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The Effect of Multiple Representations of Physical and Chemical Changes on the Development of Primary Pre-service Teachers Cognitive Structures

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Abstract The purpose of this study was to describe the effect of multiple knowledge representations of physical and chemical changes on the development of primary pre-service teachers' cognitive structures. The study took place in an introductory general chemistry laboratory course in a four-year teacher education program. Multiple knowledge representations in chemistry refer to the macroscopic (visible), sub-microscopic (invisible), and symbolic (formulas and equations). The study adopted one group pretest-posttest design supported by qualitative data. Forty primary pre-service teachers participated in this study. The results revealed that enabling the primary pre-service teachers to learn multiple representations of physical and chemical changes was effective in developing both groups of pre-service teachers' cognitive structures, low and high-level understanding of particulate nature of matter, the latter benefitting the most. This finding was instructive because it emphasizes the difficulty that some primary pre-service teachers had on the particulate and symbolic representations of physical and chemical changes. The improvement in primary pre-service teachers' cognitive structures of physical and chemical change by the use of multiple representations.

Keywords Cognitive structure · Multiple representations · Particulate nature of matter · Physical change · Chemical change · Word association

Introduction

The particle theory of matter is at the heart of chemistry and chemistry curricula (Adadan 2014a, b; Adbo and Taber 2009; Ayas and Özmen 2002; Taber and Franco 2010). Particulate

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nature of matter forms the basis for the understanding of the macroscopic observations of elements, mixtures and compounds, chemical reactions, chemical equilibrium, and acids and bases (Ayas et al. 2010; Taber and Coll 2002). Many science education researchers assert that the transition among knowledge-types–the macroscopic, sub-microscopic, and symbolic and the corresponding representations with ease are critical to chemistry learning, but poses difficulty to learners at various levels from school to university (e.g., Ayas et al. 2010; Author and Co-author).

There are two principal reasons for studying primary pre-service teachers' (PSTs') cognitive structures of physical and chemical change through their understanding of the particulate nature of matter. The first is the inclusion of particulate nature of matter in the primary science curriculum (Çökelez 2009; Griffiths and Preston 1992; Özmen 2011; Stavy 1990; Taber and Franco 2010; Talanquer 2009). The second is the particulate nature of matter underpins student understanding of many chemistry concepts. They are the structure of matter and phase change (Çökelez 2009; Griffiths and Preston 1992; Özmen 2011), diffusion, the dissolution process, solution chemistry (Adadan 2014a), chemical reactions, and the effect of pressure, volume, and temperature on gases (Nakhleh 1992). These two reasons, related to their future students' learning (Jarvis et al. 2003), have wider appeal and application for primary PSTs' learning of the particulate nature of matter in chemical science (Adadan 2014a; Özmen et al. 2002). Thus, the study at hand focuses on the primary PSTs' learning of the multiple knowledge representations in an introductory general chemistry laboratory course. We group the PSTs to the low and high-level understanding of the particulate nature of matter based on the scores they obtained in the pre-test of Particulate Nature of Matter Diagnosis Questions scale. We classified those PSTs who scored 2.5 and below as the low-level understanding group and those who scored more than the specified mean value as the high-level understanding group because, as we mentioned above, the particulate nature of matter underpins student understanding of many chemistry concepts. The reason for classifying the PSTs low and high levels is to help both groups to become aware of their sub-microscopic ideas and the level of understanding. This grouping gives us an opportunity to monitor both groups' improvement so that no one is left behind in his or her learning of the sub-microscopic, which is necessary for understanding chemical topics such as physical and chemical changes. Only if we and the PSTs are aware of the PSTs' level of understanding of the sub-microscopic, we will be able to design activities and strategies that are equitable so that both groups of PSTs will excel in this area.

The Literature Review

The literature review focuses on the PSTs' understanding of the particulate nature of matter and the relationship of their understanding to students' learning. Findings of previous studies on particulate nature of matter (PNM) range from primary to university although our focus is on understanding the primary teachers' knowledge development in science. Instead of reviewing an exhausting number of studies on the PNM, we will argue our case with a few relevant studies.

Özmen (2011) claimed that the grades four, five, and six students' understanding of the sub-microscopic properties of matter is low. This study pointed out that elementary students have little knowledge or alternative conceptions about the sub-microscopic properties of the particles such as the order of the particles, spaces between particles, the number of particles in different phases, the size of particles, and the movement of the particles. Working with 163 Turkish middle school students (grades six, seven, and eight), Çökelez (2009) found out from his qualitative study that the learners had difficulties about the space between particles, the number of particles, the size of particles, and the movement of the particles. For example, learners thought that the size of the particles increased from solid to gas, and the volume of matter increased as the matter changed from solid to gas. These findings reveal the middle school students often transfer macroscopic observation to the sub-microscopic explanation. We cannot expect primary students to visualize the behavior of the particle in the three states of matter to develop a deeper understanding. However, the teachers cannot afford to neglect teaching the three states of matter and discuss the relationship between the visible and the invisible. Otherwise, the problem compounds as students move from one grade to the other.

Stavy (1990) noted that students' definition of "gas" depends on their grade level. Seventh graders, for instance, primarily used a particle model. However, Griffiths and Preston (1992) found even the 12th-grade students visualize matter as continuous, not particulate. High school students often conceive the solid particles static, and the liquid and gas particles movable (Adbo and Taber 2009; Boz 2006; Pozo and Gómez-Crespo 2005). 16-year-old Swedish science students view solid particles in contact with each other as well as the liquid particles one particle, and the gas particles three-four particles apart (Adbo and Taber 2009). A considerable number of high school and university students lack the conceptual understanding of electrostatic forces between the particles of matter (Adadan et al. 2009; Boz 2006), and the intermolecular interactions cause physical and chemical changes (Talanquer 2009). The findings of K-12 students' understanding of chemical science concerning the PNM is of relevance because some of these very same students aspire to become future teachers and are teaching now. Concerning the phenomenon of chemical and physical change, which is the focus of our study, many eighth -grade students used the terms interchangeably, thus showing that they cannot differentiate between the two (Boujaoude 1991). Nieswandt (2001} noticed a little progress when assisting ninth grade students with the understanding of chemical change of substances. Eleven to fourteen years old learners are not able to identify chemical change (Johnson 2000). According to Othman et al. (2008), Ninth and 10th grade Singapore students revealed limited understanding how the PNM influences chemical bonding.

While the school students' PNM studies are numerous, the focus on pre-service teachers is relatively few. However, the studies on the school students' understanding of the PNM have implications for the future teachers of science. For example, studies on the primary (Özmen 2011) and middle (Çökelez 2009) school students' ideas found for the same phenomena mentioned above corroborate with the study of Banda et al. (2011). These authors probed thirty Zambian junior high school pre-service science teachers' understanding of the PNM on the effect of phase change on speed, spaces and number of particles in a substance. They found that although their macroscopic understanding of the phase change is usually correct, many of them have a poor understanding of the effect of phase change, cooling and heating on the size of the particles in substances. Most of the Zambian pre-service science teachers erroneously believed that when a substance is cooled it constricts because the sizes of its particles decrease, and when a substance is heated (melting), the size of its particles increases.

The pre-service teachers are, in fact, like the school students seem to translate their macroscopic senses of the phase change to the sub-microscopic explanation. Similarly, many of the 40 prospective chemistry teachers understand the concept of particles; however, they have inaccurate knowledge about the pattern and distance of particles in solid, liquid, and gases (Adadan 2014b). They believed that "it is the collective behavior of the particles making up the matter that determines the physical properties of the matter" (p. 395). Also, these future teachers had problems with the concepts of electrostatic attraction force and the presence of PNM in a vacuum. These claims parallel the studies about the K-12 school students (Adadan et al. 2009; Adbo and Taber 2009; Boz 2006; Çökelez 2009; Franco and Taber 2009; Talanquer 2009). The inference from these studies is K-12 students, and pre-service teachers, both primary and chemistry encounter difficulty in explaining various chemical phenomena using the particle model (Ayas et al. 2010; Liu and Lesniak 2005; Özmen 2011). Their explanations reflect a similar understanding of the PNM (Ayas et al. 2010).

Jarvis et al. (2003) researched with 70 primary teachers in 31 schools over a period of two years that monitored teacher change in understanding the topics of electricity; melting, evaporation and dissolving; and friction. Their in-service programme consisted of a ten-day-core module on Developing and Assessing Investigations. This module comprises of strategies to develop investigations to enable the teachers to understand the relationship between conceptual knowledge and inquiry. The researchers used a constructivist approach, starting with teachers becoming aware of their conceptions in a targeted area and then providing experiences to accept the scientific view through collaborative learning. Concerning the physical and chemical changes, their study observed the teacher lack understanding of dissolving because of their confusion with the concept of melting. Also, these authors revealed that many of the primary teachers did not have a particulate model, and some of them, even before in-service education had confusions about the particles or molecules. Hence, Jarvis et al. assert how a teacher provides children inappropriate experiences to develop an understanding of the science concepts unless he or she knows the learning outcomes.

