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Diagnostic Assessment of Student Misconceptions about the Particulate Nature of Matter from Ontological Perspective

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Abstract: Student conceptions related with matter and the particulate nature of matter (PNM), are vital for advanced understanding in chemistry, and have been a research area of significant attention. Lacking in the literature are studies addressing chemical misconceptions from an ontological point of view. The purpose of the current study was to develop a diagnostic instrument by utilizing ontological categories as theoretical lens and to evaluate student understanding on the topic PNM through assessment based on the relationship between ontology and misconceptions. Aligned with content in the middle school curricula, an assessment instrument of 25 distractor-driven, multiple-choice items, 15 of which were two-tier, was constructed. Subsequent to content validity work, to utilize student feedback for the improvement of the items and the validity of the inferences, we pilot tested our instrument with 178 students. Cross-sectional survey methodology was employed for the larger assessment work across Grades 6-11. Data were collected from a randomly selected sample of 696 students attending primary and secondary schools. The overall trend emerged to be improved student knowledge with increasing grade level. The students most often tended to attribute the properties of macroscopic matter to its microscopic particles and had most difficulty in explaining dissolution at the particle level, confirming previous national and international findings. An understanding of misconceptions from an ontology perspective may further assist educators to enhance a radical conceptual change. Distractor-driven, two-tier multiple-choice items are envisioned to aid stakeholders in curriculum development and

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2
3 implementation by illuminating student conceptions and ways of thinking.

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5 **Key words:** particulate nature of matter, ontology, misconceptions, two-tier items

6
7 **Introduction**

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9 Science education researchers and practitioners have widely recognized the
10 importance of students' conceptions in the process of science learning. Because of this policy
11 makers put an emphasis on materials that help teachers to assess students' conceptions of
12 several topics in science (Keeley, Eberle, & Farrin, 2005). If students do not understand the
13 conceptions truly, their misunderstandings may result in misconceptions. The literature
14 indicates that "misconceptions" is used for a wide range of terms, such as alternative
15 frameworks (Driver, 1981), alternative conceptions (Arnaudin & Mintsez, 1985; Hewson &
16 Hewson, 1983), preconceptions (Gallegos, Jerezano & Flores, 1994; Osborne & Freyberg,
17 1985), erroneous ideas (Sanders, 1993) and naïve beliefs (Caramazza, McCloskey & Green,
18 1981). Smith, diSessa and Roschelle (1993) also define learner misconceptions as "faulty
19 extensions of productive prior knowledge" (p. 152).

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Chemistry is the science of matter and its structure, composition and properties as well
as the interactions between atoms and the changes that occur in matter during chemical
reactions (Pinto & Silvestre, 2014). Evident from the definition and as a chemist would argue,
matter is the fundamental topic constituting the foundation of chemistry. Thus, student
conceptions related with matter and the PNM are crucial for advanced understanding in
chemistry. Student conceptions related with the PNM has been a research area of interest for
quite a while because it is strongly related to other primary and secondary school topics such
as states of matter, chemical changes and chemical bonds.

Given its importance, misconceptions in understandings of the PNM have been
researched by science educators for a long time (i.e., Boz, 2006; Griffiths & Preston, 1992;
Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Margel, Eylon, & Scherz, 2004;

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3 Nakhleh, Samarapungavan, & Sağlam, 2005; Othman, Treagust, & Chandrasegaran, 2008).
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5 This body of research has exposed a variety of misconceptions about the PNM. For instance,
6
7 some students think that water molecules are water droplets (Boz, 2006). Similarly, others
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9 think that molecules melt (Boz, 2006), water molecules expand when water is heated (Griffths
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11 & Preston, 1992; Kind, 2004; Kokkotas & Vlachos, 1998; Lee, Eichinger, Anderson,
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13 Berkheimer, & Blakeslee, 1993; Stepans, 2003), gold atoms are shiny and hard as gold itself
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15 (Stepans, 2003), and that there is air between particles (Kind, 2004). Also, some students
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17 think that particles (atoms and molecules) can be seen under a microscope (Griffths &
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19 Preston, 1992; Lee et al., 1993; Nakhleh, Samarapungavan & Saglam, 2005; Tezcan &
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21 Salmaz, 2005); and some substances do not have atoms (Tezcan & Salmaz, 2005).
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25 Øyehaug and Holt (2013) conducted a two-year longitudinal study to investigate four
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27 primary school students' understanding of the nature of matter and chemical reactions to find
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29 out their knowledge structures. Their findings indicated that although the students'
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31 understanding of matter and chemical reactions become somewhat more integrated and
32
33 cohesive over time, at some points students expressed incomplete knowledge elements. For
34
35 instance, the students' understanding about the difference between the smell particles and air
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37 particles were not clear, and their descriptions of how smell spreads were incomplete. Another
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39 finding was that the students' understandings advanced step by step. For instance, one of the
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41 students described particles in fluids as moving spheres, but over time he described them as
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43 molecule, atom and symbol.
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47 Another study was conducted with students ranging from secondary to tertiary
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49 educational levels by Ayas, Ozmen and Calik (2009) to identify their understanding of the
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51 PNM. They administered a questionnaire with five-item open-ended questions to 166
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53 students. They identified some misconceptions such as the following: sunrise causes getting
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55 rid of the water molecules completely; air pressure is high in hot weather and low in cold
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3 weather, ice cubes in a jar melt and pass among the glass particles; ink particles affect the
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5 water particles by giving their color to the water particles and turning their color blue. Similar
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7 results were reported by Bridle and Yeziarski (2012). They indicated that some students were
8
9 not able to provide correct identification of the phases of matter, some students could not
10
11 provide a description about the liquid behavior at the particulate level. They did not clearly
12
13 distinguish between the particle spacing of a liquid and a gas. Students represented the change
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15 that occurs between the heated liquid in a beaker and the space above the liquid by breaking
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17 the substance apart into its elements. The students expressed that heating caused
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19 decomposition of a compound during boiling.
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23 In their study, Nyachwaya, Mohamed, Roehrig, Wood, Kern and Schneider (2011)
24
25 developed an open-ended drawing instrument to assess students' understandings of the PNM.
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27 The results indicated that students have problems with fundamental chemistry concepts
28
29 related to PNM. For example, some students' drawings of ionic compounds did not indicate
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31 charged species. Most of the students used the same particulate model of bonding for both
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33 ionic and covalent compounds. In addition, they only used covalent models when they
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35 depicted the ionic compounds. For some of the cases, they tended to portray molecular
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37 compounds as having dissociated in solution. They reported that although the students
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39 received explicit instruction in representing the PNM, they still struggled to represent a
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41 chemical reaction correctly at the particulate level.
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46 Conducted at college level, Kahveci (2009)'s research involving pre-service chemistry
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48 teachers revealed that the teacher candidates were challenged in reasoning at sub-microscopic
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50 level. Nearly half of the first year and 20-26% of the fourth and fifth (final) year students in
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52 the study could not differentiate between an element and a compound illustrated at sub-
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54 microscopic level. Based on the research findings, Kahveci (2009) drew attention to the need
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56 of chemistry and chemistry education curricula including a more explicit focus on particle
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3 level chemistry supported with inquiry-oriented teaching strategies and methods.
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5 As many researchers agree, the PNM topic is critical in further understanding of
6 sophisticated chemistry topics. Also conducted at college level, the purpose of Adadan
7 (2014)'s research was to investigate the influence of pre-service chemistry teachers'
8 understanding of the particle nature of matter on their conceptual understanding of solution
9 chemistry in the context of multirepresentational (MR) instruction. The MR instruction,
10 according to the researcher, allowed students to "build referential coherent links between the
11 verbal and the corresponding visual mental representation, as well as integrating them with
12 the relevant aspects of existing prior knowledge from long-term memory" (p. 221). The
13 analysis of questionnaires about the PNM and interviews on solution chemistry indicated that
14 although both groups of participants improved their understanding of solution chemistry, the
15 participants with a high understanding of the PNM performed better than the participants with
16 a low understanding of the PNM in terms of developing a more scientific conceptual
17 understanding of the topic after the MR instruction.
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34 In Ozmen's (2011) study related to 4th, 5th, and 6th grade primary students'
35 conceptions about the PNM in daily-life events, the interview analysis indicated that students
36 in all grades have little knowledge of or misconceptions about the sub-microscopic particles
37 such as atoms and molecules. For example, the students stated that the particle size and the
38 number of the particles increase after heating; particles can freeze, get smaller when they are
39 cooled; when a balloon is cooled the particles would disappear and the particles combine with
40 each other and their numbers decrease; solids do not have particles; and there is no space
41 between solid particles. Similar results were reported by Tsitsipis, Stamovlasis Papageorgiou
42 (2011). The purpose of their study was to identify the effect of logical thinking, field
43 dependence/ independence, and convergent/divergent thinking on some specific students'
44 misconceptions about the PNM. Three hundred twenty nine, ninth-grade junior high school
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3 pupils participated in their study. The results showed that the students have different
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5 misconceptions. Some these were considering matter as being continuous; the same
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7 substance, molecules, other substance such as air exist between the particles of a substance;
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9 molecules especially in the solid do not move; molecules are always solid; and water
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11 molecules are composed of two or more solid spheres.
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14 Go'mez, Benarroch and Mari'n (2006) examined the degree of coherence found in
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16 students' conceptions concerning the PNM. The analysis of the interviews that were
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18 conducted with 43 students indicated high degree of coherence in the replies given to different
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20 tasks. Students' replies to the confrontation questions indicated a greater degree of coherence
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22 than the predicting events. The analysis also indicated that for some students matter is
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24 continuous and static, for some of them it is continuous and stuffed with particles, or gaps,
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26 and there is a causal correlation with the movement of the particles and vacuum.
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30 The studies identify several reasons for students' misconceptions. Some of these are
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32 everyday conversations, experience and communication at home and with media, science
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34 textbooks and creative thinking (King, 2009; Marques & Thompson, 1997). Goldstone and
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36 Downey (2012) state that the images and symbolic representations used in textbooks
37
38 unintentionally foster misconceptions and construction of inaccurate understandings. In
39
40 addition, storybooks and cartoons also cause students to misinterpret the world. They also
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42 argue that the partial or incorrect answers given to students by individuals such as parents,
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44 peers, grandparents and even teachers lead students to develop misunderstandings about the
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46 world.
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50 Chi and Roscoe's (2002) comprehensive analysis reveals that the source of student
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52 misconceptions is the miscategorization of conceptions between ontological categories.
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54 Ontology is a science of entities and it searches entities' categories and it has been known
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56 since Aristoteles times (Chi, 2003). In the present research, students' misconceptions of the
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3 PNM were assessed based on ontological categories. The study aimed to identify how
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5 students miscategorize their conceptions in comparison with the ontological categories to
6
7 which the conceptions belong.
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9 10 **Purpose of the Study**

11 The main purpose of this study was to evaluate student understanding on the topic
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13 through assessment based on the relationship between ontology and misconceptions.
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15 Specifically, our study sought answers to the following research questions:
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- 17 1) What are middle and high school students' misconceptions about the PNM?
- 18 2) Do middle and high school students' understandings about the PNM differ based
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20 on grade levels or on extra science classes taken out of school?
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- 23 3) How do miscategorizations between the ontological categories explain students'
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25 misconceptions of the PNM?
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29 30 **Importance of the Study**

