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Exploring Pre-Service Elementary Science Teachers' Conceptual Understanding of Particulate Nature of Matter through Three-Tier Diagnostic Test

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Abstract

The purpose of this study was to explore Pre-service Elementary Science Teachers' (PSTs) conceptual understanding of Particulate Nature of Matter (PNM) through a three-tier diagnostic test. Participants were 215 PSTs from Turkey. Data consisted of participants' responses to the Particulate Nature of Matter Test (PNMT). The PNMT consists of three-tier items. Students were asked to choose the correct choice in the first tier, and then to justify their choice of the answer provided in the second tier. Finally, they were asked to indicate the confidence level of their responses in the third tier. Results showed that the PSTs were not competent in their understanding of the PNM concepts. Moreover, some had strongly held misconceptions. Finally, the PSTs struggled to provide coherent answers to the items on the PNMT across three tiers.

Introduction

One of the challenges of assessing students' conceptual understanding in science is the scarcity of reliable assessment tools and methods (Briggs, Alonzo, Schwab, & Wilson, 2006; Caleon & Subramaniam, 2010; Chu, Treagust, & Chandrasegaran, 2009; Hudson & Treagust, 2013; Kirbulut & Beeth, 2014). Historically, educators have attempted to measure students' conceptual understanding in science through multiple-choice assessments, with a single correct answer choice and two or more incorrect options (Linn & Gronlund, 2000; Treagust, 1986). The assumption behind these assessments is that by giving students the opportunity to eliminate the distracting answer choices, and measuring students' ability to identify the correct answer choice, one can gather reliable information about students' conceptual understanding of the target scientific ideas (Briggs et al., 2006; Kirbulut & Beeth, 2014). While these assessments have been widely used in science education, they have been heavily criticized in recent years. These assessments have been criticized because they have certain limitations in helping educators to access and understand students' reasoning behind their answer choices (Pesman & Eryilmaz, 2010; Tan, Goh, Chia, & Treagust, 2002; Voska & Heikkinen, 2000). Critics who have voiced their concerns about the limitations of multiple-choice assessments, developed, used and promoted the use of such assessment tools as open-ended questionnaires (Khalid, 2003) and interviews (Griffiths & Preston, 1992; Osborne & Gilbert, 1980) to assess students' conceptual understanding.

Although these assessment tools give students opportunity to elaborate on and justify their responses, they have several drawbacks (Adadan & Savasci, 2012; Briggs et al., 2006; Kirbulut & Beeth, 2014; Tan et al., 2002). First, scoring student responses to open-ended questions takes significant amount of time, which many teachers lack, especially if they are teaching large classes and assessing students' understanding frequently (Briggs et al., 2006). Second, while it is true that student responses to open-ended questions or interviews can provide more reliable information about student thinking and knowledge structure, it is hard to get a comprehensive evaluation of students' cognitive structure related to core scientific ideas (Briggs et al., 2006; Wang, 2004). More precisely, due to time it takes to answer, it is difficult to administer as many questions as necessary, thus to gather a wide range of information on students' knowledge structure related to the topic of interest (Haladyna, 1997).

To overcome the limitations of multiple-choice tests, and the challenges of using tools such as interviews and open-ended questions, science educators have developed a new model of assessment called two-tier tests (Haslam & Treagust, 1987; Hudson & Treagust, 2013; Odom & Barrow, 1995; Sia, Treagust, &

Chandrasegaran, 2012; Tamir, 1989; Tan et al., 2002; Treagust, 1986; Voska & Heikkinen, 2000; Wandersee, 1983). These types of assessments are advantageous because they ensure the reliability and efficiency of multiple-choice assessments, as well as the capability to diagnose student understanding and reasoning at a deeper level. However, since two-tier tests do not discriminate students' lack of knowledge from the misconceptions they hold, educators have come up with three-tier tests, tests that include an additional tier checking on students' confidence level in their responses to address this issue (Arslan, Cigdemoglu, & Moseley, 2012; Caleon & Subramaniam, 2010; Kiray, Aktan, Kaynar, Kilinc & Gorkemli, 2015; Kirbulut & Beeth, 2014; Pesman & Eryilmaz, 2010).