Focusing on the primary PSTs' levels of understandings of the PNM is significant because the topic of Matter is a fundamental part of the Turkish science curriculum (e.g., Adadan 2014b; Ayas et al. 2010; MEB-TTKB 2013). In fact, the worldwide primary curricula (Trends in International Mathematics and Science Study—TIMSS 2015) refer to physical and chemical changes even if there is no mention about the PNM. The English science curriculum includes 'States of Matter' in year four and 'Properties and Changes of Materials' in year five. The Israel Science and Technology curriculum at the primary level includes Matter and Energy, for example, topics such as properties and uses, and physical changes. Fourth-grade science students across Canada develop knowledge and skills in units on Matter and Energy–properties of matter; physical changes; and energy transformation. Eighth-grade science students study three units on Matter and Energy–properties of materials; mass, volume and temperature; and physical/chemical change. Primary students' understanding of the PNM is a global thrust. Thus, the priority of the current study is to enhance primary PSTs'cognitive structures of the PNM, using a unit on physical and chemical changes that offer multiple representations. Primary school students do not need to understand the PNM, though that is not to say that their teachers should not have a sense of it. There is a need to appreciate its fundamentals of particle theory because the upper primary curricula in some countries include it. For example, the USA curriculum discusses the PNM regarding the visible and the invisible (National Research Council 2013). For quality learning to occur, primary teachers need a PNM background to assist in developing students' ideas. The previous assertion lies in the question: How do teachers use the knowledge of the PNM and support student learning across the primary years so that they move towards developing a complete understanding?

The study at hand is similar to the case study of Derman and Eilks (2016), which identified 157, 11th-grade students' cognitive structures based on the topic of 'Dissolution' via a Word

Association Test (WAT) analysis. These authors utilized a non-experimental descriptive design and a response frequency mapping method to identify the students' cognitive structures. Overall, Derman and Eilks' study revealed a very diverse picture of students' cognitive structures, including many poorly developed concepts. Furthermore, the study showed that students' cognitive structures on the topic of 'Dissolution' are static, non-interactive, and limited regarding the external connectedness. It seemed to Derman and Eilks that the students did not meaningfully integrate any potential foreknowledge (i.e., the particulate nature of matter) that underpins solution chemistry.

Although we use Derman and Eilks' (2016) response frequency mapping method with minor revisions to create a cognitive map, the present study has a different design, domain, study participants, and the context. The current study aimed to assure a further insight into the effect of multiple representations on the Primary PSTs' cognitive structure of physical and chemical changes using the elaborate version of the WAT to develop a qualitative map. The probing methods have a practical value because science education teachers and researchers will be able to use with the PSTs. Going through this experience will enable the PSTs to use the assessment tools in the primary classroom. Thus, the study aimed to ask the following questions:

1. What is primary PSTs' level of understanding of the particulate nature of matter?
2. How does the use of multiple representations in general chemistry laboratory teaching effect primary PSTs' cognitive structures of the physical and chemical changes in both low and high understanding level groups of particulate nature of matter?

Answering these questions is expected to improve the PSTs' PNM knowledge and cognitive structure of physical and chemical changes. In turn, the PSTs will be able to teach their students science with more in-depth understanding.

Conceptual Frameworks

Constructivist Theory of Learning and the Cognitive Structures

Constructivist learning theory espouses that the construction of knowledge depends on the interaction between the learner's mental processes and the environment (NRC 2000). This experiential connection develops conceptual structures that represent networks of concepts in long-term memory of an individual (Shavelson 1974). Piaget (1978) and Vygotsky (1978) in their theories of learning, emphasize that pre-existing knowledge be fundamental to the process of knowing for cognitive development and conceptual change. The assumption is that learners' prior knowledge influences how they organize and interpret or make sense of the incoming information from their environment. According to the National Research Council (2000), the learner's development of science concepts involves the construction of organized knowledge structure and the development of abilities and strategies for understanding, reasoning, reflecting, remembering, and solving problems. In other words, the science of learning advocates that construction of new knowledge and understandings rests on what learners already know and believe, epistemology, and ability levels (Tyson et al. 1997). Because prior knowledge affects learning, Ausubel (1968) admonishes that meaningful learning involves eliciting learners' prior knowledge and teaching them accordingly.

A Constructivist View of Learning Advocates an Alternative Teaching Approach

A constructivist view of learning calls for educators to understand what cognitive structures are and how they function, as well as use the principles to explore and assess learners' cognitive structures. Educational studies continue to use different techniques such as word association testing (Derman and Eilks 2016; Nakipoğlu 2008), concept mappings (Edmondson 2000; Kilic 2003), and individual interviews (e.g., Ebenezer and Fraser 2001; Harrison and Treagust 1996). After eliciting the cognitive structures, teachers help learners to make sense of the new information. In this perspective of teaching, teachers respect and value learners' prior knowledge of natural phenomena and integrate them into curriculum frameworks and meaningful lesson activities to help students clarify, elaborate, or reject their theories and models through various tests (Ebenezer et al. 2010). Metaphorically speaking, just like early scientists went through conceptual changes, the learners move through their developing, developed, and matured ideas over time (Thagard 1992 as cited in Ebenezer et al. 2010).

In the interest of the study at hand, we focused on chemistry education studies that have successfully explored and developed students' conceptions of solubility through conceptual change inquiry (Ebenezer and Gaskell 1995). If we do not explore and expose learners' ideas and subject to public scrutiny and appraisal from the nature of science perspective (Ebenezer et al. 2010; McComas 2000; NRC 2007), the teachers will go through the motion of covering the standards, rather than uncovering them (NRC 2007, 2013). Any wonder (Abd-El-Khalick and Lederman 2000; Lederman and Abd-El-Khalick 1998; Lederman et al. 1998), international studies on the students understanding of the nature of science and how they approach learning based on their existing ideas or cognitive structures convey discouraging results.

Striving to dispel students' prior knowledge that we interpret them as misconceptions and tenacious (Duit and Treagust 2003) is fruitless. Instead, students should be taught to distinguish between contexts of learning so that their conceptions of physical and life phenomena fit their everyday experiences and language as well as the scientific context and culture (Ebenezer and Erickson 1996; Linder and Erickson 1989). The teachers should not wait for students to construct theoretical ideas that took even the early scientists more than a thousand year. Rather they should listen to students' interpretations and forge the link between the experiential and the theoretical knowledge. The next step in this process helps the learners to translate their understandings to shape socio-scientific inquiry such as dissolved salts in water (Ebenezer and Haggerty 1999). However, the teachers should cherish the romantic period of students exploring their ideas and follow through with teaching them scientific precisions and generalizations (Whitehead 1929; Ebenezer et al. 2010). Students' conception and conceptual change science education literature reveal ample evidence that teachers taking the time to explore students' conceptions and using these as starting points for construction and negotiation of explanatory models, and monitoring students' conceptual development and change as teaching improves learning (Ebenezer et al. 2010; Ayas et al. 2010). Teaching through lectures without students becoming aware of the ideas and explicitly and consciously incorporating their prior knowledge into curriculum frameworks and inquiry is not a constructivist view of learning.

Multiple Representations in Chemistry Education

In the last four decades, chemistry educational studies have facilitated the student generation and validation of knowledge on the relationship between the three different levels:

macroscopic, sub-microscopic, and symbolic (Eilks 2013; Talanquer 2011). Johnstone (1982) first validated the triadic relationship, and since then many researchers, curriculum developers, and textbook writers have used it as a framework (Gilbert and Treagust 2009).

While expert chemists view the study of chemistry as a combination of macroscopic, sub-microscopic, and symbolic, novice learners seem to remain at the sensual level because they are unable to associate with the other levels that require explanatory models (Talanquer 2011). A goal of chemistry education is to support students in developing an understanding of the concepts related to the particulate nature of matter so that they appropriately translate what they learn to novel situations. However, students frequently have difficulties solving socio-chemistry problems because of the lack of a thorough conceptual understanding (e.g., Nakhleh 1992; Taber 2001) of the macroscopic, sub-microscopic, and symbolic relationship (Johnstone 1991, 2000). The educational research has shown that students must learn to transition from one representation to another (Adadan 2014a; Chittleborough and Treagust 2008; Talanquer 2011).

The secondary chemistry teachers often move from the symbolic to submicroscopic. Instead, chemistry teaching should first establish the relationship between a chemical phenomenon and sub-microscopic entities such as molecules, atoms, and electrons (Adadan 2014a; Chittleborough and Treagust 2008; Cook et al. 2008; Talanquer 2011). In the words of Ngai et al. (2014): *Meaningful learning about chemical identity and related core chemistry concepts might be better facilitated by fostering sophisticated reasoning at the macroscopic and submicroscopic levels in a parallel and coordinated manner* (p. 2456).

The most sophisticated representation of knowledge is symbolic, the basis for the phenomenology of science. While developing the sophistication of the symbolic chemical representations is essential, school science beginning a unit of study with the symbolic knowledge is counterproductive. Thus, Ngai et al. (2014) reasoned the importance of promoting the higher level of reasoning at the macroscopic and submicroscopic levels concurrently in the first place.

Method

Design

The current study uses pre-experimental one group pretest-posttest design (Campbell and Stanley 1971) supported by qualitative data and content analysis procedures (Berg and Lune 2015). This configuration facilitates the comparison of primary PSTs' cognitive structures of chemical and physical change, who had low or high-level understanding of the particulate nature of matter, before and after multiple representations in the introductory general chemistry laboratory teaching course.

Educational Context

The Primary Teacher Education Department is an arm of the Turkish higher education. The duration of the primary teacher, non-major science program, is four years, which consists of eight semesters. Science laboratory learning is part of primary teacher education, which stresses the importance of learning the three knowledge-types (macroscopic, submicroscopic, and symbolic). This emphasis is because an examination of elementary science Turkish textbooks shows the depictions of entities such as molecules and atoms even in the primary grades, although the age level at which students are learning the particulate nature of matter varies. While the fourth and fifth-grade Turkish science textbooks refer to the particulate nature of matter implicitly, sixth to eighth grades resources mention explicitly. The knowledge-types are integral to learning secondary science.