31 The definition of conceptual change and the factors that inhibit or enable those
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33 changes is one of the concerns of researchers for a long time. Identification of student
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35 misconceptions based on ontological categories and figuring out their miscategorizations is
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37 important since it provides a base to understand the process and patterns of conceptual
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39 change. Using ontological categories helps to understand the organization of the concepts and
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41 how the categorization affects the subsequent understanding of the conceptions (Johnson &
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43 Southerland, 2000). According to Chi, Slotta, and Leeuw (1994), learners categorize new
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45 concepts into ontological categories that seem more appropriate to them. In this process, the
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47 concepts take their meaning based on the related concepts in the category to which they are
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49 assigned. This suggests that figuring out the expected category of the concept and comparing
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51 it to the category to which it is assigned is important because learners derive the meaning of
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53 the concept from the ontological characteristics of that category. Although in the literature
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3 there is plenty of research on student misconceptions, researchers argue for the importance of
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5 characterizing those conceptions instead of simply identifying them (Wandersee, Mintzees, &
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7 Novak, 1994). Understanding student miscategorizations provides a way to figure out the
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9 underlying cause of common misconceptions. This helps not only finding ways to address
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11 those misconceptions but also finding the reasons of why some misconceptions are resistant to
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13 change which is an important problem in the conceptual change process. Knowing the
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15 possible reasons of the misconceptions may be useful for teachers and educators to structure
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17 their teaching to help students overcome erroneous thinking. Awareness of miscategorizations
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19 may shift the focus of teaching from misconceptions to relevant ontological debates which
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21 may enrich and strengthen the process of teaching for conceptual change.
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25 **Contribution of the Study**

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27 Research in ontology and science misconceptions has extensively been conducted in
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29 the disciplines physics and biology (Johnston & Southerland, 2000). On the other hand,
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31 research in chemistry education and particularly, in the topic PNM, has often focused on
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33 revealing student misconceptions through various methods of assessment, such as multiple_
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35 choice testing or interviewing the PNM. In this study, we explored students' misconceptions
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37 from an ontological point of view.
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41 The literature concerning misconceptions suggests that students' misconceptions about
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43 the PNM have been investigated. However, there is lack of research in the literature
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45 concerning student misconceptions about the PNM from an ontological point of view. This
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47 study addresses this gap by exploring the ontological categories of the concepts as well as
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49 those to which the students assigned the concepts, which may be different than the categories
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51 that they scientifically belong. Therefore, the study contributes to the literature by providing
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53 insight about the ontological nature of students' knowledge structures of the PNM.
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Theoretical Framework: Ontology and Ontological Categories

A number of researchers have focused on ontology with an attempt to understand conceptual change and sources of misconceptions. Ontology refers to the categorical structure of reality (Chi & Hausmann, 2003). It assumes that entities in the world essentially belong to different ontological categories (Chi & Hausmann, 2003). Chi and her colleagues propose three primary *ontological categories*; Matter, Processes and Mental States (Chi, 1997; Chi & Hausmann, 2003; Chi, Slotta, & Leeuw, 1994) (Figure 1). Each category has ontological attributes and subcategories. According to Chi and Slotta (1993), “an ontological attribute is a property that an entity may potentially possess as a consequence of belonging to that category (or any of its subordinates)” (p. 252). Conceptions that belong to the Matter category have ontological attributes such as mass and volume, being storable and cumulative. Students can conceptualize these concepts more easily because they can interact with these entities (Johnston & Southerland, 2000). Table, pen, tree, etc. are the entities in the Matter category. Matter category has two subcategories: natural kinds and artifacts (Chi, 1997). Concepts in the Process category do not have physical attributes. For instance, reading, writing, talking, etc. belong to this category (Johnston & Southerland, 2000). Also, these concepts do not have color, mass, and volume. Therefore, Process and Matter categories are fundamentally distinct ontological categories. Process category has three subcategories. These are procedure, event and constraint-based interactions (Chi et al., 1994). One of the most important subcategories is constraint-based interactions because many physics and chemical concepts belong to constraint-based interactions category. For instance, heat, light, current, chemical bond belong to this category. Concepts which are about emotions, thoughts, wishes such as dream, wish, and fear belong to Mental States category (Chi et al., 1994).

Primary ontological categories are distinct from each other. Also, each subcategory of one ontological category is distinct from the other ontological category. The Processes

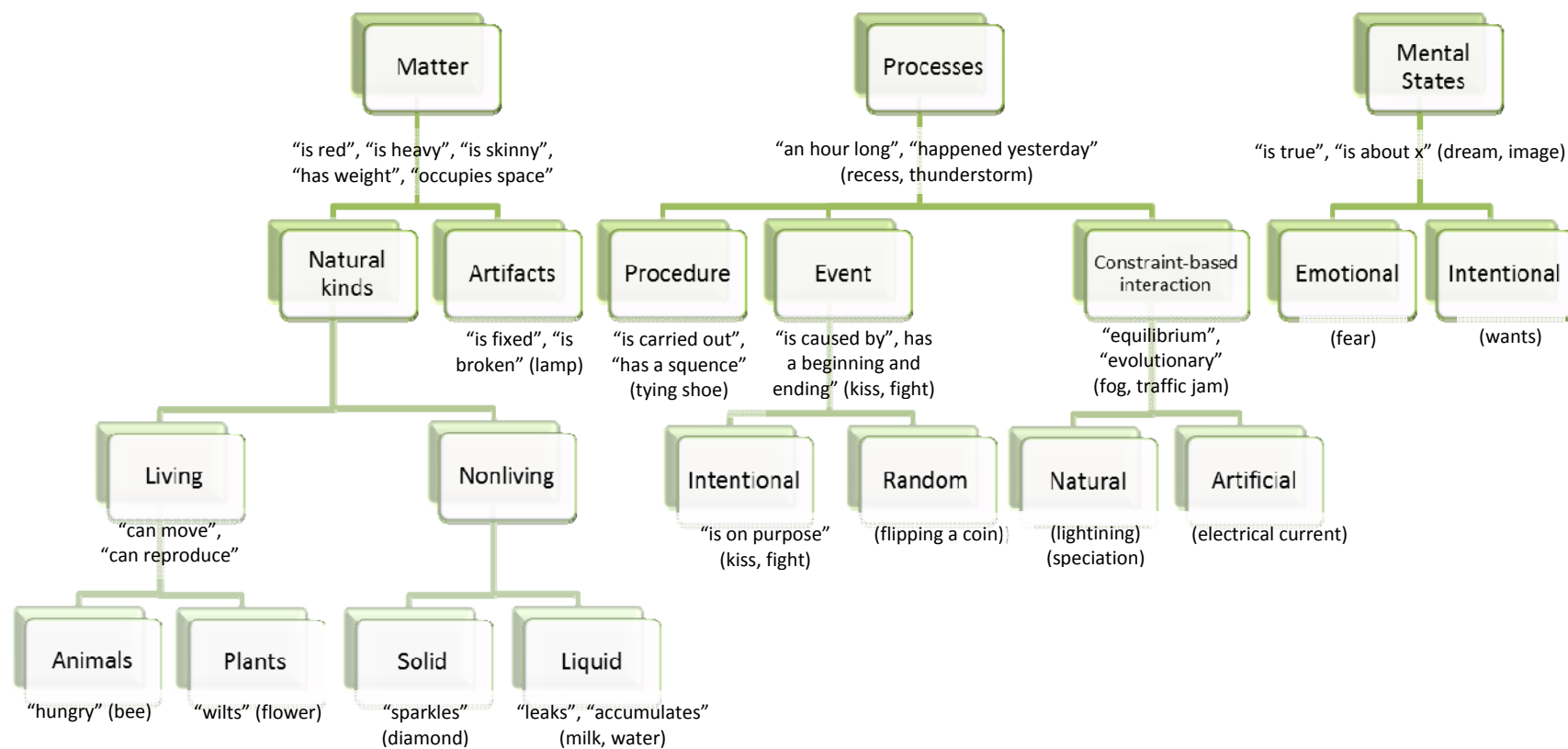


Figure 1. A plausible structure of ontological categories¹ (Chi, et al., 1994, p. 29).

¹Reprinted from Learning and Instruction, 4(1), Chi, M. T. H., Slotta, J. D., & Leeuw, N. From things to processes: A theory of conceptual change for learning science concepts, 27-43., Copyright (1994), with permission from Elsevier.

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2
3 category is ontologically different from any category of Matter since they have
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5 nonoverlapping sets of ontological attributes. For instance, an event in the Process category
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7 has an ontological attribute such as “being an hour long”, on the other hand an animal in the
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9 Matter category cannot be “an hour long”. This suggests they do not share “time” as an
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11 ontological attribute. As Chi and Slotta (1993) suggest, “...two categories are ontologically
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13 distinct if the attributes of one category cannot be applied to members of another category” (p.
14
15 252). On the other hand, the subcategories of the same primary ontological category have the
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17 potential to share ontological attributes. For instance, humans and animals are the
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19 subcategories of Matter and they are not ontologically distinct. Being hungry is one of the
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21 ontological attribute of humans and also of animals. Both humans and animals have the
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23 potential to be hungry.
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27 **Ontology and Misconceptions**