While both students' and PST's understanding of particulate nature of matter has been studied by several science educators (Banda, Mumba, Chabalengula, & Mbewe, 2011; Nakhleh, Samarampungavan, & Saglam, 2005; Özalp & Kahveci, 2015; Özmen & Kenan, 2007; Yeziarski & Berk, 2006), only few of these studies have used two-tier or three-tier assessments in their attempts to measure the PST's conceptual understanding of the PNM. We focused on the PST's conceptual understanding of the PNM, because this topic is taught first at the elementary school and thus the most relevant topic for pre-service elementary science teachers. Similarly, science education literature has reported problems with pre-service and in-service science teachers' conceptual understanding of the PNM (Chang, 1999; De Jong, Van Driel, & Verloop, 2005; Haidar, 1997; Kahveci, 2009; Özalp & Kahveci, 2015; Özmen, Ayas, & Coştu, 2002; Tatar, 2000; Valanides, 2000). Therefore, an investigation of pre-service elementary science teachers' conceptual understanding of the PNM merits further exploration. In this study, we used a three-tier diagnostic test to assess the PST's understanding of particulate nature of matter.

Review of Relevant Literature

Pre-service science teachers' and students' conceptual understanding of the PNM has become subject of scholarly investigations for quite sometimes. We discuss a few of these studies in this section. For example, Valanides (2000) investigated pre-service teachers' understanding of the macroscopic and microscopic properties of matter. The results of Valadines's study showed that majority of the pre-service teachers exhibited limited understanding of the particulate nature of matter. More specifically, they failed to understand the connection between the observable macroscopic changes in matter and the interactions between atoms and molecules at the microscopic level. They also failed to understand how molecules in solutions moved in relation to one another and how they molecules are held together in solutions and gaseous state.

Kahveci (2009) conducted a study with pre-service chemistry teachers in Turkey in which she challenged pre-service teachers to reason about the particulate nature of matter at sub-microscopic level. She found that nearly half of the first year and 20–26% of the fourth and fifth (final) year students could not differentiate between an element and a compound illustrated at sub-microscopic level. Kahveci reasoned that pre-service chemistry teachers develop these misconceptions mainly because they are taught through teacher-centered instructional methods. These methods are not effective at helping students develop meaningful and robust conceptual knowledge. As a result, students end up developing misconceptions. She further argued that if we want pre-service chemistry teachers to develop robust, scientifically accurate knowledge of chemical concepts, we need to adopt effective instructional methods such as inquiry-based instruction.

Özalp and Kahveci (2015) conducted a study in which they investigated middle and high school students' conceptual understanding of the PNM through an instrument that consisted of 25 distractor-driven, multiple-choice items: fifteen of which were two-tier and 10 were one-tier diagnostic items. They reported several misconceptions held by the students. Some of the reported misconceptions were: 'since ice is solid its molecules are solid and since water is liquid its molecules are liquid', 'since iron heats during it melts, its atoms also heat and so atoms melt and their volume increases', 'water molecules break up into oxygen and hydrogen atoms when water evaporates'. The prevalence of these misconceptions among primary and high school students suggests that teachers themselves might hold onto the same misconceptions. Lemma (2013) reported such a connection between Ethiopian science teachers and their students. Lemma (2013) studied 192 8th grade Ethiopian students' and their six teachers' conceptual understanding of particulate nature of matter using a multi-tiered assessment. She found that 50% of the teachers and 79.16% of the students considered bubbles from boiling water as gases like oxygen, hydrogen, and carbon dioxide. Moreover, she found that 33.34% of the teachers and 50% of the students held the misconception that water molecules change to air when they evaporate.

Collectively, the results of these studies suggest that: 1) both teachers and students harbor several misconceptions related to the particulate nature of matter, 2) teachers' can pass their misconceptions onto their students, 3) two-tier multiple-choice items provide an in-depth understanding of learners' thinking, thus allows educators to identify and address learners' misconceptions through effective interventions such as inquiry-based instruction. While all of these studies have used one or another form of two-tiered assessments, none has used three-tiered assessments.