Multiple Representations in Laboratory Teaching Context

Following Talanquer (2011), the study at hand integrated the conceptual and contextual approaches in the 'Science Laboratory Practices I' course for the PSTs. The content of this course was the Multiple Representations in Laboratory Teaching (MRsLT). The goal of the course was to enable the primary PSTs to relate and translate experiences, models, and visualizations as they made sense of the of the composition/structure of substances and processes physical and chemical changes over time at the macroscopic, sub-microscopic and symbolic levels. The primary PSTs answered the Particulate Nature of Matter Diagnosis Questions and The Word Association Test (WAT) to elicit their preexisting knowledge. These tests were administered based on two assumptions: (1) Learners' existing ideas have consequences for the learning of science; and (2) teaching science is more effective when we explore the learner's existing ideas and integrate them into the curriculum (Ebenezer et al. 2010; Taber 2008). To elicit their preexisting ideas of physical change and chemical change, the primary PSTs' conducted the tasks represented in Table 1.

There were eight groups in the class. Each group comprised of five primary PSTs. 'Science Laboratory Practices I' course consisted of eight different experiments. Each group conducted a different experiment each week throughout the semester. Thus, the experimental task represented in Table 1 was carried out each week by one group throughout the semester. By the end of the semester, all groups completed the experiment.

As a group, the PSTs predicted whether or not the given task is a chemical or physical change. An example of physical change is leaving ice cubes in a beaker at room temperature. The PSTs observed the ice cubes at room temperature based on criteria such as change of state, color change, odor, and gas release. Then, each small group compared its records and discussed the results with the class. The primary PSTs viewed the online simulation of the state of matter (https://phet.colorado.edu/en/simulation/states-of-matter), which explained the macroscopically observed phenomenon of melting ice sub-microscopically. Then the instructor drew attention to the symbolic representation as shown: $H_2O_{(s)} \rightarrow H_2O_{(l)} \rightarrow H_2O_{(g)}$, and emphasized the changes concerning the distance and the movements of the particles. The primary PSTs were required to make the strongest and the weakest arguments within and between groups. They compared their new and prior knowledge in writing. Thus, through a process of metacognitive awareness, they were asked to rearrange and reconstruct their cognitive structure.

The instructor adopted a mentor role with the primary PSTs through the knowledge construction period. For each task, she incorporated the preexisting knowledge into a conceptual statement, asked formative questions, pointed out the observational criteria, showed simulations, evaluated journal writings, gave them feedback, and answered questions.

Participants

The 40 undergraduate primary PSTs (28 = 70% female and 12 = 30% male; age range 20–21) enrolled in the third semester of the primary teacher education program participated in the

Table 1 The context of the multiple representations in laboratory teaching- MRsLT

Targeted concept	Nature of activities	Learning tasks
The nature of physical property /change	a. Observing tearing paper into small pieces and burning them b. Observing the candle while melting c. Observing the behavior of ice cubes in a glass beaker at room temperature d. Observing the sublimation of naphthalene	a. Discussing conceptually with the group about the phenomena to be observed before the activities. Estimating for physical-chemical change. b. As observing the chemical and physical changes using criteria such as form change, color change, odor, gas release, and change of state. Determining the chemical-physical change in observed activities. Keeping observation report. c. Viewing online simulation of state of matter, dissolving of sugar, melting of a solid (https://phet.colorado.edu/en/simulations/category/chemistry). d. Explaining the macroscopically observed phenomena, sub-microscopically (at the particle level) and symbolically: ($H_2O(s)$ $H_2O(l) \rightarrow H_2O(g)$). Determining the strongest and the weakest arguments in groups and between groups. e. Comparing the estimations and observations. Sharing and discussing ideas in small groups. f. Comparing observation reports between groups; and, if possible, graphically representing data; Journal writing.
The nature of physical property/change The nature of chemical property/change	a. Adding an amount of pure water into different solids (sugar, starch, a piece of zinc, Na_2CO_3, $CuSO_4$, $CaCl_2$, $Ba(NO_3)_2$ and observing the dissolution behavior of these solids at room temperature b. Adding HCl, H_2SO_4 and HNO_3 separately into sugar, starch, a piece of zinc, Na_2CO_3, $CuSO_4$, $CaCl_2$, $Ba(NO_3)_2$ and observing the interactions between them	a. Discussing conceptually with the group about the phenomena to be observed before the activities. Estimating for physical-chemical change. b. While observing the phenomena, taking into consideration criteria such as form and color change, gas and odor release, temperature change, dissolution, precipitation. Determining the chemical-physical change in observed activities. Keeping observation report. c. Viewing the video of reaction of sodium in water (https://www.youtube.com/watch?v=B3422Zk5tj4). d. Explaining the macroscopically observed phenomenon at the sub-microscopic and symbolic ($Zn(s) + HCl(l) \rightarrow ZnCl_2(s) + H_2(g)$) levels. Determining the strongest and the weakest arguments in groups and between groups. e. Comparing the estimations and observations. Sharing and discussing ideas in small groups. f. Comparing observation reports between groups; and, if possible, graphically representing data; Journal writing.

present study. At the time of the study, the primary PSTs were pursuing the “Science Laboratory Practices I” course and had already completed the Introductory General Chemistry course with five credit in European Credit Transfer System in the second semester.

Data Collection

All participants were informed about the nature and methods of the study. All 40 primary PSTs voluntarily agreed to participate in the study. The pre-tests consisted of Particulate Nature of Matter Diagnosis Questions (PNM-DQ) scale and The Word Association Test (WAT) that included two stimulus words "physical change" and "chemical change." These pre-tests were administered two weeks before the commencement of the 'Science Laboratory Practices I' course. After all the PSTs in the class completed the physical and chemical change learning tasks by the end of the semester, they took only the same WAT as post-test.

PNM-DQ Scale

The PNM-DQ scale comprises of open-ended questions that provide information with better insight than multiple choice questions. For determining learners' conceptions, researchers use scales like the PNM-DQ (Abraham et al. 1994; Coştu 2008; Özmen 2011; Özmen et al. 2002).

Students are familiar with the phenomena represented in the PNM-DQ. Thus, this scale was used to identify participants' conceptual understanding of the PNM of physical and chemical changes. The PNM-DQ (see Table 2) depicted the effect of heat on the gas particles; and the concepts of condensation, evaporation, and dispersion of liquids. The PNM-DQ were adapted from the pioneer studies (e.g., Ayas et al. 2010; Coştu 2008; Özmen 2011; Özmen et al. 2002) with minor revisions such as changing the sentence structure or rewording. Three experts, who

Table 2 The questions and the context of the questions in the PNM-DQ Scale

Questions	The context of the questions
Q1. A glass filled with water was left in front of the window. A few days later it was observed that there was no water left in the glass. How do you explain this change using your knowledge of matter?	This question is related to the concept of "vaporization". Primary PSTs are expected to name the concept and explain it in terms of "particulate nature of matter" and "temperature".
Q2.On a hot day, a soccer ball was completely filled with air until hard. The same ball left in the balcony at night was observed to be softer in the early hours of the day when it was cooler. Assuming that the ball had no air leak, how do you explain this change occured between day and night using the idea that matter is composed of particles?	This question determines the primary PSTs' level of explanation in terms of the "particulate nature of matter" to account for the change in pressure with temperature change in a closed system.
Q3. A drop of colored liquid (e.g., ink) in a glass of distilled water was observed. The color spread all over the water. How do you explain this phenomenon?	This question is related to the chemical concept of "diffusion" or "permeation". Primary PSTs are expected to explain this phenomenon using the "particulate nature of matter" and "distance between particles."
Q4. A tightly closed glass jar containing ice was dried and left on a table. After a while it was observed that the surface of the jar had moisture. Where did this water on the glass surface come from? How do you explain this situation?	This question aims to assess whether or not primary PSTs apply the concept of "condensation" or "phase transition" using the "particulate nature of matter"
Q5. Illustrate the particulate nature of the three states of matter (solid, liquid and gas).	This question aims to determine whether or not primary PSTs conceptualize how the particulate nature of matter is represented by the three states of matter.

previously taught General Chemistry and Science Laboratory Practices I and II in the primary education department, evaluated the appropriateness of the scale for the study at hand, and accordingly, the PNM instrument changed.

Word Association Test

Johnson (1967, 1969 as cited in Gunstone 1980) suggested the Word Association Tests (WATs) for exploring students' ideas. In recent years, the WATs has become common in science education research to identify and map student understanding of science concepts, and the relationship between cognitive structures and disciplinary content knowledge (Nakipoğlu 2008; Schizas et al. 2013). Word associations also allow insights into the structure and work of the human memory (Petrey 1977; Thomson and Tulving 1970). Many related studies have also shown that using WAT is a robust method since it reveals the types and numbers of concepts in the learners' developmental cognitive structures (Bahar and Hansell 2000; Nakipoğlu 2008). Most recent examples of chemistry education are the atomic structure (Nakipoğlu 2008), decomposition (Schizas et al. 2013), and dissolution (Derman and Eilks 2016).

Physical and Chemical Change WAT Activity

The current study included two field expert-approved stimulus words from a unit on Matter, namely, physical and chemical change. On each side of the A4 paper, a stimulus word appeared ten times with sufficient space for students to write their thoughts. This format was to prevent a chain-reaction effect in case the superfluous information distracts someone. The participants took the WAT test with the time limit of one minute. The pre-test WAT was applied before MRsLT learning task by the researcher. Data analysis was carried out after all data collection to prevent any possible influence of the researcher-instructor role since the first researcher of the present study was the instructor/teacher of the "Science Laboratory Practices I" course.