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29 Chi (2008) defines categorizing as the process of identifying or assigning a concept to
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31 a category to which it belongs. As stated above, the concepts that are named as the members
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33 of an ontological category possess features of that category (Chi, 1997; Chi & Slotta, 1993;
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35 Chi & Hausmann, 2003). Once a concept is categorized it can take the attributes from its
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37 category membership. Therefore, categorization is very important in the learning process.
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39 When students confront a new concept, they assign them to a category which is more
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41 reasonable for them. A concept is assigned to a category through relating it with previous
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43 concepts.
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48 Although there are many other explanations, in ontology theory framework
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50 misconceptions are considered to be closely related with ontological categorizations, i.e.,
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52 misconceptions involve the assignment of a concept to an inappropriate ontological category.
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54 In other words, from ontological perspective, students might assign the concepts to a wrong
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56 category which may result in misconceptions. Chi and Roscoe (2002) state that concepts are
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3 related to the notion of categories. Concepts are represented, understood and interpreted in the
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5 context of category membership. That means when a concept is assigned to a category then
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7 the concept inherits all the features of that category. This suggests misconceptions are the
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9 instances of miscategorization, not hierarchically but laterally (Chi & Roscoe, 2002). In other
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11 words, misconceptions involve the assignment of a concept to an inappropriate ontological
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13 category.
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16 According to the researchers, if a concept is assigned to a different ontological
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18 category or subcategory than it scientifically belongs, a misconception is likely to emerge. For
19
20 example, the concept of chemical bonding belongs to the Processes category; however, many
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22 students think that bonds have mass and volume, thus assign the concept to the Matter
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24 category. Eventually, this mismatch is likely to grow into a chemical misconception. Another
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26 example is electricity. If the concept of electricity is assigned to Matter category this is likely
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28 to lead to a misconception because electricity belongs to the Process category and does not
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30 have ontological attributes of matter (Chi & Roscoe, 2002).
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34 Similarly, misconceptions may occur with relation to ontological subcategories which
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36 have lateral relationship. Chi (2008) refers to categories on different branches as “lateral”
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38 categories. For example, artifacts can be considered a lateral category to living beings.
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40 Artifacts include a set of subcategories, such as furniture and toys, and furniture includes
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42 subcategories such as tables and chairs but it does not include the subcategories of living
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44 beings, such as animals, bees, reptiles, birds, or robins (Figure 1). Therefore, artifacts and
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46 living beings categories have distinct properties. For example, while *living beings* ‘can move’
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48 *artifacts* cannot; and *living beings* ‘can reproduce’ but *artifacts* cannot. Being able to move is
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50 an ontological attribute of living beings. Chi, Slotta and Leeuw (1994) define ontological
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52 attribute as “an ontological attribute is a property that an entity may *potentially* possess as a
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54 consequence of belonging to that ontological category” (p. 29). That means, the entities in the
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3 living beings category potentially possess the ability of moving. For example, a cat in the
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5 living beings category can potentially move (an ontological attribute).
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7 Chi, Slotta and Leeuw (1994) also provide the definitions of the defining attributes and
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9 a characteristic feature, and they explain how those definitions are different than the
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11 ontological attributes. They state that “defining attributes are those an entity *must have*, and a
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13 characteristic feature is one that an entity *most frequently has*”. They explain those definitions
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15 through the example of a coffee carafe. They state that “a coffee carafe which is an artifact in
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17 the Matter category must have a spout (a defining attribute). It is often made of glass, though
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19 not necessarily (a characteristic feature), but it can potentially be broken (an ontological
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21 attribute). “Thus, an ontological attribute is qualitatively different (and probably orthogonal)
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23 to either characteristic features or defining attributes” (p. 29).
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27 As an entity, a car belongs to the non-living category. Being able to move is not an
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29 ontological attribute of that category because not all the entities in the non-living category
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31 have potential ability of moving. For instance, a table, a chair, a pen belong to non-living
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33 category and they cannot move; they potentially are not able to move. Therefore, being able to
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35 move for a car can be a defining attribute, not an ontological attribute. This suggests that
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37 “moving” of living beings is ontologically different than the moving of “a car”.
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40 If a concept is assigned to a lateral category then a misconception is likely to emerge.
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42 For instance, if the concept of bee is assigned to the artifacts category (or its subcategory)
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44 instead of living beings category then the ontological attributes of the artifacts category is
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46 assigned to the concept of bee which is a misconception.
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49 On the other hand, assigning a concept to a hierarchal category does not mean a
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51 misconception. Hierarchal categories are the ones that have a hierarchal relationship in the
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53 same ontological tree (Chi & Roscoe, 2002). For instance, Matter, living beings, animals have
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55 a hierarchical relationship. The concepts that have hierarchal relationships share the
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3 ontological attributes of the topmost category. For instance, animals share the ontological
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5 attributes of the living beings, such as ‘can move,’ living beings share the ontological
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7 attributes of the matters such as ‘has shape’. Since they share the ontological attributes,
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9 assigning a concept to a hierarchal category does not lead to a misconception. For instance, if
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11 the concept of ‘robin’ is assigned to living beings category instead of animals this does not
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13 result in misconception because robin has potential to share the ontological attributes of living
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15 beings or animals (Chi & Roscoe, 2002).
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19 One of the most important reasons of why students miscategorize is the assignment of
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21 the new concept to a more familiar category. This happens because of lack of alternative
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23 ontological categories. When students encounter with a new concept, if they do not have the
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25 correct category they assign it to one of the existing categories that is more familiar. Once a
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27 concept is assigned to an existing category then the concept inherits all the features of that
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29 category (Chi & Roscoe, 2002). For example, students think that the earth is flat rather than
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31 spherical. Johnson and Southerland (2000) suggest that students categorize it in a way that
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33 does not allow it to be a planetary object. Instead, from an ontological categories perspective,
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35 we are more familiar with the notion of earth that acts as a container of entities rather than as
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37 an entity contained within some greater system. Therefore, students may assign the concept of
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39 earth to a flat object rather than a spherical object category.
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44 Similarly, students think that atoms are alive. The reason from an ontological point of
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46 view is that they probably try to make a connection with atoms and another entity that they
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48 already know and that is very small like atoms. In their daily life, they know that microbes are
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50 very small. They think that atoms and small organisms such as microbes are of a similar kind.
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52 When students encounter the concept of atoms they try to find a category that they are more
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54 familiar with and have similar characteristics with atoms. Since they are familiar with the
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56 small organisms like microbes that “share” some characteristics with atoms such as being
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3 very small, cannot be seen and can move, they assign the concept of atoms to the living
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5 beings category. Hence, they think atoms are alive like microbes.
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7 Another example is drawn from Moss and Abrams's (1999) study in which the
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9 researchers describe students' conceptions of models. Moss and Abrams found that students'
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11 understandings of models were related to the physical models rather than conceptual models
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13 which reflect a process or interaction. According to Johnson and Southerland (2000) from an
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15 ontological point of view the reason is students are more familiar with the physical models
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17 that represent the objects in the matters category rather than the conceptual models that
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19 represent the processes. Therefore, when they were asked about models, they referred the
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21 models that represent an entity which physically exists.
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25 If misconceptions are not detected and altered in the learning process, the students are
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27 likely to have difficulties when faced with desired ideas (Chi, Treagust, & Chandrasegaran,
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29 2009; Duit & Treagust, 1995). Therefore, identification of student misconceptions is very
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31 important to support their learning. Student misconceptions need to be challenged and
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33 replaced with correct ones in order to achieve a deep understanding. This process is called as
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35 conceptual change. Conceptual change theories that are related to how learners restructure
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37 their conceptions are widely used by science educators. They have been discussed by many
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39 researchers for several decades yet there is a blurry picture of why change is difficult (Chi,
40
41 2008).
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45 Chi (2008) claims that misconceptions are resistant to change because they are
46
47 laterally or ontologically miscategorized. If a concept is assigned to a category and the desired
48
49 conception belongs to another category then their characteristics and definitions conflict. In
50
51 such cases, Chi (2008) suggests identifying the nature of misconceptions in order to figure out
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53 whether conceptions belong to different ontological categories. Researchers argue that
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55 correcting those misconceptions requires an ontological shift (Chi & Roscoe, 2002; Chi &
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3 Hausman, 2003). From ontological perspective conceptual change is a shift of a concept
4
5 between lateral categories. They claim that this process is not inherently difficult but very
6
7 challenging when students lack awareness of their miscategorizations, of when a shift is
8
9 necessary and of alternative categories that are needed to reassign the new concepts (Chi,
10
11 2008; Chi & Roscoe, 2002).

12
13
14 Lack of alternative categories is one of the main reasons of the difficulty of conceptual
15
16 change (Chi & Hausman, 2003). If the students do not have the correct category to assign the
17
18 new concepts they will be challenged in doing the correct categorization. Therefore,
19
20 conceptual change will not easily occur. On the other hand, even if students have alternative
21
22 categories they still may have difficulties because they may not be aware of the need to shift
23
24 the meaning of the concept from one ontological category to another. Therefore, Chi and her
25
26 colleagues argue that “shifting on our own, without being told, may be more cumbersome,
27
28 largely because we are not aware of the necessity to shift” (Chi & Hausman, 2003, p.13). So,
29
30 they suggest that students should be made aware of the need to make a shift and attribute the
31
32 features of the appropriate category to the new concept. In the learning experience, as
33
34 explained next, students need to be involved in the radical conceptual change process. In this
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36 process, students learn about the new ontological category, reflect on the meaning of the
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38 concept within this category and finally the concept is reassigned to this new ontological
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40 category.
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45 Understanding of student misconceptions from an ontology perspective may further
46
47 assist educators to enhance a conceptual change for scientific competency. In this approach,
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49 conceptual change process involves reconsideration of ontology. Chi (1992) suggests radical
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51 conceptual change addressing misconceptions that requires a change across ontological
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53 categories. She defines radical conceptual change as a process that requires crossing the
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55 ontological boundaries.
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3 Chi gives examples from physics in order to explain the process of radical conceptual
4 change. The concepts such as heat and current belong to the constraint-based category, but the
5 students generally think that those concepts belong to the matter category. She states that in
6 order for students to understand those concepts they need to understand that those concepts
7 belong to the constraint-based interactions category rather than the matter category. That
8 means their understandings require an ontological shift. For such misconceptions she suggests
9 radical conceptual change that requires a three-step procedure summarized as following (Chi,
10 1992):

- 11 1. In this step, the properties of the new ontological category should be learned,
- 12 2. Then, the meaning of the concept within the new ontological category should be
13 learned,
- 14 3. Finally, the concept should be reassigned to this new ontological category. This
15 final step might be done in three different ways:
 - 16 a. In the first way, the concept's original meaning can be replaced with the new
17 meaning while the original meaning is abandoned.
 - 18 b. In the second way, both meaning is coexisted in order to access them
19 depending on context,
 - 20 c. In the third way, the concept is replaced automatically depending on the
21 coherence and strength of new meaning.

22 Chi suggests that in step 1, students should be directly told that the physics entities
23 belong to a different ontological category (constraint-based category). She states that this
24 explanation should be made directly since configuration of this explanation requires the
25 process of discovery, which would otherwise be very difficult for students to find out
26 themselves. In this step, students should learn the properties of constraint-based category. In
27 step 2, she suggests that the learning process of the concepts (heat and current) should
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3 proceed as traditional instruction by using common acquisition processes. She also suggests
4 that accretion and assimilation steps should be achieved in the context of the constraint-based
5 categories. This will help students to start making connections between the properties of this
6 category and those concepts. In step 3, students need to reassign those concepts to the
7 constraint-based category. There are three different ways for the reassignment. In the first way
8 (3a), the person has dual meanings for the concept and has to consciously think the new
9 meaning of the concept. Consciously thinking of whales as a kind of mammals rather than a
10 fish is an example of the first way. In the second way (3b), the concept takes two different
11 meanings or assigned to two different categories and they are accessed under different
12 circumstances. For example, in order to make predictions about the daily events physicists
13 revert back and use the naive conceptions. In the third way (3c), the reassignment occurs
14 automatically and that may be because the new meaning of the concept is more reasonable
15 and robust, while the original meaning is learned from the everyday environment. Chi states
16 that radical conceptual change takes place after these three steps have occurred.

33 34 **Research Design and Procedures**

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36 Within the frame of the 2004 curriculum reform initiatives of the Turkish Ministry of
37 National Education, primary science curriculum had been revised in light of contemporary
38 international science education literature and science curricula of developed countries such as
39 US. The science curriculum in Turkey at the time of the study included the teaching of states
40 of matter and changes in states of matter as well as phenomena such as expansion and
41 contraction in Grades 4 and 5. In Grade 6, the PNM is introduced as a separate unit within
42 which students learn about matter as being composed of tiny, invisible, and moving particles
43 with space in between. Within the unit, students are gradually introduced to the concepts of
44 atoms, molecules, elements, compounds, physical and chemical change, and states of matter
45 as explained with the particle model (Ministry of National Education, [MEB], 2006). Included
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3 in reform-based curriculum, in essence, these topics thematically overlap with the related
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5 middle school Benchmarks for Science Literacy (American Association for the Advancement
6
7 of Science [AAAS], 1993) and the National Science Education Standards (National Research
8
9 Council [NRC], 1996).

10
11 There is a large variety of research utilizing various instruments to assess PNM
12
13 concepts. Kahveci (2013) provides an overview of diagnostic assessment research with a
14
15 focus on the type and content of the instruments used for PNM assessment. The researcher
16
17 particularly emphasizes that two-tiered assessment has more practical power in everyday
18
19 classroom use. In our study, we constructed an assessment instrument of 25 distractor-driven,
20
21 multiple-choice items (Sadler, 1998) aligned with content in middle school curricula
22
23 (Appendix A). Fifteen of these were two-tier and 10 were one-tier diagnostic items. Ten of the
24
25 two-tier items were developed based on misconceptions reported in the national and
26
27 international literature regarding the PNM (Othman et al., 2008; Yeziarski & Birk, 2006). In
28
29 developing the instrument, Chi, Slotta, and Leeuw's (1994) theory of ontological categories
30
31 was utilized as a theoretical lens. The misconceptions were framed within ontological
32
33 categories. In other words, concepts addressed by those items were identified as entities in
34
35 certain ontological categories. Subcategories related with chemistry were developed on the
36
37 basis of Chi and Roscoe (2002)'s work on biological categories.