In this study, taking the advantages of three-tier test into consideration, we used a three-tier diagnostic test to assess the PST's conceptual understanding of the particulate nature of matter. The research questions guiding our inquiry were:

1. How competent are pre-service elementary science teachers (PSTs) in understanding particulate nature of matter concepts?
2. How consistent are the PST's answers in the Particulate Matter of Nature Test (PNMT) across three tiers?
3. What are the strongly held misconceptions about the particulate nature of matter by the PSTs?

Method

This is a descriptive quantitative study, goal of which is to reliably measure a particular phenomenon and develop assertions that can potentially be generalizable to the whole population (Creswell, 2012). In this study, we measured Turkish PSTs' conceptual understanding of the PNM through a three-tier assessment to identify the PST misconceptions.

The sample was drawn from the elementary science pre-service teachers from second tier universities in Turkey. This study took place at four regional universities in Turkey. These are the universities that have been established within the last 20 years and with a heavy focus on teaching with relatively limited research facilities for basic sciences. The participants of the study were 215 PSTs enrolled in four science teacher education programs at four state universities in Turkey. Of the 215 total participants, 89 were sophomores (3rd year) and of 126 were junior (2nd year) students, 165 females and 50 males. All participants had similar background in science content based on the number of mandatory science courses taken in their program areas. The elementary science education program requires students to take 92 mandatory course credits. Of these, 45 credits consist of content courses, such as fundamentals of physics, chemistry, and biology. The participants had taken these science courses in their first and second year of the elementary science education program. These fundamental science courses consisted of two parts: lectures that focus on relevant theories of the science field and laboratory that focus on hands-on lab investigations.

Data Collection

Data consist of the PSTs' responses to the PNMT (see Appendix A and Kirbulut & Beeth, 2014 for the instrument). The PNMT consists of three-tier items. Students are asked to choose the correct choice in the first tier, and to justify their choice of the answer with a blank space where students are asked to write an explanation of their reasoning if different from the given reasons is presented in the second tier. Finally, they are asked to indicate their confidence in their responses using a scale ranging from 1-7. The PNMT examines the conceptual areas of Charles Law (3 items), Boyle Law (2 items), Gay-Lussac Law (2 items), conservation of matter (2 items), evaporation (3 items), condensation (2 items), boiling (3 items), and vapor pressure (2 items). The Cronbach alpha reliability coefficient was estimated to be .78 for the PNMT. Participants were informed of the purpose of the study and their consent was sought prior to data collection. Then, the PNMT was administered to the participants at the end of spring semester. They were not given time or instructions to study before they were asked to take the test. They used an entire class period (45 minutes) to complete the test. A sample question from the PNMT is presented below.

- 1.1 When an amount of water is boiling, you see bubbles coming from the boiling water. What do you think that the bubbles are made of?
 - A) Air
 - B) Oxygen gas
 - C) Oxygen and hydrogen gas
 - D) Water vapor

1.2 Which one of the followings is the reason of your answer for the previous question?

- A) When water evaporates, it breaks into oxygen and hydrogen gas.
- B) There is air in water and bubbles are made of air.
- C) When water evaporates, the distance between water molecules increases.
- D)

1.3 How sure you are about your answers for the previous two questions?

	Unconfident						Confident
Confidence Rating:	1	2	3	4	5	6	7

Data Analyses

We used quantitative techniques in analyzing the data. We primarily relied on frequency and percent analyses in reporting our results. Our analyses focused on calculating students' correct answers across three tiers of items. Tier I scores were created by using student answers to the first tier of items, students' correct answers were coded as 1 and others were coded as 0. Tier II scores were calculated based on student responses to the first and second tiers of items. When student answers to both the first and the second tier of items were correct, they were coded as 1, otherwise 0.