Data Analysis

Analysis of the PNM-DQ Data

The primary PSTs' written answers to the PNM-DQ were carefully read and subjected to content analysis to construct the categories (Berg and Lune 2015). The primary PSTs' written answers to each of the first four questions in the PNM-DQ scale were evaluated by the following categories based on the related studies. For determining learners' comprehension/understanding levels in detail with a qualitative perspective, researchers (e.g., Adbo and Taber 2009; Ayas et al. 2010; Coştu 2008; Özmen 2011) use such categories: understanding, misunderstanding, not understanding, and no-response. The responses to the fifth question were evaluated by the following categories: particulate, continuous, particulate but false, no response. The answers in the "understanding and particulate" category, considered scientific, were coded "1″, and the responses in the category of "misunderstanding, not understanding, continuous, particulate but false, no response" were coded "0″. Each response of a student was entered as 0 or 1 into the data table. Each question in the PNM-DQ scale consists of only one essential item, and the loading value for each question is 1. Therefore, the minimum score that the primary PSTs could get from the PNM-DQ scale is 0, and the maximum score is 5. Table 3 presents the findings obtained from the descriptive statistics (Table 4).

Table 3 PNM-DQ descriptive results

N	40
Mean	2.5000
Std. Deviation	1.13228
Minimum	.00
Maximum	5.00

The "Low-Level Understanding" group composed of PSTs that obtained a score of 2.5 and below. The "High-Level Understanding" group consisted of those who scored more than the specified mean value. The results indicate excerpts from primary PSTs. Their expressions are in quotes and abbreviations are used as follows: (H, primary PST14), (High Level; primary pre-service teacher 14); (L, primary PST35), (Low Level; primary pre-service teacher 35). To establish the inter-rater reliability, a science education expert and the first author independently analyzed the PNM-DQ data. In the decoding of the preceding categories, the consensus between the expert and the first author was above 90% according to Miles and Huberman's (1994) reliability formula, namely: (Number of agreements/Number of agreements + disagreements) × 100.

Analysis of the WAT Data

Counting different responses for each stimulus word is a method, which can be used to summarize the data gathered through WAT (Bahar et al. 1999; Shavelson 1974). The data were also analyzed independently by a second science education expert to provide the inter-judgmental reliability. The criterion of counting the total number of different response words was employed to compare the analyses. For example, in pre-test WAT for LPNMU, the primary PSTs responded to the "Physical Change" stimulus word. We compared the total number of different response words defined by the first author of the current study and a second expert. The inter-judgmental reliability of the consensus and consistency estimates the raters achieved reflect the agreement range as Miles and Huberman suggest (1994). Based on this, we used Excel to evaluate the whole data. Table 5 represents the agreement of the total number of different response words.

We classified the pre-post-test WATs for each primary PST as "Low Level" and "High Level" by analyzing the PNM-DQ data. For the data analysis of the WATs, the study adopted the Nakipoğlu's (2008) response frequencies' map method, which is an integration of relatedness coefficient method (Gussarsky and Gorodetsky 1988) and the response frequencies' map method (Bahar et al. 1999). According to Nakipoğlu (2008), this method is useful for displaying the power of students' knowledge structure and the direction of the associations between concepts in a specific domain. In this case, we constructed a frequency table including stimulus and response words and the corresponding cognitive map according to the frequency values. Frequency tables determine the direction and strength of the associations shown on the cognitive maps. In the current study, we conducted content analysis to identify the sort of the concepts (number of different response words that associated with stimulus words), the direction of the concepts (from stimulus words to the response words), and also the strength of the concepts (how many times a stimulus word associated with a response word for example how many times the "physical change" stimulus word associated with "freezing" response word) before the construction of the cognitive map. We transferred students' response words, which were meaningful and valid (e.g., freezing, melting, breaking, tearing, electrolysis, oxidation) in the context of physical and chemical changes topics to an Excel sheet for the

Table 4 The frequency and percentage scores of the primary pre-service teachers' responses to the PNM-DQ

Questions	Code1 (*f*-%)			Code 0 (f-%)	
	Excerpt examples			Excerpt examples	
		MU	SU		FU
Q1. A glass filled with water was left in front of the window. A few days later it was observed that there was no water left in the glass. How do you explain this change using your knowledge of matter?	37–92.5	"The water in the glass turned from liquid into vapor. We call this phenomenon vaporization..." (H, primary PST14).		3–7.5	
Q2.On a hot day, a soccer ball was completely filled with air until hard. The same ball left in the balcony at night was observed to be softer in the early hours of the day when it was cooler. Assuming that the ball had no air leak, how do you explain this change occured between day and night using the idea that matter is composed of particles?	9–22.5		"The speed and the kinetic energy of the gas particles inside the ball increased because of hot weather. This energy was more concentrated on the surface of the ball. However, the speed of gas particles decreased during the night due to cold weather. These particles came closer, putting less force on the surface of the ball. This resulted in the ball becoming softer during the cold weather..... (H, primary PST9).	31–77.5	"The ball expands and becomes softer because the weather gets cold during the night … (L, primary PST38)"
Q3. A drop of colored liquid (e.g., ink) in a glass of distilled water was observed. The color spread all over the water. How do you explain this phenomenon?	15–37.5		"This situation is related with the vacuolar structure of liquid. There are spaces between water molecules. When ink is dropped into water, it penetrates into thesespaces. Therefore, the ink diffuses.... (H, primary PST9)"	25–62.5	"When ink is mixed with water, it spreads homogeneously, because both substances are categorized as liquids and have the same density... (H, primary PST14)" "The chemical component of ink increases the kinetic energy of

Table 4 (continued)

Questions	Code1 (*f*-%)	Excerpt examples MU	Excerpt examples SU	Code 0 (f-%)	Excerpt examples FU
					ink molecules, when ink is added to water. This energy helps the ink to diffuse in water... (L, primary PST35)."
Q4. A tightly closed glass jar containing ice was dried and left on a table in the laboratory. After a while it was observed the surface of the jar hadmoisture. Where did this water on the glass surface come from? How do you explain this situation?	5–12.5		"When water vapor, present outside the jar, comes in contact with a cold surface during hot weather, the surface of the jar gets humid. This humidity symbolizes condensation and the changing state of water, which occurs due to the presence of vapor in the air.... (H, primary PST14)"	35–87.5	"When the glass jar that contains ice is set aside for a while, the ice inside the jar melts and the water evaporates. The particles in the ice are congested and intertwined. The particles break apart and turn into water, thereby causing evaporation ... (L, primary PST12)"
Q5. Illustrate the particulate nature of the three states of matter (solid, liquid and gas).	34–85			6–15	

*MU*Macroskopic Understanding, *SU* Sound Understanding, *FU* Faulty Understanding

Table 5 The percentages of interjudge reliability for pre and post test WAT

Stimulus word	LPNMU (%)		HPNMU (%)	
	Pre-test	Post-test	Pre-test	Post-test
Physical change	95	96	96	97
Chemical change	94	95	95	97

LPNMU low-level particulate nature of matter understanding, *HPNMU* high-level particulate nature of matter understanding

evaluation of data (e.g., to determine the frequency value of the response words). After selecting and screening the data, we developed a frequency table by counting the response words for physical change and chemical change stimulus words.

Table 6 provides only a partial list of response words that helps to understand how we developed Figs. 4 and 5 to represent the frequency or cognitive maps. Table 6 lists the stimulus words in the third row. The first column contains the response words obtained from the pre-post-test WAT. We then constructed a frequency map to represent the data in Figs. 4 and 5. We determined the frequency ranges and vertical directions for weak or strong correlations in the map according to the association frequency scores, between stimulus and response words. A frame encloses the stimulus word in each frequency range. The tip of the arrow that outstretches from the frame contains the response word. The frequency score of an association between a stimulus word and its response words regulates the lengths and thickness of the arrows. The length and thickness

Table 6 A sample frequency table from the pre-test and post-test WAT

Response words	Pre-test WAT				Post- test WAT			
	LPNMU		HPNMU		LPNMU		HPNMU	
	Physical change	Chemical change	Physical change	Chemical change	Physical change	Chemical change	Physical change	Chemical change
External structure	23	–	–	–	8	–	6	–
Freezing	11	3	6	–	15	–	9	–
Melting	15	–	11	–	18	–	18	–
Change of state	7	4	7	5	9	–	8	–
Breaking	18	–	12	–	19	–	17	–
Tearing	15	–	13	–	16	–	16	–
Acidity	–	14	–	6	–	15	–	–
Electrolyse	–	5	–	–	–	7	–	–
Change in internal structure	–	15	–	15	–	19	–	21
Become moldy	5	11	2	6	1	8	–	5
Oxidation	3	15	–	9	–	17	–	9
Burning	3	15	2	19	–	19	–	23
Matter	6	–	6	–	–	–		–
Decomposition	–	7	–	8	–	–	–	–
Fermentation	3	9	–	7	–	4	–	4
Change in external structure	–	–	18	–	–	–	19	–

LPNMU low-level particulate nature of matter understanding, *HPNMU* high-level particulate nature of matter understanding of the arrows also show the power of associations. The arrows, which have the same length and thickness represent the same frequency value. The longest and widest arrows show the highest frequency scores, and they are put in the first cell. The direction of the arrows is in parallel with the direction of the relationships in Figs. 4 and 5. Bidirectional arrows labeled "strong" to "weak" are also used to represent the variation of the power of associations through the frequency ranges regarding cognitive organization in Figs. 4 and 5.

The earlier case study (Derman and Eilks 2016) also constructed a cognitive map based on the Nakipoğlu's (2008) response frequencies' map method that provides a comprehensive record of high school students' cognitive structure of the chemical concept of "dissolution." To describe the students' cognitive structure in detail and more comprehensively, several sorts of arrows were used (e.g., a dotted bi-directional arrow represents a reverse relation between concepts; square dotted arrow to show a concept that can be interpreted as misconception). The arrows in the cognitive maps of the earlier study are different from the current study. The present study uses vertical arrows to represent any relationship in the cognitive maps (see Figs. 4 and 5). These cognitive maps provide us a deeper view into the effect of multiple representations on the primary PSTs' cognitive structures of physical and chemical changes regarding the sorts of associations, the direction of relationships, and the strength of the associations.

