grade level on students' understanding of matter	90 students (from grade 8, 10 and 11)	X		X		
49. Flores-Camacho, Gallegos-Cazares, Garritz and Garcia-Franco	2007	X	X		To determine representations of the structure of matter in undergraduate chemistry students	106 university chemistry students		X	X		
50. Özmen and Kenan	2007	X	X		To determine Turkish primary students' understanding of PNM	411 grade 4, 5 and 6 students				X	
51. Stains and Talanquer	2007	X			To determine students' classification of chemical substances using particulate representations of matter	804 students from different courses		X	X		
52. Boz and Boz	2008	X			To investigate prospective	22		X			X

					chemistry teachers' knowledge about instructional strategies, one component of pedagogical content knowledge about introducing particulate theory	prospective chemistry teachers						
53. Löfgren and Hellden	2008	X	X		To investigate students' understanding of three phenomena in which transformations of matter occur (longitudinal)	25 students (from 7 to 13 years)				X		
54. Margel, Eylon and Scherz	2008	X	X		To investigate the progression in junior high school students' conceptions of the structure of materials (longitudinal)	1082 junior high school students (grade 7-9)					X	X
55. Miller	2008	X	X		To determine prospective elementary school teachers' understanding of the PNM (longitudinal study - doctoral dissertation)	68 prospective teachers	X	X	X	X		
56. Othman, Treagust and Chandrasegaran	2008	X			To assess students' understanding of the PNM and chemical bonding so as to identify possible associations between students' understanding of the two concepts	260 students from grade 9 and 10		X				
57. Papageorgiou, Johnson and Fotiades	2008			X	To investigate the effect of a software on students' understanding of particle ideas in explaining melting and evaporation below boiling point	35 primary school students			X			
58. Pierri,	2008			X	To explore the phenomenon of	79 students			X			

Karatrantou and Panagiotakopoulos						change of phase of pure substances using the microcomputer-based -laboratory system	from grade 10						
59. Stern, Barnea and Shauli	2008			X		To evaluate the effect of a dynamic software simulation on the understanding of the kinetic molecular theory by 7th graders	133 students from grade 7	X					
60. Adadan, Irving and Trundle	2009			X		To examine the effect of multi-representational instruction on high school students' understanding of the PNM	42 high school students	X		X			
61. Adbo and Taber	2009	X	X			To investigate the mental models of matter at the particulate level (longitudinal)	18 upper secondary science students (16-19 years of age)				X		X
62. Bouwma-Gearhart, Stewart and Brown	2009	X				To assess students' atomic /molecular level explanations of real-world phenomena after their participation in a modeling-based PNM unit	11 high school students				X		
63. Talanquer	2009				X	To identified basic assumptions that constrain students' ideas and reasoning on the PNM based on the analysis of research on students' alternative conceptions about the PNM	Related literature						X
64. Adadan,	2010			X		To identify and describe grade 11	19 students	X		X			X

Trundle and Irving						students' conceptual pathways of the PNM and to determine efficacy of the multi representational instruction on the PNM	from grade 11						
65. Ayas, Özmen and Çalık	2010	X	X			To determine and compare students' conceptions of the PNM at secondary and tertiary levels	166 students	X					
66. Chang, Quintana and Krajcik	2010			X		To investigate the effect of molecular animations on middle school students' understanding of the PNM	271 students from grade 7	X		X			
67. Devetak, Vogrinc and Glazar	2010				X	To investigate the content of textual and pictorial material of Slovenian science textbooks and notebooks on topic states of matter	Science textbooks from grade 1 to grade 9						X
68. Durmuş and Bayraktar	2010			X		To investigate the effects of conceptual change texts and laboratory experiments on fourth grade students' understanding of matter and change concepts	104 students from grade 4	X					
69. Johnson and Papageorgiou	2010			X		To determine the effectiveness of substance-based framework on students' understanding of particle theory	12 students (ages 9-10)			X			
70. Rahayu and Kita	2010	X	X			To analysis of Indonesian and Japanese students' understandings of macroscopic and	447 Indonesian + 446 Japanese senior high			X			

					submicroscopic levels of representing matter and its changes	school students (Grade 10, 11 and 12)			
71. Treagust, Chandrasegaran, Crowley, Yung, Cheong and Othman	2010	X	X		To evaluate students' understanding of kinetic particle theory concepts relating to the states of matter, changes of state and diffusion (cross-national study)	148 high school students from Brunei, Australia, Hong Kong, Singapore	X		
72. Tsitsipis, Stamovlasis and Papageorgiou	2010	X			To determine three cognitive variables on students' understanding of the PNM and its changes of state	329 ninth grade junior high school students	X		
73. Özmen	2011 (a)			X	To determine the effect of animation enhanced conceptual change texts on grade 6 students' understanding of the particulate nature of matter and transformations during the phase changes	51 students from grade 6	X		X
74. Özmen	2011 (b)	X	X		To determine 4th, 5th, and 6th grade primary students' conceptions about the particulate nature of matter in daily-life events and compare the result.	12 students from grade 4, 5, and 6 (four students from each grades)		X	
75. Beerenwinkel, Parchmann and Grasel	2011			X	To explore the effect of a conceptual change text on students' awareness of common misconceptions on the particle model of matter	214 students from grade 7 and grade 8			X

76. Nyachwaya, Mohamed, Roehrig, Wood, Kern and Schneider	2011	X				Developing of an open-ended alternative diagnostic tool for assessing students' understanding of the particulate nature of matter	110 students in a first-semester freshman general chemistry class at a mid-western university in USA	X				X	
77. Treagust, Chandrasegaran, Zain, Ong, Karpudewan and Halim	2011			X		To evaluate an instructional strategy for the purpose of assessing students' understanding of particle concepts	190 students from high school, undergraduate and postgraduate students from five educational institutions in Malaysia		X				
78. Pimthong, Yutakom, Roadrangka, Sanguanruang, Cowie, Cooper	2012			X		To enhance the teaching and learning of matter and its properties for grade 6 students	Three primary teachers and grade 6 students from their classes			X	X		
79. Adadan	in press			X		To determine the effect of multiple representations on grade 11 students' understanding of the particle theory of matter	42 grade 11 students	X		X		X	

SU: Students' understanding; C: Comparative; E: Experimental; R: Review; OEQ: Open-ended question; MCQ: Multiple-choice question; I: Interview; Q: Questionnaire; D: Drawings; DA: Document analysis