Tier III scores were calculated based on student answers to all three-tier items. The third tier is the confidence tier. When student answers to the first two tier of items were correct, and his/her confidence level was above 4 on a 1-7 scale, they were coded as 1; otherwise 0 (Turker, 2005). The PSTs' overall test scores and descriptive statistics were calculated using Microsoft Excel. The maximum possible score for the PNMT is 19. After we calculated frequencies of correct responses for the first tier, the second tier and the confidence tier, we calculated the percentages of students who performed correctly at each tier to compare their answers' consistency across all tiers.

We also calculated misconception scores for all tiers based on the list of identified misconceptions presented in Appendix B. While calculating misconception scores, we used a three variable-misconception framework: first-tier, both-tier, and all-tier scores. The first-tier misconception score was produced based on a student's answer for the first tiers of the items which constitute related misconceptions as indicated in Appendix B. When a student's answer to the first tier was a misconception, it was coded as 1; otherwise 0. The both-tier misconception score was created according to a student's answer to the both the first and the second tiers for each misconception. When a student's answer to both tiers was a misconception as indicated in Appendix B, it was coded as 1; otherwise 0. Misconception all-tier was created based on a student's answer to all tiers for each misconception in Appendix B. When a student's answer to both tiers was misconceptions and when a student was confident about his/her answers, it was coded as 1; otherwise 0.

Results

The PST's test scores on the PNMT showed that they are not competent in understanding the PNM. The percentage of the PSTs who correctly answered all item tiers ranged from 0.9 to 43.3 (Please see Table 1). The maximum score of the PNMT was 9.0 and the minimum score was 0.0. The mean scores of the PNMT were 2.9 with 2.1 standard deviation.

Results showed that the PSTs struggled to provide consistent answers across all tiers. Participants performed well only on two questions: Q1 (90.2%) and Q5 (81.4%) at the first tier. They performed fairly well on five questions: Q3 (54.9%), Q4 (47.9%), Q9 (50.7%), Q12 (61.4%) and Q13 (48.4%) and they performed poorly or very poorly on 12 questions that were on the PNMT. Meaning less than 45% of the participants were able to answer these questions. When participants were challenged to justify their answers in the second tier, even those who performed well on the first tier items, failed to show the same performance.

The percent of students who answered Q1 correctly dropped from 90.2% to 23.3% at the second tier, from 81.4% to 13.5% for Q5. Furthermore, only 19.1% of the participants felt confident about their answers to Q1 and 9.5% about their answers to Q5. Participants' performance on other questions varied; however, this trend among the first tier, second tier, and confidence tier continued to be the same across all questions.

Table 1. Summary of students' performance for the PNMT (%)

Question#	Tier III
Q1	9.3
Q2	10.7
Q3	43.3
Q4	24.7
Q5	13.0
Q6	1.9
Q7	27.4
Q8	0.9
Q9	18.6
Q10	6.9
Q11	18.1
Q12	25.1
Q13	16.7
Q14	7.9
Q15	2.8
Q16	5.6
Q17	7.4
Q18	23.7
Q19	22.3

Participants performed very poorly on nine questions (i.e. Q2, Q6, Q7, Q10, Q11, Q14, Q15, Q16, and Q17, even at Tier I). They performed poorly on six questions (i.e. Q4, Q8, Q9, Q13, Q18 and Q19). No matter how well or how poor students performed on the first tier of the questions, the PSTs did not provide consistent answers across all tiers. The PSTs struggled to justify the responses that they provided in the first tier. Moreover, the majority of the PSTs did not feel confident in their responses. (Please see Table 2 for details).

Table 2. Summary of students' competency across question tiers (%)

Question#	First Tier	Second Tier	Confidence Tier
Q1	90.2	23.3	19.1
Q2	22.3	11.2	7.9
Q3	54.9	46.0	38.6
Q4	47.9	32.6	19.1
Q5	81.4	13.5	9.8
Q6	6.0	2.8	1.9
Q7	37.2	29.3	23.7
Q8	42.3	35.3	25.6
Q9	50.7	22.8	14.4
Q10	21.9	7.9	5.6
Q11	29.8	10.7	16.3
Q12	61.4	31.6	20.5
Q13	48.4	23.7	13.5
Q14	28.4	10.7	6.0
Q15	28.4	7.9	4.7
Q16	19.5	8.4	4.2
Q17	28.4	8.4	5.6
Q18	40.0	28.8	18.6
Q19	42.3	24.2	20.9