Results

Results for the PNM-DQ

The primary PSTs' responses to the first question have a percentage of 92 at code 1 with mostly macroscopic knowledge. Table 4 presents an excerpt that supports the results.

The primary PSTs' responses to the second question scored 77.5% at code 0. The primary PSTs were unable to explain the change in pressure with temperature using the particulate nature of matter. Furthermore, they incorrectly applied the principle of thermal expansion to the relationship between pressure and temperature. Table 4 represents an excerpt that supports the preceding claim. Table 4 also indicates the student's response that reflects the best understanding of the phenomena asked in the second question. The responses of the primary PSTs to the third question carries a score of 37.5% at code 1 and 62.5% at code 0. Table 4 presents two responses at code 0 and code 1. Franco and Taber (2009) consider the latter as a well-developed particle model. The responses of primary PSTs to the fourth question scored 87.5% at code 0. Table 4 shows excerpts that reflect meaningful conceptualization of the phenomenon of condensation and a very sound understanding of the subject matter. The response of primary PSTs to the fifth question scored 85% at code 1 (particulate representation) and 15% at 0 code (continuous representation). Figure 1 represents examples of responses given at code 1 (H, primary PST19; H, primary PST9). Figure 1 shows the primary PSTs' visualization of the states of matter.

Primary PSTs' representations show their understandings of the particulate nature of matter. However, the conceptual understanding of the primary PSTs on the distance between solid, liquid and gas particles contradict the scientifically accepted 1:1:10 distance ratio (Adadan 2014b). The representations of primary PSTs' understanding of PNM that depict "continuous" rates code 0. As observed in Fig. 2, there is no representation of particle model for the states of matter. Figure 2 provides examples (L, primary PST28; L, primary PST30), which is not

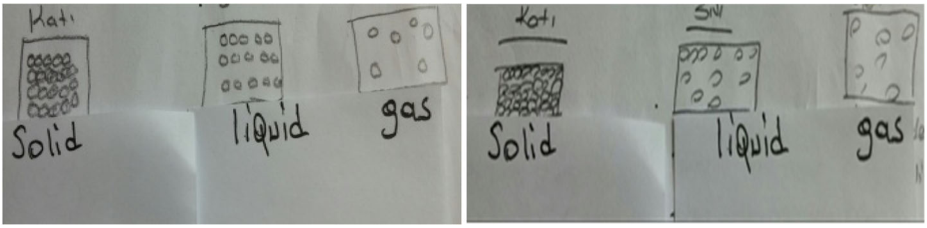

Fig. 1 Two examples of primary PSTs' particulate representations

surprisingly much different (Adbo and Taber 2009; Coştu 2008; Franco and Taber 2009; Harrison and Treagust 2002; Özmen 2011; Özmen et al. 2002).

The hybrid mental models consisting of both particulate and continuous representations rate at code 0. As seen in Fig. 3, there is a particulate depiction for solid and gas states of matter, and also a continuous representation for solid state. We might interpret these depictions as a hybrid mental model. Figure 3 shows an illustrative example (L, primary PST39). Previous research studies support the preceding hybrid mental models (Adbo and Taber 2009; Johnson 1998; Özmen 2011; Talanquer 2009).

Results for the WAT

As represented in Fig. 4, the frequency score of associations between the stimulus words and response words correspond to the two frequency range ($21 \leq f \leq 30$ and $11 \leq f \leq 20$). We did not take into consideration any frequency score of association for ten and above 30. We excluded the frequency score of associations below ten from the cognitive maps in Figs. 4 and 5.

In addition to the graphical representations shown above, we garnered some qualitative results. The findings support the assumption that learners construct meaning through their already held concepts while acquiring new knowledge. The WAT suggests that each response word relates to any stimulus word representing such a concept (Bahar et al. 1999; Nakipoğlu 2008). For example, in pre-test WAT, the LPNMU and the HPNMU primary PSTs used 20 and 26 response words, respectively to construct the meaning of "Physical Change. Table 7 presents the number of different response words for each stimulus word.

As represented in Table 7, the LPNMU primary PSTs associated the "Physical Change" stimulus word with 20 response words in the pre-test and 29 response words in the post-test. On the other hand, the same primary PSTs associated the "Chemical Change" stimulus word with 22 response words in the pre-test and 30 response words in the post-test. The HPNMU primary PSTs associated the "Physical Change" stimulus word with 26 response words in the pre-test and 35 response words in the post-test. Furthermore, these primary PSTs associated the "Chemical Change" stimulus word with 28 response words in the pre-test, and 33 response words in the post-test. According to Schaefer (1979 as cited in Bahar et al. 1999), a word

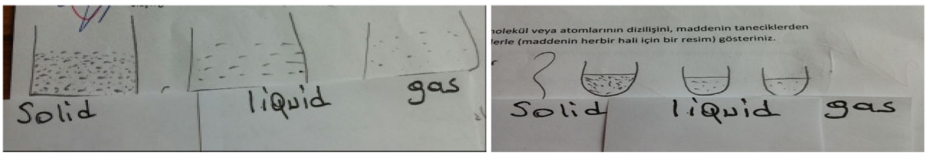

Fig. 2 Two examples of primary PSTs' continuous representations

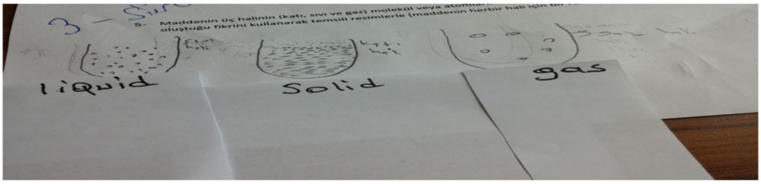

Fig. 3 An example of primary PSTs' hybrid mental model

without any associations in a cognitive structure does not have a meaning, and the meaning of that word is extended when more associations are formed. The more association a stimulus has, richer the meaning.

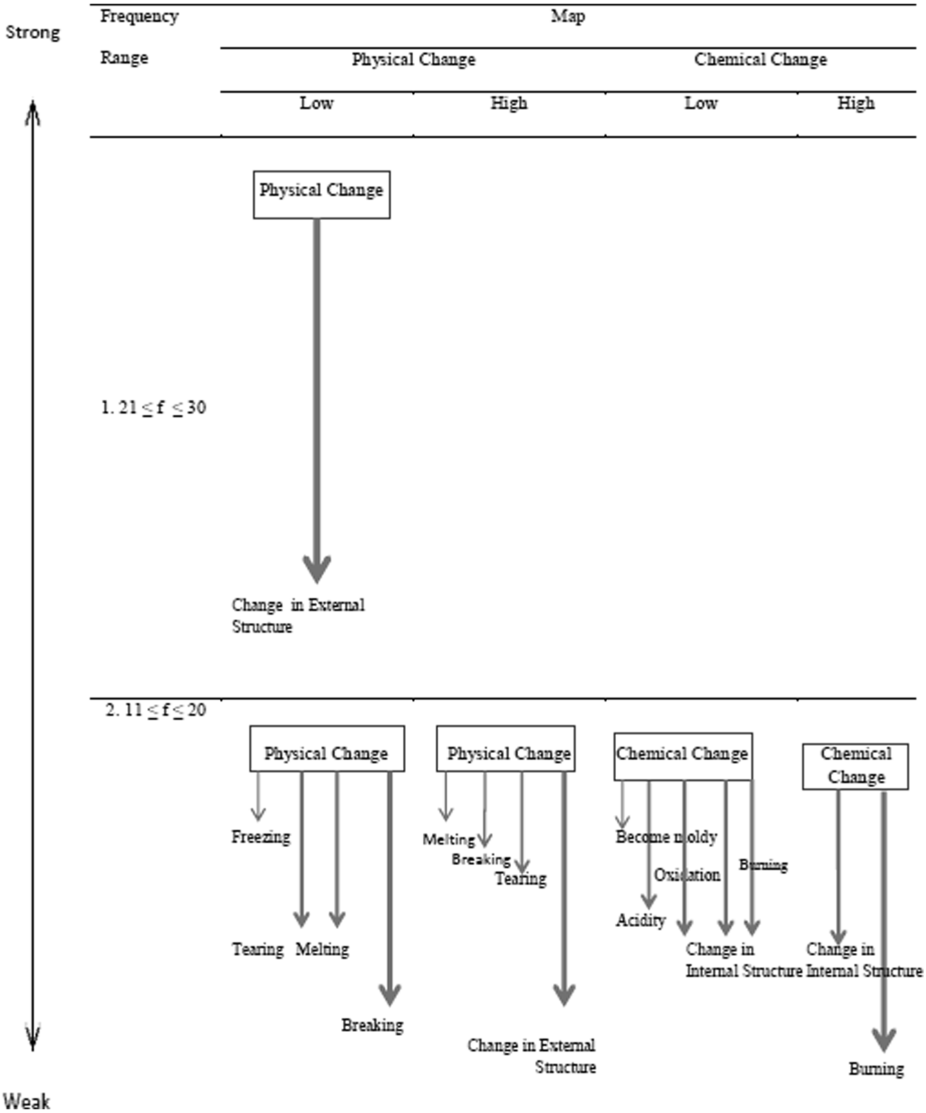

Fig. 4 Primary PSTs' cognitive structures related to chemical change and physical change before MRsLT