38
39 Distractor choices were statements constructed based on ontological categories, to
40
41 which students might possibly assign the targeted concepts in a scientifically unacceptable
42
43 way. The second tier of each of the items included possible reasons for the statements in the
44
45 first tier. If students selected one of the distractors and the related explanation, then a
46
47 misconception resulting from an ill-assigned concept to an ontological category would be
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49 evident. For instance, the first question of the test was concerned with student understanding
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51 of atoms in terms of their being living or nonliving entities. The ontological category Matter
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3 has two subcategories, living and nonliving (Chi, 1997; Chi & Slotta, 1993). If students
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5 assigned atoms to the ‘living’ category they would attribute properties of living beings to
6
7 atoms, thus giving rise to further misconceptions.
8

9
10 The 25-item instrument was revised by experts in chemistry education for content
11
12 validity. To validate the items which were adopted from nonnative language instruments
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14 (Othman et al., 2008; Yeziarski & Birk, 2006) back translation method was utilized
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16 (permissions from the authors were obtained prior to use of the PNM items in their
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18 instruments.). The items were first translated to Turkish by a group of bilingual chemistry
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20 teachers and then these translations were translated back to English by a second group of
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22 teachers. Both versions in the English language were compared, contrasted, and
23
24 inconsistencies discussed and eliminated by the translating teachers. As a final step, the
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26 instrument was examined by a Turkish language expert for the editing and refinement of the
27
28 items.
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30

31 **Pilot Test**

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33 Following the scholarly recommendation of DeBoer, Dubois, Herrmann-Abell, and
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35 Lennon (2008), to utilize student feedback for the improvement of the items and the validity
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37 of the inferences we pilot tested our instrument with students, the majority of whom were
38
39 middle graders. Pilot testing of the items was conducted with students attending a primary
40
41 school and a private tutoring center in a metropolitan area in Turkey. A total of 178 students
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43 responded to the items, 128 of whom were middle school (Grades 6-8), and 50 were high
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45 school (Grades 9-11) students.
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50 In the pilot test, we asked the students a series of 15 questions about each test item,
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52 derived from DeBoer et al.’s (2008) sample feedback items (Appendix B). We basically asked
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54 the students if there was anything confusing about the particular test item, if there were words
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56 hard to understand, if there should have been any other answer choice, or any associated
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3 picture or graph. We asked if each choice in an item was correct or incorrect, and also
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5 solicited explanations about why a choice was correct or incorrect. For the two-tier items, we
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7 asked the feedback questions for the second tier, as well. Including the feedback items, in
8
9 total, since we ended up with more items than students would be able to efficiently complete
10
11 in a typical class period, we divided the instrument in three sections, each of which was
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13 administered to approximately 60 students in the six grade levels.
14
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16 **Pilot Test Findings**

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18 In this section, we illustrate the way we used validity work and student feedback to
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20 improve the test items by exemplifying our work on two of the items. We also exemplify
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22 ways of student thinking as revealed by student responses to the feedback questions for the
23
24 test items.
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28 One of the reason options of each of the ten two-tier questions developed by the
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30 researchers was the statement “None of the above. For me, the reason is:...” In this way,
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32 although we did not conduct interviews, we provided the students an opportunity to write their
33
34 own reasons if they were different than the presented choices. Though, this open ended choice
35
36 was selected only 34 times in the pilot test. It is likely that the provided choices reflected
37
38 students’ ways of reasoning to an adequate degree as these were constructed based on
39
40 misconceptions research. Although this option was selected 34 times, 14 of them did not
41
42 include any reason. Of the 20 written reasons, eight did not include a scientific explanation;
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44 instead the students wrote statements such as “I think all of them are same”, “I did not
45
46 understand this question”, “it is not”, “the correct answer is not included in the choices”, and
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48 “it is not, choice E is correct”. Most of the other reasons written by the students were already
49
50 included in the presented choices. In other words, the students did not provide sufficient
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52 feedback for this open ended option in order for us to make significant changes in the
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54 questions. However, we made changes based on student feedback to the 15 items derived
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3 from DeBoer et al.'s (2008) feedback items, which we explain next. The rest five two-tier
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5 questions adapted from Othman, Treagust and Chandrasegaran's test (2007) did not originally
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7 include an open ended option. We used DeBoer et al.'s (2008) feedback items to improve
8
9 those questions, as well.

10
11 Item 1 in the test was asking if the atoms should be considered as living or nonliving-
12
13 entities. The initial form of the item is shown in Figure 2. After the pilot testing one of the
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15 reason choices was omitted since a number of both middle and high school students indicated
16
17 that the reason choices were confusing. According to their comments, the confusion was
18
19 caused by the similarity in the wording. To resolve the confusion we decided to leave the fifth
20
21 reason alternative out since it was repetitive of the first and second alternatives.
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24
25 Item 3 was related with dissolution. Its initial form is presented in Figure 3. In
26
27 accordance with subject matter expert comments, the phrase "When sugar is dissolved in
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33 Green leaves (the ones on the tree) are comprised of living cells, and these cells involve
34 atoms. Also, the element iron is comprised of atoms. Accordingly:

- 35
36 (46.7%) (A) The atoms in the leaf are alive.
37 (11.7%) (B) The atoms in the iron are alive.
38 (16.7%) (C) The atoms in the leaf and iron are nonliving.*
39 (21.7%) (D) The atoms in the leaf and iron are alive.
40 (3.30%) No response.

41
42 Reason:

- 43 (50.0%) 1. Since leaves are alive their atoms are also alive.
44 (13.3%) 2. The atoms in the iron are alive because they are moving.
45 (11.7%) 3. Atoms do not have living characteristics.*
46 (8.30%) 4. No matter the kind all atoms are alive.
47 (3.30%) 5. Some atoms are alive some are not.
48 (1.7%) 6. None of the above. For me, the reason is:
49 (11.7%) No response.
50
51

52
53 *Figure 2.* Initial form of Item 1 in the instrument and answer percentages from the pilot
54 testing (N=60). *Correct answer

water” was revised to exclude “dissolving” because one of the purposes of asking the question was to assess student understanding of what was happening to the sugar in the water. Also, according to student feedback from the pilot testing, water temperature should have been specified since dissolving was dependent on temperature. Another student pointed out that the amount of water should have been given. Considering these suggestions the item was revised as following: “When a teaspoon of sugar is added to a glass of water at room temperature a chemical reaction occurs.” Also, an image was added. An additional comment made by a Grade 11th student suggested that the first reason could have been perceived as correct since the mixture of sugar and water may be thought as new matter by some students, indicating a false negative response (DeBoer et al., 2008). To avoid this situation, the first reason was rewritten as following: “When sugar is dissolved in water a new compound forms.”

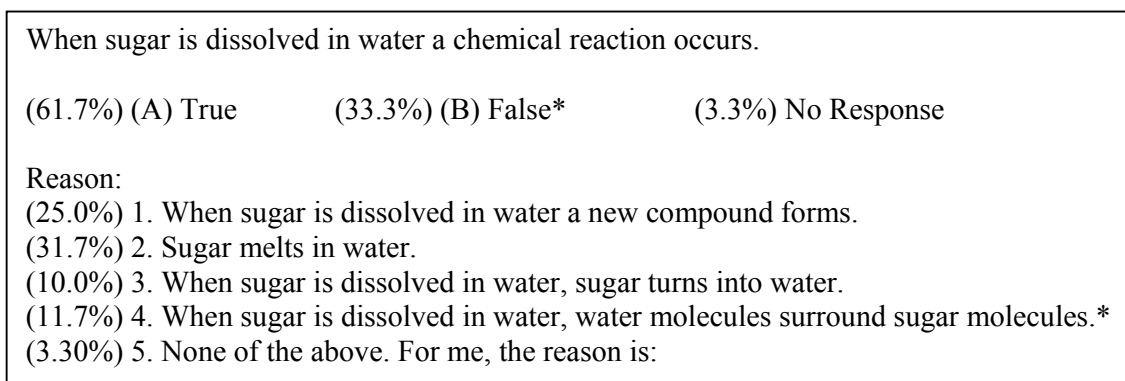


Figure 3. Initial form of Item 3 in the instrument and answer percentages from the pilot testing (N=60). *Correct answer

An analysis of the percentage of correct responses for all items revealed a pattern of significantly lower correct percentages for the two-tier items (range: 1.6-18.3%) than those for the one-tier items (range: 18.0-57.9%). Similarly, the students were more successful in the first tier of the two-tier items, in agreement with previous research findings (Othman et al,

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3 2008). Since the second tiers include justifications of responses in the first tiers, clearly, two-
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5 tier questions probe for a meaningful learning of the concepts as opposed to a factual, rote
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7 learning. Failing in these questions is an indication of unsatisfactory student understanding of
8
9 the topic and existence of misconceptions.
10

11 **Larger Study**

12
13
14 Cross-sectional survey methodology (Fraenkel & Wallen, 2003) was employed to
15
16 evaluate student understanding of the PNM across Grades 6-11. According to Fraenkel and
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18 Wallen (2003);
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20
21 a cross-sectional survey collects information from a sample that has been drawn from
22
23 a predetermined population. Furthermore, the information is collected at just one point
24
25 in time, although the time it takes to collect all of the data may take anywhere from a
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27 day to a few weeks or more (p. 398).
28

29
30 In this research, the population was middle and high school students, and the randomly
31
32 selected sample was drawn from this population. The data were collected at one point in time
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34 in a period of about ten days.
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36 **Sampling of the Participants**

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38 Following the pilot study and subsequent revisions of the instrument, data were
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40 collected from a randomly selected sample of 696 students attending primary and secondary
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42 schools in a metropolitan area in Turkey. 382 of these students were attending middle school,
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44 and 314 were attending high school. The selection process involved cluster and stratified
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46 random selection techniques. The accessible population was defined as all middle and high
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48 school students in the metropolitan area.
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52 First, four municipalities out of 33 were randomly selected by coding each and
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54 entering the codes into the SPSS software. Then, information on all primary and secondary
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56 schools in these four municipalities was accessed and listed. The schools were stratified as
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3 primary and secondary schools and one school from each stratum was randomly selected.

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5 This process was repeated for each of the four municipalities until a total of eight schools
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7 were determined. Three classes from each high school (Grades 9-10-11) and three from each
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9 primary school (Grade 6-7-8), were selected. The test was administered in a period of about
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11 ten days. With active cooperation of the teachers, the students were motivated to carefully
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13 respond to the items in one lecture hour.
14

15
16 For this research, ethical considerations were taken into account. In Turkey, the
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18 researchers have to obtain the consent firstly from the Provincial Directorate for National
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20 Education. After reviewing our application materials including the research proposal in which
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22 we explained the purpose, method, sample and population, and research instrument of the
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24 study, the Provincial Directorate for National Education approved the research and provided
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26 us a consent report. After reading the report, each school principal and the teacher of each
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28 class in the study informed us they approved the administration of our instrument. Before the
29
30 administration, in each class the researchers explained to the students in detail that why they
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32 were requested to participate, how the research was valuable, what kind of questions they
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34 were asked to do, how they needed to answer the questions, and how long it would take. They
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36 were explained the purpose of the research and they were informed that the instrument would
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38 be administered to be used in a research that was conducted in one of the universities. In
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40 addition, this information explained on the first page of the research instrument. The students
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42 read this information and the instrument were administered after they voluntarily consented to
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44 participate.
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49 **Analyses and Findings**

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51 Data were coded and entered into SPSS spreadsheets and subsequent analyses
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53 performed. First, cumulative scores for the one-tier, two-tier and all items were computed by
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55 scoring each correct answer as 1 and false answer as 0. For the two-tier items, only students
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who answered *both* tiers correctly received a score of 1 with the rest receiving 0. The total scores were converted to percent values. Next, these variables were checked for normal distribution on both individual item and cumulative score levels. As small significance values ($<.05$) were obtained from one-sample Kolmogorov-Smirnov tests, the distributions were found not to be corresponding to normal. Therefore, nonparametric techniques were employed to further analyze the variables. In addition, reliability statistics yielded a Cronbach's Alpha value of .78, indicating an acceptable reliability level for the test.

In Table 1, overall percent correct mean scores by grade levels for the ten one-tier items, 15 two-tier items and all 25 items as three separate variables are reported. In addition, conducted for grade-to-grade comparisons, a Kruskal-Wallis test indicated that the difference among the grades was significant ($X^2(5) = 225.751, p <.05$) for all items combined. Subsequent Mann-Whitney U tests revealed the significant differences to be between Grades 6 and 7, 6 and 8, 6 and 9, 6 and 10, 6 and 11, 7 and 9, 7 and 10, 7 and 11, 8 and 9, 8 and 10, and 8 and 11. The overall trend emerged to be improved student knowledge with increasing grade level. The greatest difference between two consecutive grade levels was observed between Grades 8 and 9, the final year in primary school and the first year in high school.