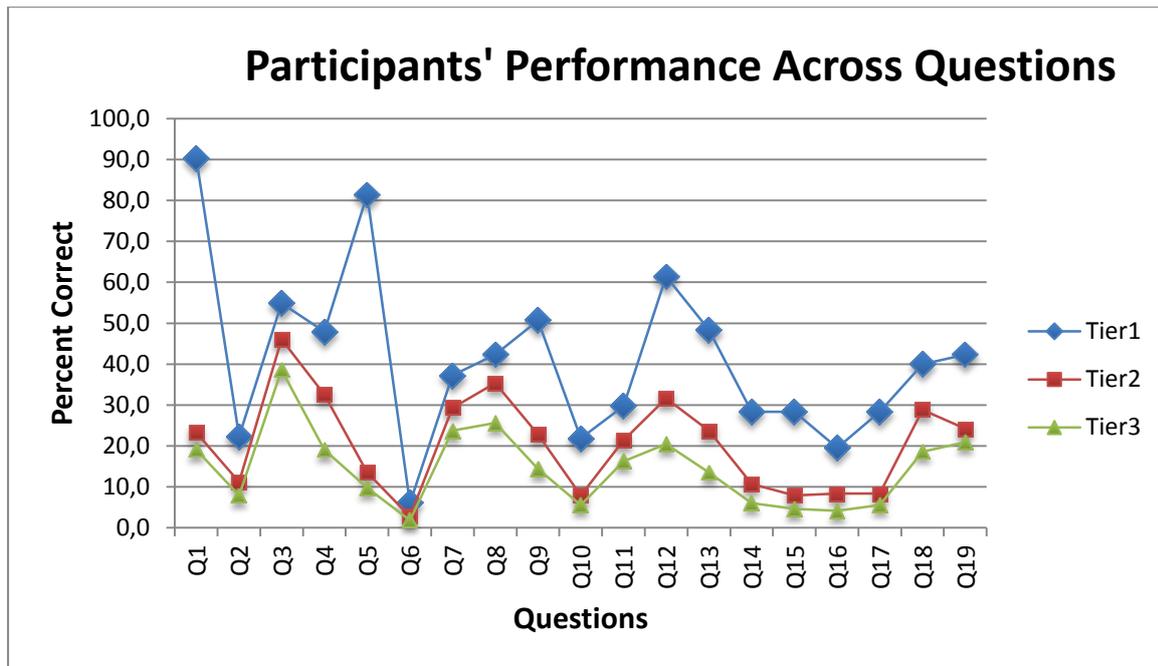


Figure 1. Participant performance across question tiers

Our analyses also revealed that the PSTs held several misconceptions ranging from ‘Vapor or gas has no weight’ to ‘When the gas pressure increases, the weight of the gas also increases’ (see Appendix B). We summarize the prevalence of each of the misconceptions reported in Appendix B for each tier in Table 3. Tan et al. (2002) reported that misconceptions that are selected by at least 10% of the sample could be considered as strongly-held misconceptions. Table 3 shows that there were eight (misconceptions 2, 3, 7, 14, 16, 17, 18 and 20) strongly-held misconceptions.

Table 3. The percentages of misconceptions for the first-tier, both-tier, and all-tier scores

Misconceptions	Percentages of Misconceptions		
	Misconception first-tier	Misconception both-tier	Misconception all-tier
Misconception1	48	11	9
Misconception 2	76	26	24
Misconception 3	45	13	11
Misconception 4	28	1	1
Misconception 5	16	7	5
Misconception 6	20	10	7
Misconception 7	47	23	19
Misconception 8	38	8	5
Misconception 9	37	10	9
Misconception 10	31	6	4
Misconception 11	23	6	5
Misconception 12	30	7	5
Misconception 13	30	7	6
Misconception 14	39	15	12
Misconception 15	14	3	2
Misconception 16	54	20	17
Misconception 17	32	24	20
Misconception 18	34	20	17
Misconception 19	37	4	3
Misconception 20	33	14	10