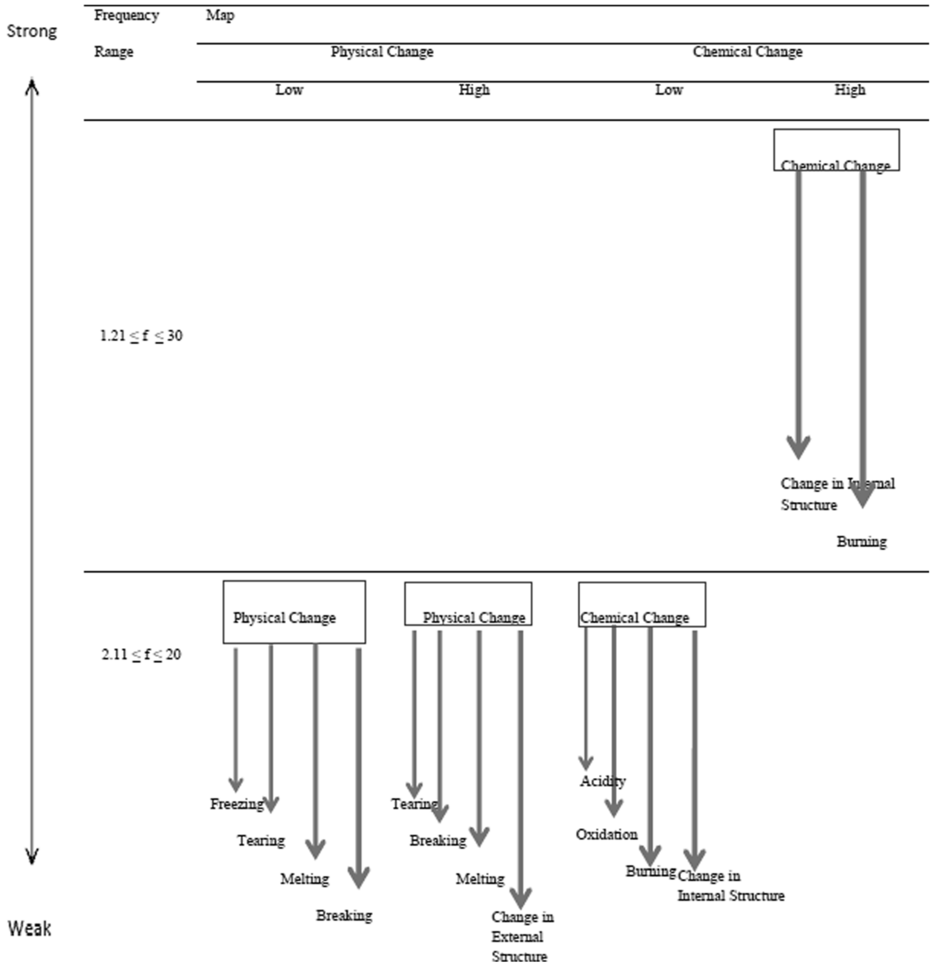

Fig. 5 Primary PSTs'cognitive structures related to chemical change and physical change after MRsLT

Discussion

The first research question focused on examining the primary PSTs' comprehension of the PNM. The study showed that primary PSTs had difficulty in connecting the "temperature-pressure" relationship in a closed system, and explaining phenomena of "diffusion, dispersion, and condensation in the context of the PNM (see Table 4). The findings of this study are

Table 7 Total number of different response words in pre-test and post-test WAT

Stimulus word	Pre-test WAT		Post-test WAT	
	LPNMU	HPNMU	LPNMU	HPNMU
Physical change	20	26	29	35
Chemical change	22	28	30	33

consistent with previous studies on school students' understanding of the PNM (Ayas and Özmen 2002; Franco and Taber 2009; Liu and Lesniak 2005, 2006).

Figure 1 reveals that primary PSTs represent the solid particles in contact with each other, the liquid particles to be one or two particles apart, and the gas particles three to four particles apart. However, the emptiness between solid, liquid and gas particles depicted in these representations is inconsistent with the scientific 1:1:10 distance ratio as Adadan (2014b), Adbo and Taber (2009), and Harrison and Treagust (2002) revealed in their studies with younger science students. Harrison and Treagust (2002) also argued that it is normal for younger students to have difficulty in establishing the reality of emptiness between particles. Students commonly think that matter is continuous and attribute macroscopic properties to particles. Perhaps, the distorted illustrations in science/chemistry course books and teachers' use of book illustrations in their lessons iterate the emptiness between the particles (Adadan 2014a; Çökelez 2009).

The second research question aimed to determine the effect of multiple representations in general chemistry laboratory teaching on primary PSTs' cognitive structures of the physical and chemical changes in both low and high understanding level groups of particulate nature of matter. Although the post-test WAT results showed a few different concepts, they were mostly similar to the ones in the pre-test WAT and were found to be located in the cognitive structures of the LPNMU primary PSTs (see Figs. 4 and 5). However, it is evident that after the MRsLT, there was an increase in the frequency score of the concepts (response words) that were found to be similar to the cognitive structures of the LPNMU primary PSTs in the pre-test WAT (see Table 6).

Although the post-test WAT revealed a few different concepts, mostly were similar to the ones in the pre-test WAT, located in the cognitive structures of the HPNMU primary PSTs (Figs. 4 and 5). However, the post-test WAT indicated that there was a rise in the frequency score of the concepts (response words) that were found to be similar to the cognitive structures of the HPNMU primary PSTs in the pre-test WAT (see Table 6).

In the post-test WAT, the primary PSTs in both groups, LPNMU and HPNMU connected the different and an expansive list of response words in comparison to what they did in pre-test WAT (see Table 7). The above findings might be interpreted about the second research question as the concepts of physical change, and chemical change became stronger and more meaningful in the primary PSTs' cognitive structures. As Schaefer (1979) has argued, if learners do not make the connections in the cognitive structure, then words (concepts) do not have any meaning. An expansive list of response words makes the words more meaningful (Schaefer 1979 as cited in Bahar et al. 1999).

When we compared the two groups concerning the number of different response words, the primary PSTs in the HPNMU group generated more response words in the post-test than the primary PSTs in the LPNMU (For example the LPNMU group associated the "Physical Change" stimulus word with 29 response words; the HPNMU group associated the "Physical Change" stimulus word with 35 response words in the post-test WAT-See Table 7). Although the response words, "change in the internal structure and burning" were observed in the cognitive structures of primary PSTs in both groups after the MRsLT, the frequency scores of these words were higher in the HPNMU group (see Figs. 4 and 5).

As Ayas et al. (2010) note, the concepts of science are building blocks for further learning. It is likely that the comprehension of the PNM positively affected the cognitive development of the HPNMU primary PSTs and allowed them to develop a comprehensive cognitive structure throughout the MRsLT. In contrast, a lack of PNM comprehension might have impeded the LPNMU primary PSTs' cognitive structure development during the MRsLT. Adadan (2014a), Franco and Taber (2009), and Liu and Lesniak (2005) point out the difference between the conceptual development of the HPNMU and LPMNU groups. Perhaps, the LPNMU primary PSTs missed out on translating their understanding of the PNM to the physical and chemical change in the MRsLT process.

This empirical study on developing the primary PSTs' cognitive structures of physical and chemical changes by probing students' prior knowledge using a research-based assessment instrument and connecting it to chemists' explanatory or theoretical models through specially designed learning tasks reflect a constructivist teaching style. The undergraduate laboratory learning of physical and chemical change as portrayed in this article was effective in developing both groups' cognitive structures. We think that the learning opportunities provided by MRsLT learning environment (see Table 1-Learning Tasks; viewing online simulations, discussing in small-group and between groups, journal writing) enabled all the participants to develop a better cognitive structure of the concepts of physical and chemical changes.

Although there was an attempt to teach the primary PSTs from a constructivist view, some steps were missing in the instructional design. The laboratory course instructor/teacher had a practical understanding of how to probe the primary PSTs' cognitive structure of chemical phenomena through the application of WAT. However, she had only a theoretical knowledge of how to integrate conceptual and contextual approaches (Talanquer 2011) into the MRsLT. She aimed to assist the primary PSTs to relate and translate experiences, models, and visualizations at different knowledge levels (macroscopic, sub-microscopic and symbolic). She attempted to frame her laboratory course with two constructivist assumptions: Learners' existing ideas have consequences for the learning of science; and teaching science is more effective when a teacher explicitly integrates the learner's existing ideas into the curriculum (Taber 2008).

While the teacher of this laboratory course was able to probe into primary PSTs' cognitive structures using WAT, she was not well-versed in how to incorporate their ideas into her laboratory learning curriculum. Consider her teaching approach: (1) The primary PSTs read the teacher-scripted notes on the theoretical ideas of the laboratory learning tasks before taking the pre-test and conducting the tasks. (2) The course instructor gathered primary PSTs' existing ideas. For example, to reveal the primary PSTs' existing ideas about the behavior of ice cubes in a glass beaker at room temperature, they were asked to discuss the phenomenon in their group (See Table 1-Learning tasks). Then, the primary PSTs placed the ice cubes in a beaker and observed the macroscopic changes at room temperature. The primary PSTs determined whether or not the given phenomenon is chemical or physical change using the criteria, such as form change, color change, odor, gas release, and change of state. (3) Immediately after, the teacher had the primary PSTs view the online simulation of the state of matter to explain the macroscopically observed phenomenon. (4) Then she asked the primary PSTs to determine the strongest and the weakest arguments in groups and between groups. (5) Considering the phase change as represented by the H2O formula, the course instructor emphasized the changes in the distance and the movements of the particles and drew attention to the symbolic representation as shown below:

$$H_2O_{(s)} \rightarrow H_2O_{(1)} \rightarrow H_2O_{(g)}$$

Noting the teacher's willingness to take the steps to transform her laboratory teaching is worthwhile. The teacher did not analyze the primary PSTs preexisting cognitive structures (the pre-test WAT DATA) to understand them before teaching. The teacher introduced the theoretical ideas prematurely. The primary PSTs did not have an opportunity to represent their prior ideas at the submicroscopic level visually. The primary PSTs did not frame the arguments visually on paper in small groups using a research-based approach. The primary PSTs did not place their worksheets in their evidence portfolio for further study and reflection.