Another pattern revealed higher overall percent correct scores for the one-tier items than the two-tier items for all grade levels. Since the second tiers include justifications of responses in the first tiers, clearly, two-tier questions probe for a meaningful learning of the concepts as opposed to a factual, rote learning. Failing in these questions is an indication of unsatisfactory student understanding of the topic, factual knowledge and misconceptions.

Table 1. *Overall percent correct mean values by grade (% correct mean)*

Question Type	Grade 6 (N = 138)	Grade 7 (N = 134)	Grade 8 (N = 110)	Grade 9 (N = 110)	Grade 10 (N = 109)	Grade 11 (N = 95)
One-tier items	21.6	25.7	27.2	44.4	45.1	46.8
Two-tier items	11.6	14.5	17.8	30.6	29.8	33.4
All items	15.6	19.0	21.6	36.1	36.0	39.0

Students' scores on 100 point scale were also analyzed. Since there were 25 questions in the test every correct answer counted for 4 points. For the two-tier items, only students who answered *both* tiers correctly received a score of 4 with the rest receiving 0. Conducted for grade-to-grade comparisons, a Kruskal-Wallis test indicated that the difference among the grades was significant for two-tier items ($X^2(5) = 187.653$ $p < 0.01$) (Table 2). Subsequent Mann-Whitney U tests revealed the significant differences to be between Grades 6 and 9, 6 and 10, 6 and 11, 7 and 9, 7 and 10, 7 and 11, 8 and 9, 8 and 10, 8 and 11.

Similar results were observed for the one-tier items. Generally, secondary school students' scores were higher than the primary school students'. Conducted for grade-to-grade comparisons, a Kruskal-Wallis test indicated that the difference among the grades was significant for one-tier items ($X^2(5) = 160.635$, $p < 0.01$) (Table 2). Mann-Whitney U tests revealed the significant differences to be between Grades 6 and 8, 6 and 9, 6 and 10, 6 and 11, 7 and 9, 7 and 10, 7 and 11, 8 and 9, 8 and 10, 8 and 11.

Table 2. *Kruskal-Wallis test results for students' scores on 100 point scale*

Question Type	Grade	N	Mean Rank	X ²	df	p
One-tier	6	138	234.31	160.635	5	<.01
	7	134	273.08			
	8	110	287.73			
	9	110	447.45			
	10	109	452.20			
	11	95	457.57			
Two-tier	6	138	219.86	187.653	5	<.01
	7	134	259.52			
	8	110	304.00			
	9	110	448.65			
	10	109	453.45			
	11	95	476.02			
Total	6	138	207.88	225.751	5	<.01
	7	134	254.69			
	8	110	288.90			
	9	110	461.44			
	10	109	470.00			
	11	95	483.92			

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3 In Turkey, students have to take the annual High School Entrance Examination
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5 conducted nationwide in order to attend a high school and they have to take the annual
6
7 University Entrance Examination also conducted nationwide to attend an undergraduate
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9 program. Those exams consist of only multiple choice questions from topics learnt during
10
11 middle or high school. In Turkey, there are tutoring centers which prepare students for those
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13 exams. Students who want to receive support from outside of school attend to a tutoring
14
15 center. When students attend to a tutoring center, they have the opportunity to learn the topic
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17 PNM in a different context which means they learn it from a different teacher and using
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19 different materials in a different class environment. This might help them to better learn the
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21 concepts of the PNM. Also, since the primary aim of these centers is to prepare the students
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23 for the nationwide exam, they focus on multiple choice questions in all science topics
24
25 including the PNM. In general, the distractors of multiple choice questions are constructed
26
27 based on student misconceptions. Therefore, the educational practices of those centers include
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29 activities that lead the students to learn about the desired concepts and also experience
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31 misconceptions in the distractors. For these reasons in this research we wanted to explore
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33 whether the tutoring centers helped students to better understand the PNM.
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39 In order to find out whether the tutoring centers are successful in helping students to
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41 better understand the topic matter; we also compared student scores based on whether they
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43 attended or did not attend a tutoring center. The Mann-Whitney U analysis indicated that there
44
45 was a statistically significant difference between the scores of attending and non-attending
46
47 students (Table 3). The analysis indicated that the scores of students who attended science
48
49 tutoring sessions were higher than the students who did not attend. Score differences on one-
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51 and two-tier questions revealed similar results.
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Table 3. *Mann-Whitney U test results for student scores by attendance to tutoring center*

Question Type	Attendance to Tutoring Center	N	Mean Rank	Sum of Ranks	U	p
One-tier	Attending	236	405.11	95605.00	40213.000	<.01
	Non-attending	457	316.99	144866.00		
Two-tier	Attend	236	403.69	95257.00	40561.000	<.01
	Non-attending	457	317.75	14521400		
Total	Attend	236	412.51	97352.00	38466.000	<.01
	Non-attending	457	313.17	143119.00		

According to a percent correct analysis for each item, nine of the items received a percent correct score of 10% or lower in at least one of the grade levels (Table 4). The items that more than two grade levels scored 10% or lower correct were dealing with: a) dissolving of sugar in water as physical change with explanation at the particle level, b) molecules not being altered during freezing, c) atoms not being altered during melting, and d) sulphur having characteristics such as brittleness or a certain melting point but not sulphur atoms. Most students scoring false in these items were the middle school students. On the other hand, seven of the items in total received a percent correct score of 40% or higher in at least three of the grade levels.

A distractor-level analysis was also conducted to investigate how common the listed misconceptions were for the students at each grade level, shown in Table 5. The most common misconceptions in the sample were the ideas that: a) when dry ice melts (turns liquid), the space between its molecules increases (51.9%), b) ice molecules are solid because ice is solid and water molecules are liquid because water is liquid (38.6%), c) when a few sugar cubes are put into water they would get heat from the surroundings, melt and then the liquid formed would mix with the water (35.2%), d) when iron is in the solid phase its atoms do not move because there is not any space between atoms of solids (32%), e) when water at 24°C is cooled to 0°C and freezes, water molecules stop moving (31.6%), and f) freezing

Table 4. *Percent correct analysis for each item*

Item		Percentage by Grade					
Number	Description	6th	7th	8th	9th	10th	11th
1	Atoms are not living beings	10.9	16.4	20.0	32.7	37.6	42.1
2	Gold atoms not having the same physical properties of gold	8.0	11.2	7.3	18.2	16.5	14.7
3	Dissolving of sugar in water as physical change with explanation at the particle level	3.6	3.7	0.9	10.9	7.3	14.7
4	The size of water molecules not altered during phase change	13.8	28.4	29.1	45.5	27.5	49.5
5	Iron atoms in solid phase move	31.3	24.6	29.1	39.1	53.2	34.7
6	Shape of water molecules not altered depending on the shape of container	15.9	22.4	27.3	54.5	46.8	55.8
7	Molecules cannot be in solid or liquid phase	2.9	8.2	15.5	26.4	33.0	36.8
8	Alcohol consists of alcohol molecules; sugar consists of sugar molecules	11.6	17.9	27.3	32.7	37.6	32.6
9	Molecules not being altered during freezing	7.2	6.0	9.1	28.2	17.4	30.5
10	Atoms not being altered during melting	7.2	9.7	3.6	31.8	25.7	37.9
11	Bubbles in water during boiling consists of water vapor	22.5	30.6	40.9	38.2	47.7	36.8
12	Total weight of iodine in a closed container not altered during sublimation	17.4	20.9	27.3	57.3	59.6	66.3
13	Space between water molecules increase during evaporation	5.1	6.0	13.6	26.4	21.1	23.2
14	Dissolving of sugar in water as physical change	11.6	9.0	10.9	8.2	10.1	18.9
15	Sulphur having characteristics such as brittleness or a melting point but not sulphur atoms	2.2	2.2	5.5	9.1	5.5	13.7
16	Water molecules move faster in gas phase than in liquid and solid phases	21.7	37.3	37.3	68.2	72.5	66.3
17	Size of molecules not being altered during phase change	5.8	14.2	14.5	34.5	19.3	25.3
18	Liquid water turning into water vapor (gas) during evaporation	48.6	51.5	48.2	45.5	54.1	65.3
19	Space between molecules of water decreasing during condensation	14.5	18.7	31.8	39.1	47.7	47.4
20	Liquid water turning into water vapor (gas) during evaporation	24.6	29.1	24.5	36.4	54.1	61.1
21	Molecules moving faster if water is heated	19.6	20.9	30.0	53.6	52.3	63.2
22	Size of molecules not being altered in phase change	4.3	11.2	9.1	32.7	25.7	36.8
23	Space between molecules of dry ice not being altered in melting	25.4	20.1	14.5	27.3	15.6	14.7
24	Molecules vibrating in solid phase	20.3	27.6	26.4	52.7	57.8	42.1
25	Space between molecules of ammonia increase in evaporation	31.2	26.9	35.5	53.6	51.4	46.3

Table 5. *Percent values of selected misconceptions by grade level*

Misconception	Grade 6 (N = 138) % (n)	Grade 7 (N = 134) % (n)	Grade 8 (N = 110) % (n)	Grade 9 (N = 110) % (n)	Grade 10 (N = 109) % (n)	Grade 11 (N = 95) % (n)	Total (N = 696) % (n)
When dry ice melts (turns liquid), the space between its molecules increase.	31.2 (43)	35.8 (48)	50 (55)	59.1 (65)	74.3 (81)	72.6 (69)	51.9 (361)
Ice molecules are solid because ice is solid and water molecules are liquid because water is liquid.	46.4 (64)	41 (55)	42.7 (47)	36.4 (40)	39.4 (43)	21 (20)	38.6 (269)
When a few sugar cubes are put into water they would get heat from the surroundings, melt and then the liquid formed would mix with the water.	35.5 (49)	38.1 (51)	34.5 (38)	37.3 (41)	35.8 (39)	28.4 (27)	35.2 (245)
When iron is in the solid phase its atoms do not move because there is not any space between atoms of solids.	31.2 (43)	44.8 (60)	31.8 (35)	27.3 (30)	21.1 (23)	33.7 (32)	32 (223)
When water at 24°C is cooled to 0°C and freezes, the water molecules stop moving.	28.3 (39)	36.6 (49)	30.9 (34)	31.8 (35)	24.8 (27)	37.9 (36)	31.6 (220)
Freezing makes water molecules larger.	29 (40)	29.9 (40)	23.6 (26)	26.4 (29)	45 (49)	29.5 (28)	30.5 (212)
Atoms in a leave are alive since leave is alive.	28.3 (39)	27.6 (37)	29.1 (32)	28.2 (31)	26.6 (29)	28.4 (27)	28 (195)
Water molecules break up to oxygen and hydrogen atoms when water evaporates.	14.5 (20)	20.1 (27)	20 (22)	41.8 (46)	37.6 (41)	20 (19)	25.1 (175)
The shape of water molecules changes depending on the shape of the container because water molecules are flexible.	23.2 (32)	32.8 (44)	30 (33)	15.5 (17)	21.1 (23)	24.7 (23)	24.7 (172)
When sugar is put into water a chemical reaction happens with the water because sugar melts in water.	31.9 (44)	23.1 (31)	33.6 (37)	20.9 (23)	13.8 (15)	12.6 (12)	23.3 (162)
During melting iron heats up, thus the iron atoms are also heating up, melting and expanding.	8.7 (12)	17.2 (23)	14.5 (16)	18.2 (20)	27.5 (30)	25.3 (24)	18 (125)
When iodine in the solid phase is heated and changes to gas phase, its weight decreases because weight of gases is less than weight of solids.	20.3 (28)	19.4 (26)	19.1 (21)	15.5 (17)	12.8 (14)	10.5 (10)	16.7 (116)
Ammonia breaks up to nitrogen and hydrogen gas when turning from liquid to gas phase.	15.2 (21)	14.9 (20)	16.4 (18)	10.9 (12)	9.2 (10)	8.4 (8)	12.8 (89)