*Percentages indicate the percentage of sample that held that particular misconception

Discussion and Conclusion

Science educators have investigated students' and teachers' conceptual understanding of various scientific ideas for quite sometimes (Adadan, 2014; Kahveci, 2009; Özmen et al., 2002). Researchers conducting conceptual change studies have identified several misconceptions in different domains of science among students and teachers (Canpolat, 2006; Chinn & Brewer, 1993; diSessa, 2006; Peterson, Treagust, & Garnett, 1986; Songer & Mintzes, 1994; Tytler, 2000). Despite the progress achieved in misconception studies, effective identification of students' misconceptions continues to be an area of concern (Briggs et al., 2006). In this study, we explored the power of a three-tiered assessment in identifying the PST misconceptions related to the PNM.

Exploring the PSTs' misconceptions related to the PNM is important because, the PNM makes up the majority of science curriculum at the elementary school level. Therefore, it is important that the PSTs develop a coherent and scientifically accurate conceptual understanding of the PNM. One way to assure that the PSTs develop such knowledge is by reliably measuring their conceptual understanding of the PNM. In this study, we measured the PSTs' conceptual understanding of the PNM through a three-tier assessment. Three-tier assessments provide more reliable information about students' level of understanding because they force students to justify their answers; thus allowing teachers to judge whether students can support their answers with confidence (Adadan & Savasci, 2012; Chandrasegaran, Treagust, & Mocerino, 2007; Tan et al., 2002; Wang, 2004). The results from this study along with the results reported in similar studies (Odom & Barrow, 1995) confirm this claim.

The PSTs' answers to the three-tier test provided an in-depth understanding of learners' cognitive structure related the structure of matter, thus allowing us to detect the PSTs' misconceptions related to the PNM. The PNMT scores revealed that the PSTs did not have sufficient conceptual understanding of the PNM. Participants showed several misconceptions such as 'Vapor or gas has no weight' and 'When the gas pressure increases, the weight of the gas also increases' in their responses to the PNMT. Moreover, the results showed that the PSTs had some strongly-held misconceptions. Also, regardless of participants' performance on tier I items, they showed inconsistency in their responses for tier II and tier III. That is, they mostly could not provide valid justifications for their responses in tier I and they did not feel confident in their responses to the PNMT items. In short, current research provided evidence for the PSTs' misconceptions of the PNM as well as identifying the way of the PSTs' justifications behind their thinking allowing the science educators to map an effective route to overcome these alternative conceptions.

Recommendations

The majority of the PSTs failed to correctly justify their answers to multiple choice questions asked of them in the first tier. Furthermore, they also failed to show confidence in their responses even when they answered the question correctly. While students can recognize the factual scientific knowledge related to the PNM, they could not elaborate or justify the reasons behind their answers. These findings imply that the instruction that the PSTs receive in their chemistry content courses is not effective. We need to reconsider the ways in which we teach the PSTs fundamental science courses, and adopt student-centered instruction methods that engage students in inquiry-based learning and argumentation. These types of instructional methods are likely to result in better outcomes because they create a context for meaningful learning, engage students in questioning their own and their peers' knowledge, and bring students' ideas under scrutiny (Duschl & Osborne, 2002; Ford & Wargo, 2011) and allow teachers to intervene and address misconceptions or the gaps in students' knowledge (Beeth, 1998).

Another implication of this finding for teacher educators is that the results of multiple-choice questions may not always be a reliable measure of students' conceptual understanding. Three-tier assessments should be incorporated in all assessments throughout the course and not just used for summative purposes. When three-tier assessments are used in midterm exams, the results can guide teacher educators' instructional decisions, at least in countries where teacher educators teach content courses. While the idea of using three-tier assessments in all science courses sounds appealing, such assessments are not easily accessible because science educators have not developed such assessments in the majority of concepts covered in college science content courses. The challenge waiting science educators is to make a concerted effort: 1) to develop three-tier assessments for fundamental science concepts and 2) to encourage and motivate college science educators to use these assessments for both summative and formative purposes. Finally, the prevalence of misconceptions among science PSTs calls for integration of more effective instructional approaches in science content courses. When the PSTs take content courses in the college of arts and sciences, we should build on these misconceptions and

use conceptual change based instructional approaches to explore and address the misconceptions that the PSTs may hold.