The following findings were instructive because it emphasizes the difficulty that primary PSTs have on the particulate and symbolic representations of physical and chemical changes. After the MRsLT, the majority of the HPNMU and LPNMU primary PSTs generated response words that coincided with the subatomic and molecular (or sub-microscopic) dimensions of chemistry knowledge. These response words were "atom, electron, bond structure," and had a frequency score range of 1–5. We did not present these response words in the sample frequency pattern in Table 6 because of their low-frequency value. None of the primary PSTs was able to represent matter symbolically based on their MRsLT experience (e.g., the formula of compounds or symbols of some elements and equations of chemical reactions). Also, before and after the MRsLT, the majority of the concepts that appeared in the primary PSTs' cognitive structures associated with physical change and chemical change reflected the macroscopic attributes such as the change in external structures, breaking, tearing, melting and burning. We can interpret these findings that the cognitive structure of the primary PSTs related to physical and chemical changes mainly constructed with macroscopic concepts. Although the macroscopic level is one of the building blocks in chemistry knowledge scale, proficient chemical thinking requires the submicroscopic and symbolic knowledge representations. Perhaps, these findings need to be connected with the missing steps of the instructional design so that both the low and the high-level groups could have achieved even more.

Implication

The probing and becoming aware of primary PSTs' prior knowledge in the context of a teacher education degree contributes to the preparation of primary PSTs in the chemical content and pedagogy, particularly making links between the macroscopic, submicroscopic, and symbolic. When the primary PSTs go through the constructivist learning process with laboratory tasks, they will acquire insights to practice the same in their classroom. Primary PSTs will be able to design activities that explore prior knowledge for the construction of desired knowledge. For this purpose, chemistry educators in a teacher education degree should use an assessment method such as WAT before a laboratory course or an instructional unit of study. This step will help identify pre-service teachers' pre-existing knowledge for the development of comprehensive cognitive structures. Chemistry educators should also use the WAT after classroom teaching to evaluate the quantity and quality of cognitive structures of pre-service teachers. This step will enable them to understand the knowledge taught, in inquiry, and problem-solving. WAT is a convenient assessment tool as it can be prepared and applied to numerous students in a short time as mentioned by Bahar et al. (1999) and Nakipoğlu (2008).

From all the outcomes discussed in the current study, chemistry educators in a teacher education degree program should teach the particulate nature of matter, physical change, and chemical change, as well as physical and chemical properties in a manner that would reach the different learners. To develop chemical knowledge, Talanquer (2011) suggests that chemistry teacher educators provide primary PSTs with effective teaching and learning models, materials, and resources. Examples are animations, simulations, visualizations; scales (subatomic, molecular, etc.); dimensions (composition, structure, energy, and time); and approaches (linguistics, mathematical, conceptual, contextual, and historical). These pedagogical elements are research-based (Eilks 2013) and are in line with NRC (2007) and (2013). However, the primary PSTs' teachers will make more meaning of these teaching and learning approaches when teacher educators use these in light of their prior knowledge. Furthermore, in science and technology teaching courses, primary PSTs should read research articles that report PNM learning difficulties. With such reading materials, it is possible to increase primary PSTs' awareness of the learning difficulties that students and they encounter. Substantial subject knowledge is also essential to enable pre-service teachers to develop useful pedagogical skills from a constructivist view.

Limitations

Considering a few methodological limitations is necessary to evaluate the results of the present study. We investigated the primary PSTs' cognitive structures in groups instead of observing individual cognitive structures before and after the MRsLT. The argument for using a group approach is to develop a model to elicit the primary PSTs' composite cognitive structures. The disadvantage is that the current study was not able to find each learner's cognitive structures. Although WAT tests lead studies to the limited modeling of each learner's cognitive structures, the design depicts commonalities in thoughts (Nakipoğlu 2008). The method used in this study is useful regarding the determination of the overall direction and strengths of the associations and presenting them on a map. However, some limitations like the associations presented in the maps in Figs. 4 and five also exist, and similar studies need to be supported or combined with other techniques such as concept mapping or free writing to eliminate this limitation.

Conclusion

As we pointed out in the Method section, word association allows insights into the structure and work of the human memory. Besides, it reveals the types and numbers of concepts and the relationships between them in the learners' cognitive structures in specific domains.

The findings of the current study indicate that the learning opportunities provided by MRsLT learning environment (for example, viewing online simulations, group and classroom discussions, report writing) enabled all the participants to develop a better cognitive structures of the concepts of physical and chemical changes despite their pre-existing knowledge of the PNM was a different level. The participants were provided with two opportunities in the MRsLT learning environment to construct the verbal and visual, which they actively processed in two different channels (verbal: ear; visual: eye) functioning through multiple representations (macroscopic, sub-microscopic, and symbolic) in their working memory and integrated into their pre-existing knowledge. First, the participants through shared understandings in small groups and classroom discussions were able to draw comparisons between their own and others. Second, the participants had the opportunity to revise their knowledge through report writing by comparing their new knowledge with the past knowledge, which may have contributed to their metacognitive awareness. The pre-service teachers were encouraged to be aware of their prior knowledge, to carry out frequent discussions, and to compare their new and prior knowledge through journal writing. These pedagogical features could be beneficial in promoting primary pre-service teachers' cognitive structures. Thus, the multiple knowledge representations in teaching physical and chemical changes with teaching methods described in this study will help to develop the cognitive structure of the primary pre-service teachers, who often have a minimal understanding of chemical concepts. The teacher educators and researchers, as part of their pedagogy and research, respectively, may replicate data collection and analytical methods leading to a collective and coherent representation of cognitive structures. Functioning through multiple representations, macroscopic, submicroscopic, and symbolic, enhances chemistry learning.

References

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: a critical review of the literature. *International Journal of ScienceEducation, 22*(7), 665±701.

Abraham, M. R., Williamson, V. M., & Westbrook, S. L. (1994). A cross-age study of the understanding of five chemistry concepts. *Journal of Research in Science Teaching, 31*(2), 147–165.

Adadan, E. (2014a). Investigating the influence of preservice chemistry teachers' understanding of the particle nature of matter on their conceptual understandings of solution chemistry. *Chemistry Education Research and Practice, 15*, 219–238. https://doi.org/10.1039/C4RP00002A.

Adadan, E. (2014b). Model-tabanlı öğrenme ortamının kimya öğretmen adaylarının maddenin tanecikli yapısı kavramını ve bilimsel modellerin doğasını anlamaları üzerine etkisinin incelenmesi (Investigating the Effect of Model-Based Learning Environment on Preservice Chemistry Teachers' Understadings of the Particle Theory of Matter and the Nature of Scientific Models). *Ondokuz Mayıs Üniversitesi Eğitim Fakültesi Dergisi, 33*(2), 378–403.

Adadan, E., Irving, K. E., & Trundle, K. C. (2009). Impacts of multi- representational instruction on high school students' conceptual understandings of the particulate nature of matter. *International Journal of Science Education, 31*(13), 1743–1775.

Adbo, K., & Taber, K. S. (2009). Learners' mental models of the particle nature of matter: a study of 16-year-old Swedish science students. *International Journal of Science Education, 31*(6), 757–786.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston Inc..

Ayas, A., & Özmen, H. (2002). Lise kimya öğrencilerinin maddenin tanecikli yapısı kavramını anlama seviyelerine ilişkin bir çalışma (A study of students' level of understanding of the particulate nature of matter at secondary school level). *Boğaziçi Üniversitesi Eğitim Dergisi, 19*(2), 45–60.

Ayas, A., Özmen, H., & Çalık, M. (2010). Students' conceptions of the particulate nature of matter at secondary and tertiary level. *International Journal of Science and Mathematics Education, 8*, 165–184.

Bahar, M., & Hansell, M. H. (2000). The relationship between some psychological factors and their effect on the performance of grid questions and word association tests. *Educational Psychology, 20*, 349–364.

Bahar, M., Johnstone, A. H., & Sutcliffe, R. G. (1999). Investigation of students' cognitive structure in elementary genetics through word association tests. *Journal of Biological Education, 33*(3), 134–141.

Banda, A., Mumba, F., Chabalengula, V. M., & Mbewe, S. (2011). Teachers' understanding of the particulate nature of matter: the case of Zambian pre-service science teachers. *Asia-Pacific Forum on Science Learning & Teaching, 12*(2), 1–16.

Berg, B. L., & Lune, H. (2015). *Sosyal bilimlerde nitel araştırma yöntemleri*. [*Qualitative research methods in social sciences*] (Hasan Aydın, Trans.). Istanbul, Turkey: Eğitim Yay.

BouJaoude, S. B. (1991). A study of the nature of students' understandings about the concept of burning. *Journal of Research in Science Teaching, 28*, 689–704.

Boz, Y. (2006). Turkish pupils' conceptions of the particulate nature of matter. *Journal of Science Education and Technology, 15*(2), 203–213.

Campbell, D. T., & Stanley, J. C. (1971). *Experimental and quasi-exprimental designs for research*. U.S.A: Rand McNally & Company.

Chittleborough, G. D., & Treagust, D. F. (2008). Correct interpretation of chemical diagrams requires transforming from one level of representation to another. *Research in Science Education, 38*(4), 463–482.

Çökelez, A. (2009). Students' (Grade 7-9) ideas on particle concept: didactical transposition. *H. U. Journal of Education, 36*(36), 64–75.

Cook, M., Wiebe, E. N., & Carter, G. (2008). The influence of prior knowledge on viewing and interpreting graphics with macroscopic and molecular representations. *Science, Education, 92*(5), 848–867.

Coştu, B. (2008). Learning science through the PDEODE teaching strategy: helping students make sense of everyday situations. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(1), 3–9.