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3 makes water molecules larger (30.5%). One of the most interesting and surprising findings
4
5 was that in some cases a higher percentage of high school (especially Grade 11) than middle
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7 school (especially Grade 6) students appeared to hold certain misconceptions. This finding is
8
9 contrary to an expectation that misconceptions would be lesser or weaker in higher grade
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11 levels as students become more proficient in chemistry. For instance, 25.3% of the Grade 11
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13 students believed that “during melting iron heats up, thus the iron atoms are also heating up,
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15 melting and expanding” in contrast to 8.7% of the Grade 6 students. Further, statistically
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17 significant difference was found between the percent correct responses of the students to the
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19 item in favor of the 6th graders. Although the grade gap is much wider in this study, similar
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21 findings were obtained in Herrmann-Abell and DeBoer (2008)’s field test research where
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23 overall, 7th graders were found to be more successful than 8th graders on the topic.
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28 As we mentioned before, ten of the two-tier questions in the test included an open
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30 ended reason option “None of the above. For me, the reason is:...”. Table 6 shows the
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32 percentage of the students who selected this option. Although this option was selected by a
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34 number of students, the feedback provided was not sufficient enough to make substantial
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36 changes.
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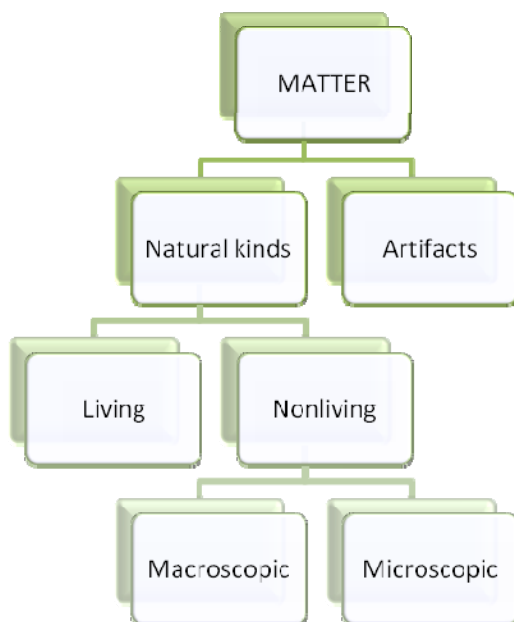
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41 *Table 6. The frequency and percentage of the students selected open ended option*

Question	1	2	3	4	5	6	7	8	9	10
N	690	684	695	680	691	693	693	689	688	670
Percentage	2%	5%	7.3%	5.7%	2%	12.1%	9.2%	8.9%	4.5%	2.2%

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47 In this research, we also analyzed students’ misconceptions based on ontological
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49 categories. First, we identified their misconceptions by using the diagnostic test as explained
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51 above. Then we aimed to compare the categories that the students’ concepts belonged with the
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53 anticipated ontological categories of the concepts. As a result of this analysis, we
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55 demonstrated how students’ misconceptions regarding PNM could be explained in terms of
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57 ontological miscategorization of the concepts. That means a miscategorization does not lead
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3 to a misconception as if in a cause-effect relationship. The misconceptions are an indication of
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5 miscategorization between the ontological categories. The students already have the
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7 misconceptions. We did not ask the students explicitly to categorize their understandings
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9 based on ontology but we used ontology as a theoretical lens to understand how students
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11 reasoned when explaining phenomena.
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14 It became evident that students' often fell into miscategorization between macroscopic
15
16 matter and microscopic particle categories (Figure 4). Chi et al. (1994) state that Figure 1
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18 shows the possible/plausible structure of the ontological categories, therefore there might be
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20 other major ontological categories and subcategories as well. From our research, it emerged
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22 that macroscopic matter and microscopic particle categories are two possible subcategories of
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24 nonliving. Students might assume a microscopic particle to be as macroscopic matter; this is
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26 an indication of miscategorization between the two categories. In this case, students attribute
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28 properties of macroscopic matter to microscopic particles.
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56 *Figure 4.* Matter category and its ontological subcategories.
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3 For instance, one of the identified misconceptions was ‘since ice is solid its molecules
4 are solid and since water is liquid its molecules are liquid’. Water and ice belong to
5 macroscopic matter category because being in a physical phase is an attribute of macroscopic
6 matter. In contrast, water and ice molecules belong to the microscopic particle category and
7 so, they cannot be in solid or liquid phase. An ontological perspective would suggest that
8 students were miscategorizing between these two categories by attributing properties of the
9 macroscopic matter to microscopic particles.
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18 Another misconception related with these two categories was reflected in the response
19 ‘since iron heats during it melts, its atoms also heat and so atoms melt and their volume
20 increase’. Because iron belongs to the macroscopic matter category it is an appropriate
21 expression to tell that when iron melts its volume increases. However, iron atoms belong to
22 the microscopic particle category and thinking that they melt would be an erroneous idea. In
23 this case, students again engage in miscategorization by attributing the properties of
24 macroscopic iron (melting) to the iron atoms. These and similar misconceptions are an
25 indication of miscategorizing between the macroscopic matter and microscopic particle
26 categories.
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39 Another example is the misconception that freezing makes water molecules larger’
40 (expressed by 30.5% of students in total). Freezing is a property of macroscopic matter. When
41 water freezes, its volume increases but the volume of water molecules does not change. By
42 thinking that water molecules get larger, students attribute the property of water to its
43 molecules. This misconception suggests that students miscategorize between the macroscopic
44 matter and microscopic particle categories.
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52 About a quarter of the student sample thought that ‘water molecules break up to
53 oxygen and hydrogen atoms when water evaporates’ (25.1%). The concept of evaporation
54 was considered as a chemical event instead of a physical event. From ontological perspective,
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the students engaged in miscategorization between two Processes sub-categories, physical event and chemical event (Figure 5).

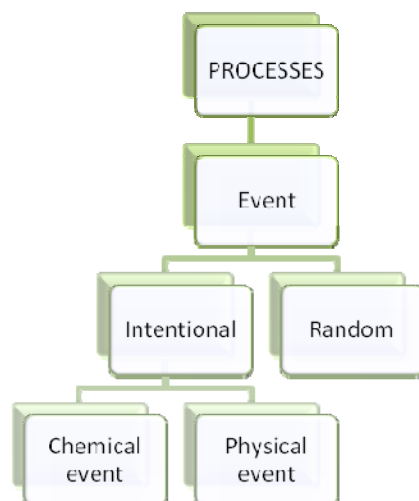


Figure 5. Process category and its ontological subcategories.

There were two other misconceptions relevant to such miscategorization. One was the idea that ‘ammonia breaks up to nitrogen and hydrogen gas when it turns from liquid to gas phase’ (12.8%). Evaporation of ammonia is a physical event but the break up of ammonia into nitrogen and hydrogen gases is a chemical event. A similar miscategorization occurred related with sugar dissolution in water. Students thought that ‘when sugar is put into water a chemical reaction happens with the water because sugar melts in water’ (23.3%). Although the dissolution of sugar is a physical event since it dissolves in water but does not melt, the students assumed it a chemical reaction. This again suggests that students miscategorize between the physical event (dissolving) category and chemical event category of Processes.

Discussion

In this study, firstly we developed a diagnostic instrument by utilizing ontological categories as theoretical lens. Secondly, we evaluated student understanding on the topic PNM through assessment based on the relationship between ontology and misconceptions.

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3 The instrument development involved rigorous validity work. Some of the items were subject
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5 to revisions pertaining to validation and pilot testing. With these revisions we anticipate that
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7 our test items as well as the validity of the inferences drawn from the test results improved.
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9 For instance, our expectation is that in a further study with the instrument as revised, the
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11 percentage of students selecting Reason 1 in Item 3, would decrease, reducing the false
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13 negative responses. Similarly, given the clarification made in Item 1, we anticipate that more
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15 students would concentrate on the meaning and respond to the item correctly. Nevertheless,
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17 we strongly recommend further revision of the items via pilot testing with diverse samples of
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19 national and international students.
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23 The relatively low percent correct levels (highest: 46.8% for 11th graders in one-tier
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25 items) for the Turkish students as compared to others [i.e., Herrmann-Abell and DeBoer's
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27 (2008)'s field test sample] may be explained in terms of the recently reformed middle school
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29 science curriculum at the time of the study to include the topic of the PNM, not given specific
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31 attention before. This may also explain the unexpected higher percentage of Grade 11
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33 students than Grade 6 students in some of the misconceptions as the high school students
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35 primarily experienced learning about matter at the macro level until this time. Grade 6
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37 students in the sample took science classes which were reformed based on the new curricula
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39 (MEB, 2006).
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43 The new curriculum specifically focuses on the PNM. For instance, in Grade 6, the
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45 third unit is titled "The Particulate Nature of Matter". In this unit, students learn about matter
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47 as being composed of tiny, invisible, and moving particles with space in between. They also
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49 learn about the concepts atom, molecule, element and compound. In addition, they classify the
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51 changes in matter as physical and chemical by making connection to the particles of matter.
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53 Grade 7 curriculum focuses on the symbols of elements and formulas of compounds, the
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55 meaning of electron, proton and neutron. In addition, one aim is that students know the
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3 relationship between dissolving and the PNM. In Grade 8, students learn the periodic table,
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5 chemical bonds and reactions by making connections to the PNM. This suggests that middle
6
7 school students in the sample were explicitly taught the PNM but the high school students
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9 were less exposed to this topic when they were in middle school. This might affect their
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11 understandings of PNM concepts resulting in higher percentages of certain misconceptions.
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13 For instance, in general more of the high than middle school students thought that “when dry
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15 ice melts (turns liquid), the space between its molecules increase”, “when water at 24°C is
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17 cooled to 0°C and freezes, the water molecules stop moving”, “freezing makes water
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19 molecules larger” “water molecules break up to oxygen and hydrogen atoms when water
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21 evaporates”, and “during melting iron heats up, thus the iron atoms are also heating up,
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23 melting and expanding.” Those misconceptions are related with phase changes their
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25 connection to the particles of matter which is the focus of the new curriculum but not of the
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27 old curriculum. This might explain why certain misconceptions were prevalent in high school
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29 students.
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34 In this research, students’ achievement on the test increased with increasing level of
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36 grades. Both one- and two-tier items were answered more successfully by the upper level
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38 students than the lower level students. Upper grade students’ achievement on the two-tier
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40 items revealed that these students were better in understanding the underlying reasons of
41
42 phenomena. Since the PNM is a difficult topic to learn, it requires higher level cognitive
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44 abilities for most primary school students (Johnson & Papageorgiou, 2010), and maturation
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46 by age is an important factor in progression of students’ understanding (Rahayu & Kita,
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48 2010). Some studies suggest that the PNM unit should be taught in higher grade levels in the
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50 curriculum (Fensham, 1994; Harrison & Treagust, 2002). These suggestions are consistent
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52 with Piaget’s cognitive development theory. The theory states that older students have more
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54 developed formal thinking ability. The theory states that older students have more
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56 developed formal thinking ability. Therefore, the result that we identified also might be
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3 related with students' cognitive development. Based on Piaget's cognitive development levels
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5 children who are 7-11 years old are in concrete operational stage and children who are 11
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7 years and older are in formal operational stage. In this view, upper grade students have
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9 developed abstract thinking ability but this ability is not fully developed by primary school
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11 students. Therefore, two-tier items are likely to be answered more properly by secondary
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13 school students.
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16 On the other hand, Liu and Lesniak (2006) suggest that "children's matter concept
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18 development is attributable to not only maturation by age but also school context, such as
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20 curriculum and instruction" (p. 322). Therefore, this result might be also related with the
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22 science curriculum that is conducted in middle and high schools in Turkey. Students are
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24 taught the unit of matter and other related units several times from middle school to high
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26 school (MEB, 2006). That means, for instance, students in 11th grade learn the unit of matter
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28 both in middle and high school. In middle school they learn the PNM, the phases, changes and
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30 properties of matter; in high school these topics are covered again but in more detail.
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32 Therefore, their understandings might have deepened as they progress grade wise.
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35 36 **Conclusions**