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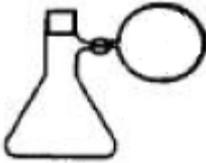
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Appendix A. Sample Questions from the States of Matter Diagnostic Test

1.1



The system shown on the left figure represents a closed flask connected with a balloon and filled with air at 40 °C. If the temperature of the system was decreased from 40 °C to 5 °C, how would the volume of the balloon change? (Atmospheric pressure is 1 atm for both temperatures.)

- A) It would decrease.
- B) It would not change.
- C) It would increase.

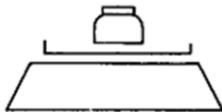
1.2 Which one of the followings is the reason of your answer for the previous question?

- A) If the temperature was decreased, air particles in the system would shrink.
- B) If the temperature was decreased, the pressure in the system would decrease.
- C) If the temperature was decreased, the pressure in the system would increase.
- D) If the temperature was decreased, the distance between air particles would decrease.
- E) Atmospheric pressure is constant.
- F)

1.3 How sure you are about your answers for the previous two questions?

	Unconfident						Confident
Confidence Rating:	1	2	3	4	5	6	7

2.1



Buket weighs a closed jar filled with cold air as shown on the left figure. Then, she exposes the jar to the sun and weighs it again. Buket also knows the weight of the jar after it is vacuumed and subtracts the weight of the container from the weight results of cold and hot air in the jar. What could be said about the weight of cold and hot air in the jar?

- A) The weight of cold and hot air is the same and equal to zero.
- B) The weight of cold and hot air is the same and greater than zero.
- C) Cold air is heavier than hot air.
- D) Hot air is heavier than cold air.

2.2 Which one of the followings is the reason of your answer for the previous question?

- A) Gases are weightless.
- B) If you heat a gas, the particles of the gas expand.
- C) When air is warmed up, it rises up.
- D) When air is cooled down, it becomes dense and its particles get closer to each other.
- E) There is no substance which goes out or goes into the jar.
- F) When a gas is warmed up, the movement and pressure of the gas particles increase and the number of collisions on the walls of the jar increases.
- G) Hot air is more moisturized than cold air.
- H)

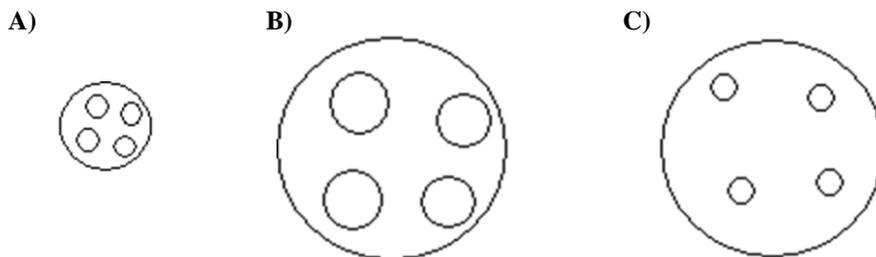
2.3 How sure you are about your answers for the previous two questions?

	Unconfident						Confident
Confidence Rating:	1	2	3	4	5	6	7

3.1



An elastic balloon is filled with helium gas at 15 °C in a room. Then, this balloon is put into another room at 30 °C. The pressures of the rooms are the same. If the picture of the gas particles in the balloon at 15 °C is like the figure shown on the left, which one of the followings shows the picture of the gas particles at 30 °C? (Note: The tensile force of the balloon is omitted. Helium gas particles were shown as “○” in the drawings.)