Derman, A., & Eilks, I. (2016). Using a word association test for the assessment of high school students' cognitive structures on dissolution. *Chemistry Education Research and Practice, 17*(4), 902–913.

Duit, R., & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*, 671–688.

Ebenezer, J. V., & Erickson, G. (1996). Chemistry students' conceptions of solubility. *Science Education, 80*(2), 181–201.
Ebenezer, J. V., & Fraser, D. (2001). First year chemical engineering students' conceptions of energy in solution process: phenomenographic categories for common knowledge construction. *Science Education, 85*, 509–535.
Ebenezer, J. V., & Gaskell, P. J. (1995). Relational conceptual change in solution chemistry. *Science Education, 79*(1), 1–17.
Ebenezer, J. V., & Haggerty, S. (1999). *Becoming secondary school science teachers: Preservice teachers as researchers*. Upper Saddle River: Prentice-Hall, Inc., Simon and Schuster/A Viacom Company.
Ebenezer, J. V., Chacko, S., Kaya, O., Koya, K., & Ebenezer, D. L. (2010). The effects of common knowledge construction model sequence of lessons on science achievement and relational conceptual change. *Journal of Research in Science Teaching, 47*(1), 25–46.
Edmondson, K. M. (2000). Assesing science understanding through concept maps. In J. J. Mintzes, J. H. Wandersee, & J. D. Novak (Eds.), *Assessing science understanding: A human constructivist view* (pp. 19–40). Cambridge: Academic Press.
Eilks, I. (2013). Teachers' ways through the particulate nature of matter in lower secondary chemistry teaching: A continued change of different models vs. a coherent conceptual structure? In G. Tsaparlis & H. Sevian (Eds.), *Concepts of matter in science education* (pp. 213–230). Dordrecht: Springer.
Franco, G. A., & Taber, K. S. (2009). Secondary Students' Thinking about Familiar Phenomena: Learners' explanations from a curriculum context where 'particles' is a key idea for organising teaching and learning. *International Journal of Science Education, 31*(14), 1917–1952.
Gilbert, J. K., & Treagust, D. F. (2009). *Chemical education: Linking the representational levels of chemistry.* Dordrecht: Springer.
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*(6), 611–628.
Gunstone, F. R. (1980). Word association and the description of cognitive structure. *Research in Science Education, 10*, 45–53.
Gussarsky, E., & Gorodetsky, M. (1988). On the chemical equilibrium concept: constrained word associations and conception. *Journal of Research in Science Teaching, 25*, 319–333.
Harrison, A. G., & Treagust, D. F. (1996). Secondary students mental models of atoms and molecules: Implications for teaching science. *Science Education, 80*, 509–534.
Harrison, A. G., & Treagust, D. F. (2002). The particulate nature of matter: Challenges in understanding the submicroscopic world. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical education: Towards a research-based practice* (pp. 189–212). The Netherlands: Kluwer Academic Publishers.
Jarvis, T., Pell, A., & McKeon, F. (2003). Changes in primary teachers' science knowledge and understanding during a two year in-service programme. *Research in Science & Technological Education, 21*(1), 17–42.
Johnson, P. E. (1967). Some psychological aspects of subject matter structure. *Journal of Educational Psychology, 58*, 75–83.
Johnson, P. E. (1969). On the communication of concepts in science. *Journal of Educational Psychology, 60*, 32–40.
Johnson, P. E. (1998). Progression in children's understanding of a 'basic' particle theory: a longitudinal study. *International Journal of Science Education, 20*(4), 393–412.
Johnson, P. E. (2000). Children's understanding of substances, part 1: recognising chemical change. *International Journal of Science Education, 22*(7), 719–737.
Johnstone, A. H. (1982). Macro- and micro-chemistry. *School Science Review, 64*, 377–379.
Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*, 75–83.
Johnstone, A. H. (2000). Teaching of chemistry - logical or psychological? *Chemistry Education Research and Practice, 1*, 9–15.
Kilic, B. G. (2003). Concept maps and language: a Turkish experience. *International Journal of Science Education, 25*(11), 1299–1311.
Lederman, N. G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (p. 83 ± 126). Dordrecht: Kluwer Academic Publishers.
Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing understanding of the nature of science: A historical perspective. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (p. 331 ± 350). Dordrecht: Kluwer Academic Publishers.
Linder, C., & Erickson, G. (1989). A study of tertiary physics students' conceptualization of sound. *International Journal of Science Education, 11*(5), 491–450.
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*(3), 320–347.
McComas, W. F. (2000). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education, rationales and strategies* (pp. 53–70). Dordcrecht: Kluwer Academy.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousend Oaks: Sage.
Milli Eğitim Bakanlığı—Talim Terbiye Kurulu Başkanlığı (MEB-TTKB) (2013). *Kimya dersi 9, 10, 11 ve 12. sınıf öğretim programı (9th, 10th, 11th and 12th Grade Chemistry Course Curriculum).* Ankara: M.E.B.—TTKB: Retrieve from: http://ttkb.meb.gov.tr/www/ogretimprogramlari/icerik/72. Accessed 5 Feb 2017.
Nakhleh, M. B. (1992). Why some students don't learn chemistry: chemical misconceptions. *Journal of Chemical Education, 69*(3), 191–196.
Nakipoğlu, C. (2008). Using word associations for assessing non major science students' knowledge structure before and after general chemistry instruction: the case of atomic structure. *Chemistry Education Research and Practice, 9*, 309–322.
National Research Council (2000). *How people learn: Brain, mind, experience, and school*: Expanded edition. Washington, DC: National Academy Press. (FREE.pdf): Retrieve from: https://www.nap.edu/download/9853 Accessed 13 October 2017.
National Research Council (2013). *Next generation science standards.* Washington, DC: National Academy Press. (FREE.pdf): Retrieve from: http://www.nextgenscience.org/ Accessed 7 March 2017.
National Research Council [NRC]. (2007). Taking science to school: learning and teaching science in grades K-8. Washington DC: National Academy Press. (FREE.pdf): Retrieve from: https://www.nsf.gov/attachments/117803/public/2c–Taking_Science_to_School.pdf
Ngai, C., Sevian, H., & Talanquer, V. (2014). What is this substance? What makes it different? Mapping progression in students' assumptions about chemical identity. *International Journal of Science Education, 36*(14), 2438–2461.
Nieswandt, M. (2001). Problems and possibilities for learning in an introductory chemistry course from a conceptual change perspective. *Science Education, 85*, 158–179.
Othman, J., Treagust, D. F., & Chandrasegaran, A. L. (2008). An investigation into the relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education, 30*(11), 1531–1550.
Özmen, H. (2011). Turkish primary students' conceptions about the particulate nature of matter. *International Journal of Environmental and Science Education, 6*(1), 99–121.
Özmen, H., Ayas, A., & Coştu, B. (2002). Fen bilgisi öğretmen adaylarının maddenin tanecikli yapısı hakkındaki anlama seviyelerinin ve yanılgılarının belirlenmesi (Determination of the science student teachers' understanding level and misunderstandings about the particulate nature of matter). *Kuram ve Uygulamada Eğitim Bilimleri, 2*(2), 507–529.
Petrey, S. (1977). Word associations and the development of lexical memory. *Cognition, 5*, 57–71.
Piaget, J. (1978). *Success and understanding*. Cambridge: Harvard University Press.
Pozo, J. I., & Gómez-Crespo, M. Á. (2005). The embodied nature of implicit theories: the consistency of ideas about the nature of matter. *Cognition and Instruction, 23*(3), 351–387.
Schaefer, G. (1979). Concept formation in biology: the concept 'Growth'. *European Journal of Science Education, 1*, 87–101.
Schizas, D., Katrana, E., & Stamou, G. (2013). Introducing network analysis into science education: Methodological research examining secondary school students' understanding of 'decomposition'. *International Journal of Environmental & Science Education, 8*(1), 175–198.
Shavelson, R. J. (1974). Methods for examining representations of a subject matter structure in a student's memory. *Journal of Research in Science Teaching, 11*, 231–249.
Stavy, R. (1990). Children's conception of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research in Science Teaching, 27*(3), 247–266.
Taber, K. S. (2001). Building the structural concepts of chemistry: Some considerations from educational research. *Chemistry Education: Research and Practice in Europe, 2*(2), 123–158.
Taber, K. S. (2008). Conceptual resources for learning science: issues of transience and grain-size in cognition and cognitive structure. *International Journal of Science Education, 30*(8), 1027–1053.
Taber, K. S., & Coll, R. K. (2002). Bonding. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 213–234). Dordrecht: Kluwer.
Taber, K. S., & Franco, G. A. (2010). Learning processes in chemistry: drawing upon cognitive resources to learn about the particulate structure of matter. *The Journal of the Learning Sciences, 19*(1), 99–142.
Talanquer, V. (2009). On cognitive constraints and learning progressions: the case of "structure of matter". *International Journal of Science Education, 31*(15), 2123–2136.

Talanquer, V. (2011). Macro, submicro, and symbolic: the many faces of the chemistry “triplet”. *International Journal of Science Education, 33*(2), 179–195.

Thagard, P. (1992). *Conceptual revolutions*. Princeton: Princton University Press.

Thomson, D. M., & Tulving, E. (1970). Associative encoding and retrieval: weak and strong cues. *Journal of Experimental Psychology, 86*(2), 255–262.

Trends in International Mathematics and Science Study-TIMSS (2015). *TIMSS 2015 Encyclopedia*: Retrieve from: http://timssandpirls.bc.edu/timss2015/encyclopedia/countries/canada/the-science-curriculum-in-primary-and-lower-secondary-grades/ Accessed 17 April 2017.

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. *Science. Education, 81*, 387–404.

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

Whitehead, A. N. (1929). *The Aims of education*. New York: MacMillan.