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38 Our findings suggest that overall, both middle and high school students have
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40 misconceptions about the PNM. An unexpected finding of this study was that in some cases
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42 misconception percentages were higher for high school than middle school students. This
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44 study also shed light on the ontological categories of the concepts as well as the categories to
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46 which the students assigned the concepts. The results suggested that the categories that the
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48 students assigned the concepts were ontologically different than the categories they
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50 scientifically belonged.
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53 Considering the most prevalent misconceptions as well as the items with percent
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55 correct of 10% or lower, it is clear that the students in the sample most often tended to
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3 attribute the properties of macroscopic matter to its microscopic particles, and that they had
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5 most difficulty in explaining dissolving at the particle level. For instance, ideas such as “since
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7 leaves are alive, atoms in the leaves are also alive; if water takes the shape of the container
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9 then water molecules also change shape to fit” were amongst the misconception choices
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11 selected by at least 20% of the students. These findings relate to findings in other studies
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13 conducted both in Turkey and in other countries concluding that students often think of
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15 properties of bulk matter to be observed in its particles, as well. For instance, it is reported
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17 that some students think that when matter is heated, the atoms would heat up (Boz, 2006; Lee
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19 et al., 1993), melt (Boz, 2006), vaporize (Griffiths & Preston, 1992; Kokkotas et al., 1998),
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21 expand (Griffiths & Preston, 1992; Kind, 2004; Kokkotas et al., 1998; Lee et al., 1993;
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23 Stepan, 2003), or condense (Lee et al., 1993). In these cases, students are attributing the
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25 characteristics of one ontological subcategory, macroscopic matter, to cases of another,
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27 microscopic matter. From an ontological point of view, mismatching reasoning as evident in
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29 the findings of the current study and previous research, results in misconceptions.
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34 The misconceptions revealed in this research were related with two ontological
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36 categories (Matter, Processes) and most of them occurred resulting from a mismatch between
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38 macroscopic matter and microscopic particle categories. This is a similar result with Othman
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40 et al.'s (2008). The researchers observed that %34.3 of the 9th grade and %25.8 of the 10th
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42 grade students thought that an atom is the smallest particle which has the same properties of
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44 elements. Also, students thought that atoms have the same physical properties of their
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46 elements. This misconception was held by %55.7 of the 9th grade and %54.2 of the 10th grade
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48 students. Students attributed the properties of the macroscopic matter to their atoms and
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50 molecules.
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54 Overall, this study explored the ontological categories of the concepts as well as those
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56 to which the students assigned the concepts, which may be different than the categories that
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3 they scientifically belong. The results of this study add to the literature documenting student
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5 misconceptions about the PNM and provide insight about the ontological nature of students'
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7 knowledge structures of the PNM.
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9 10 **Implications**

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12 This research has important implications for chemistry education. The research results
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14 could have a directive role for teachers. Also, this study is an important step for understanding
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16 misconceptions regarding the particulate nature of matter on the basis of ontological
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18 categories.
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21 In this research, misconceptions were approached from ontology perspective because
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23 this perspective illuminates reasons of student misconceptions in more depth. In other words,
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25 ontology facilitates to explain the way students think and possess misconceptions. Being
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27 sensitive to misconceptions and their underlying reasons might benefit both teachers and
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29 students. Teachers who are aware of their students' misconceptions may plan their teaching
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31 based on student thinking and so, may provide better teaching context. Also, as in the process
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33 of radical conceptual change, they can teach the ontological categories in their classrooms and
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35 help their students to ontologically categorize their concepts.
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39 According to Sadler (1998) distractor-driven multiple choice assessments based on
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41 alternative conceptions identified through qualitative studies are powerful and reliable tests
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43 measuring conceptual understanding. In this study, we also attempted to augment the power
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45 of distractor-driven multiple choice items with a second tier requiring reasoning. Furthermore,
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47 our construction of the distractors addressing chemical misconceptions of the PNM was
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49 informed by the theory of ontological categories. Studies such as the current one are important
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51 for science educators and teachers as they evaluate student conceptions and reveal
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53 misconceptions in specific topics significant to enhance achievement in science.
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3 Distractor-driven, two-tier multiple-choice items such as those developed in the
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5 current work may serve to aid chemistry teachers, teacher educators and stakeholders in
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7 curriculum development and implementation by illuminating student conceptions and ways of
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9 thinking in depth. Furthermore, understanding student misconceptions from ontology
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11 perspective may assist educators to effectively enhance a conceptual change via experiences
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13 of radical conceptual change toward scientific competency. Such an analysis is promising in
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15 terms of evaluating curricula, finding weak areas in our teaching and optimizing teaching
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17 methods to meet the goals of science education reforms.
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Appendix A: The Particulate Nature of Matter Diagnostic Test

In this test, there are 25 questions about the particulate nature of matter. Please read the questions carefully. In the first 15 questions, select the correct answer choice of the question then select your reason statement that most appropriately explains why your answer is correct. Since there are no reason statements after the 16th question, you only need to mark one of the correct answer choices. Please circle the correct answers.

- 1) Green leaves (the ones on the tree) are comprised of living cells, and these cells involve atoms. Also, the element iron is comprised of atoms. Accordingly:

- (A) The atoms in the leaf are alive.
(B) The atoms in the iron are alive.
(C) The atoms in the leaf and iron are nonliving.
(D) The atoms in the leaf and iron are alive.

Reason:

1. The atoms in the iron are alive because they are moving.
2. Atoms do not have living characteristics.
3. Since leaves are alive their atoms are also alive.
4. No matter the kind all atoms are alive.
5. None of the above. For me, the reason is:

- 2) Which statements below is true regarding to the properties of gold atoms?

- I. Gold atoms are shiny and hard.
II. If gold is heated, its atoms heat up as well.
III. When gold is shaped its atoms take the same shape.
IV. Most of the volume of gold atoms is empty space.

- (A) Only I (B) Only II (C) Only III (D) Only IV (E) I, II, and III

Reason:

1. Any outside change made to gold affects the gold atoms in the same way.
2. If we compare the volume of nucleus and atom, the volume of the nucleus is so much smaller than the volume of the atom (If atomic volume is considered as a football field, volume of the nucleus would be like a ball in this field). Therefore, the rest of the volume of the atom is empty space.
3. All properties of gold exist in its atoms as well.
4. None of the above. For me, the reason is:

- 3) If a teaspoon of sugar is put into a glass of water at room temperature, a chemical reaction occurs between sugar and water.

- (A) True (B) False



Reason:

1. When sugar is dissolved in water, a new compound forms.
2. Sugar melts in water.
3. When sugar is dissolved in water, it turns into water.
4. When sugar is dissolved in water, water molecules surround sugar molecules.
5. None of the above. For me, the reason is:

4) Which statement below is true regarding to the properties of gold atoms?

- (A) The size of the water molecules in the solid phase is the largest, in the liquid phase is the smallest.
- (B) The size of the water molecules in the solid phase is the smallest, in the gas phase is the largest.
- (C) The size of the water molecules is same in the solid, liquid and gas phase.
- (D) The size of the water molecules in the liquid phase is the largest, in the solid phase is the smallest.

Reason:

1. The volume of a molecule increases from solid to liquid phase and from liquid to gas phase.
2. The volume of molecules does not alter during phase change.
3. The volume of a molecule decreases from solid to liquid phase and from liquid to gas phase.
4. None of the above. For me, the reason is:

5) The atoms of iron do not move in solid phase.

- (A) True (B) False

Reason:

1. Atoms vibrate in solid phase.
2. Atoms do not move in solid phase because there is no space in between them.
3. Atoms do not move in solid phase since it is the most regular phase of matter.
4. None of the above. For me, the reason is:

6) Liquids take the shape of their container. Accordingly;

The shape of water molecules changes depending on the shape of the container.

- (A) True (B) False

Reason:

1. Since water molecules are solid their shape does not change.

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2
3 2. Water molecules are flexible.
4 3. Whatever the shape of the container is, the shape of the molecules does not change.
5 4. Water molecules have the shape of water droplets.
6 5. None of the above. For me, the reason is:
7

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9 7) Which statement is true regarding ice and water molecules?

- 10
11 (A) Ice molecules are solid, water molecules are liquid.
12 (B) Both ice and water molecules are solid.
13 (C) Both ice and water molecules are liquid.
14 (D) Molecules cannot be in solid or liquid phase
15

16 Reason:

- 17 1. Being in solid or liquid phase of matter is related with the interactions between its
18 molecules
19 2. Molecules are always in liquid phase.
20 3. Ice molecules are solid because ice is solid and water molecules are liquid because
21 water is liquid.
22 4. Molecules are always in solid phase.
23 5. None of the above. For me, the reason is:
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26
27 8) The smallest particle of alcohol is a drop of alcohol, the smallest particle of sugar is a
28 sugar crystal.

- 29 (A) True (B) False
30
31

32 Reason:

- 33 1. The particles of sugar and alcohol are the same.
34 2. Alcohol consists of alcohol molecules; sugar consists of sugar molecules.
35 3. The smallest particles of sugar and alcohol are their smallest parts that are visible.
36 4. None of the above. For me, the reason is:
37
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39 9) When water is held in the refrigerator, it freezes and turns into ice. During this, water
40 molecules.....

- 41
42 I. Cool down II. Freeze III. Shrink IV. Expand V. Do not alter
43

- 44 (A) Only IV (B) Only V (C) I and II (D) I, II and III (E) I, II and IV
45
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47 Reason:

- 48 1. Since the temperature decreases during freezing, the temperature of molecules
49 decrease as well, therefore molecules freeze.
50 2. Since the temperature decreases during freezing, the temperature of molecules
51 decrease therefore molecules freeze and their volume decrease.
52 3. Freezing do not make any change on molecules.
53 4. Since the temperature decreases during freezing, the temperature of molecules
54 decrease therefore molecules freeze and their volume increase.
55 5. Since volume of water increases during freezing, its molecules expand.
56 6. None of the above. For me, the reason is:
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3 10) When a piece of iron melts through heating, iron atoms.....

- 4
5 I. Heat up II. Melt III. Expand IV. Do not alter V. Shrink
6
7 (A) Only IV (B) Only V (C) I and II (D) II and III (E) I, II and III
8

9 Reason:

- 10 1. Since volume decreases during melting, iron atoms shrink.
11 2. Since iron is heated during melting, its atoms heat up as well, therefore the atoms melt
12 and their volume increases.
13 3. Melting does not cause a change in atoms.
14 4. The temperature of atoms does not change during melting but atoms melt therefore
15 their volume increases.
16 5. Since the temperature increases during melting, atoms heat up and melt. No other
17 changes happen.
18 6. None of the above. For me, the reason is:
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22 11) Assume a beaker (heat resistant glass container) of pure water has been boiling for 30
23 minutes. What is/are in the bubbles in the boiling water?
24



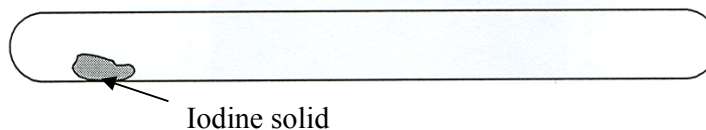
- 35
36 (A) Air
37 (B) Oxygen gas and hydrogen gas
38 (C) Oxygen
39 (D) Water vapor (water in the gaseous state)
40 (E) Heat
41

42 Reason:

- 43 1. The hydrogen and oxygen atoms in water molecules break away from each other to
44 form gases.
45 2. Heating gives the particles more energy and they are able to break away from their
46 attractions. As the particles break apart, the air between the particles is released in the
47 form of bubbles.
48 3. Heat energy is absorbed by the water and released as bubbles.
49 4. The forces between the water molecules are overcome, and the water molecules break
50 free from the liquid to form steam.
51 5. Oxygen dissolved in water is expelled as air bubbles.
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- 12) Information: Iodine has chemical symbol I and atomic number 53; it is an element in group VIIA of the Periodic Table. It is a dark grey-dark purple solid at room temperature.

A 1.0 g sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The total mass of the tube and the solid iodine is 27.0 g.



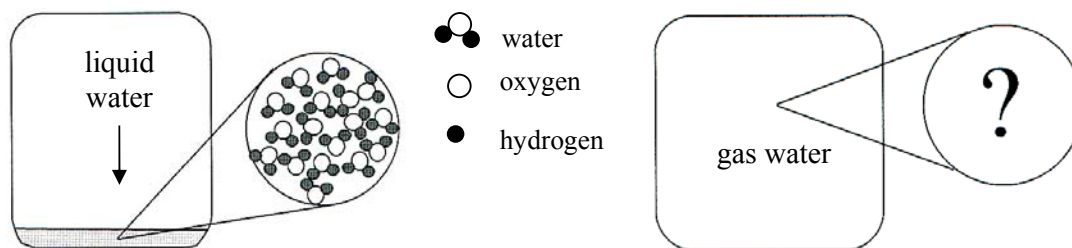
The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. The mass after heating will be

- (A) less than 27.0 g
 (B) 27.0 g
 (C) more than 27.0 g

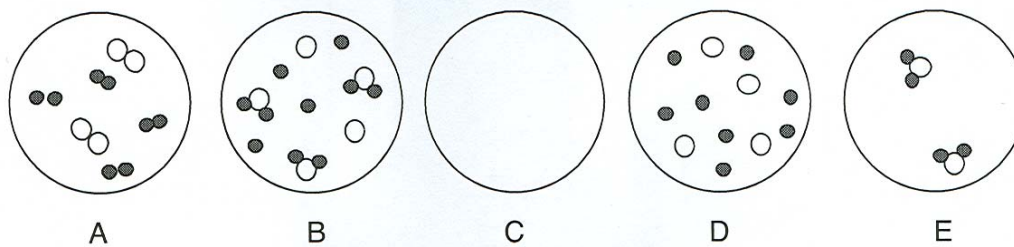
Reason:

1. A gas weighs less than a solid.
2. Mass is conserved.
3. The particles become more spread out when the iodine becomes a gas.
4. Iodine gas is lighter than air.

- 12) The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



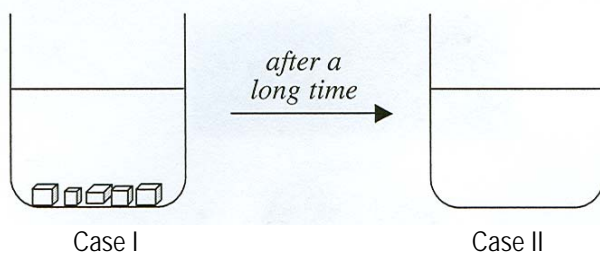
What would the magnified view show after the water evaporates?



Reason:

1. Water molecules have decomposed into oxygen atoms and hydrogen atoms.
2. Water molecules have escaped into the air.
3. Water molecules have decomposed into oxygen and hydrogen gas.
4. Water molecules have spread further apart.
5. A mixture of water molecules, oxygen atoms and hydrogen atoms is produced.

- 13) Crystals of sugar are placed in a beaker (heat-resistant glass container) of water (Case I). If the mixture is left to stand long enough, the sugar crystals eventually can no longer be seen, and the water will taste sweet (Case II).



- (A) True (B) False

Reason:

1. The sugar molecules gain heat from the surrounding and melt, forming a liquid. This liquid mixes with the water.
2. The sugar fills the air spaces in the water and therefore 'disappears'.
3. Water molecules surround sugar molecules on the surfaces of the crystals and pull them away from the crystal lattice.
4. The sugar crystals will only dissolve when stirred. Stirring causes the sugar crystals to break up into smaller particles that will then spread in the water and can no longer be seen.

- 15) Information: Sulphur has chemical symbol S and atomic number 16; it is an element in group VIA of the Periodic Table. It is a lemon yellow solid at room temperature.

A sample of solid sulphur has the following properties:

- I. brittle,
- II. melting point 113°C.

Which, if any, of the above properties would be the same for one single atom of sulphur obtained from the sample?

- (A) I and II
- (B) I only
- (C) II only
- (D) None of the properties

Reason:

1. An atom is the smallest particle of an element that has the same properties as the element.
2. A sulphur atom has smooth faces and sharp edges and so breaks easily when a force is applied.
3. Sulphur is a non-metal therefore the sulphur atom melts at a relatively low temperature.
4. The properties of an element are a result of the interactions of its individual particles.

16) Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the solid phase.

- (A) Move faster than
- (B) Move slower than
- (C) Move at the same speed as
- (D) Move less randomly than
- (E) Travel in the same direction as

17) Which of the following processes will make water molecules larger?

- (A) Freezing
- (B) Melting
- (C) Evaporation
- (D) Condensation
- (E) None of the above

18) When water is vaporized, it is changed to

- (A) Hydrogen and oxygen
- (B) Hydrogen only
- (C) Gaseous water
- (D) Air, hydrogen, and oxygen
- (E) Oxygen only

19) A pot of water on a hot stove begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?

- (A) The lid became sweaty.
- (B) Steam cools and water molecules move closer together.
- (C) Water from outside leaked into the pot.
- (D) Hydrogen and oxygen combined to form water.
- (E) Steam combined with the air to wet the inside of the lid.

20) A wet dinner plate is left on the counter after it has been washed. After a while it is dry. What happens to the water that did not drip onto the counter?

- (A) It changes to carbon dioxide.
- (B) It just dries up and no longer exists as anything.
- (C) It goes into the air as molecules of water.
- (D) It goes into the plate.

(E) It changes to oxygen and hydrogen in the air.

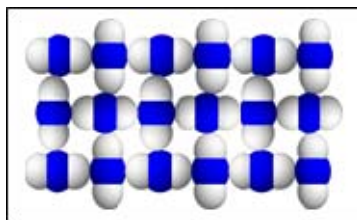
21) When water molecules in the gas phase are heated, the molecules themselves

- (A) Expand.
- (B) Move faster.
- (C) Become less massive.
- (D) Change to a liquid.
- (E) Release air.

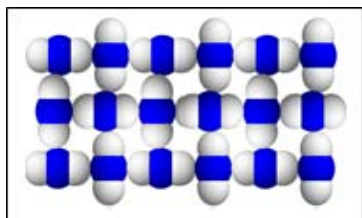
22) Which of the following processes will make molecules smaller?

- (A) Freezing
- (B) Melting
- (C) Evaporation
- (D) Condensation
- (E) None of the above

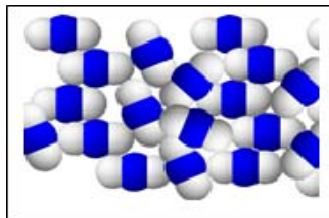
23) A diagram representing carbon dioxide molecules in the solid phase, also known as dry ice, is shown below.



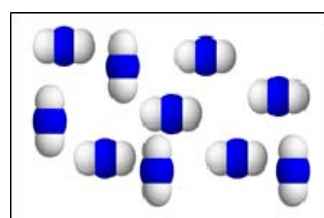
Which of these molecular diagrams best shows what dry ice would look like after it melts (changes to a liquid)?



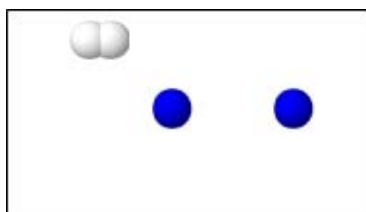
(A)



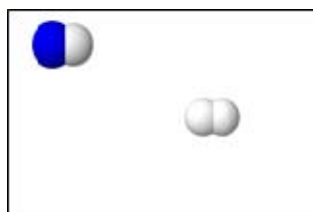
(B)



(C)



(D)

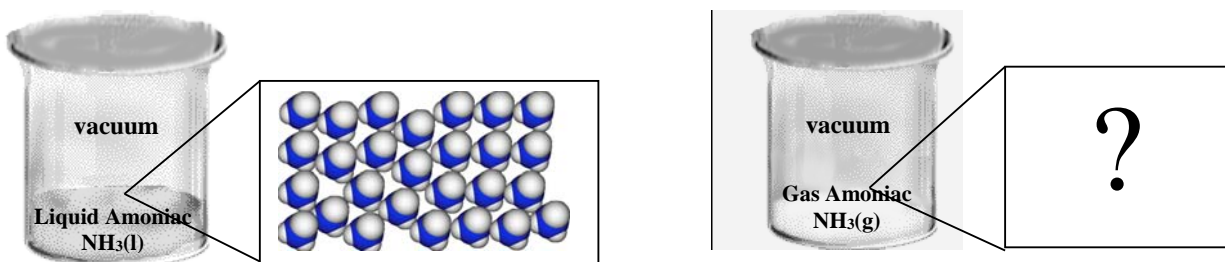


(E)

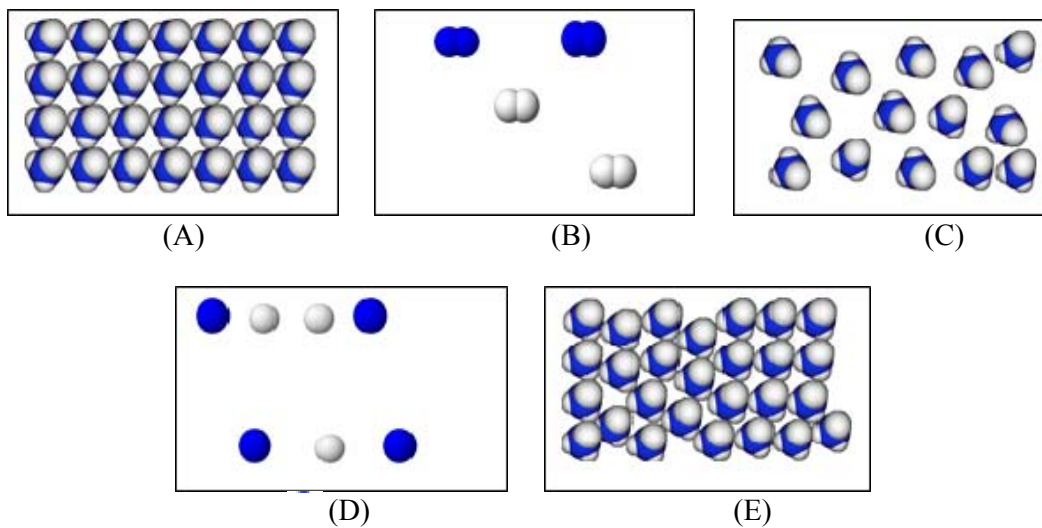
24) When water at 24°C is cooled to 0°C and freezes, the water molecules

- (A) Become less organized.
- (B) Move much faster.
- (C) Stop moving.
- (D) Break apart.
- (E) Move much more slowly.

25) A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



Which of the following diagrams best represents what you would “see” in the same area of the magnified view of the vapor?



Appendix B: Questions Asked During Pilot Testing

1. Is there anything about this test question that was confusing? Explain.
2. Circle any words on the test question you don't understand or aren't familiar with.
3. Is answer choice A correct? Yes No Not Sure
Explain why or why not.
4. Is answer choice B correct? Yes No Not Sure
Explain why or why not.
5. Is answer choice C correct? Yes No Not Sure
Explain why or why not.
6. Is answer choice D correct? Yes No Not Sure
Explain why or why not.
7. Is answer choice E correct? Yes No Not Sure
Explain why or why not.
8. Did you guess? Yes No
9. Should there be any other answer choice? Yes No
If you think so, what are they?
10. Was the picture or graph helpful? Yes No
Why or why not? [Or, if there was no picture...]
Would a picture or graph be helpful? Why or why not? Yes No
11. Have you studied this topic in school? Yes No Not Sure
12. Have you learned about it somewhere else? Yes No Not Sure
Where? (TV, museum, etc.)?
13. Is there anything about the reasons of this test question that was confusing? Explain.
14. Circle any words on the reasons of this test question you don't understand or aren't familiar with.

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3 15. Should there be any other reason choice? Yes No
4

5 If you think so, what are they?
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