3.2 Which one of the followings is the reason of your answer for the previous question?

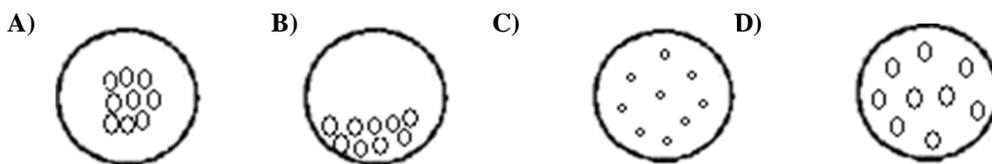
- A) If the temperature increases, the pressure of helium gas in the balloon increases.
- B) If the temperature increases, the distance between helium gas particles increases.
- C) If the temperature increases, helium gas particles expand.
- D) If the temperature increases, the distance between helium gas particles decrease.
- E)

3.3 How sure you are about your answers for the previous two questions?

Unconfident Confident

Confidence Rating: 1 2 3 4 5 6 7

6.1  The figure shown on the left represents a closed steel tank containing hydrogen gas at 20 °C and 3 atm. The balls in the drawings represent the distribution of hydrogen molecules. Which one of the followings represents the distribution of hydrogen molecules if the temperature is lowered to -5 °C? (Note: At -5 °C, hydrogen is still a gas.)



6.2 Which one of the followings is the reason of your answer for the previous question?

- A) If the temperature was decreased, the distance between hydrogen molecules and the volume of the gas would decrease.
- B) If the temperature was decreased, hydrogen molecules would shrink.
- C) If the temperature was decreased, hydrogen molecules would become heavy and sink to the bottom of the tank.
- D) If the temperature was decreased, the movement of hydrogen molecules would slow down and the pressure of the gas would decrease.
- E)

6.3 How sure you are about your answers for the previous two questions?

Unconfident Confident

Confidence Rating: 1 2 3 4 5 6 7

10.1 When an amount of water is boiling, you see bubbles coming from the boiling water. What do you think that the bubbles are made of?

- E) Air
- F) Oxygen gas
- G) Oxygen and hydrogen gas
- H) Water vapor

10.2 Which one of the followings is the reason of your answer for the previous question?

- E) When water evaporates, it breaks into oxygen and hydrogen gas.
- F) There is air in water and bubbles are made of air.

- G) When water evaporates, the distance between water molecules increases.
- H)

10.3 How sure you are about your answers for the previous two questions?

Unconfident Confident

Confidence Rating: 1 2 3 4 5 6 7

12.1 At room temperature (25 °C), there is an open plastic bottle half-filled with water. If this bottle were left for several days in this room, what would happen to the level of water in the bottle? (Note: The humidity in the air should be considered too little.)

- A) The level of water decreases.
- B) The level of water stays the same.
- C) The level of water increases.

12.2 Which one of the followings is the reason of your answer for the previous question?

- A) In order for evaporation to take place, temperature has to be increased.
- B) Water evaporates with its own energy at every temperature.
- C) Water evaporates at or above its boiling point, which is 100 °C.
- D) In order for evaporation to take place, a liquid has to take heat from its environment.
- E) Hot air condenses in the bottle.
- F)

12.3 How sure you are about your answers for the previous two questions?

Unconfident Confident

Confidence Rating: 1 2 3 4 5 6 7

Appendix B . List of Alternative Conceptions

Alternative Conceptions	Item Choices
1. When heated, particles expand; when cooled, they shrink.	(1.1.A, 1.2.A, 1.3.A), (5.1.C, 5.2.B, 5.3.A), (2.1.D, 2.2.B, 2.3.A), (3.1.B, 3.2.C, 3.3.A), (6.1.C, 6.2.B, 6.3.A)
2. In a closed container filled with a gas, when temperature increases/decreases, the gas pressure always increases/decreases.	(1.1.A, 1.2.B, 1.3.A), (5.1.C, 5.2.A, 5.3.A), (3.1.C, 3.2.A, 3.3.A)
3. Hot air is lighter than cold air.	(5.1.C, 5.2.C, 5.3.A), (2.1.C, 2.2.C, 2.2.A), (2.1.C, 2.2.D, 2.3.A), (6.1.B, 6.2.C, 6.3.A)
4. Gas always weighs less than liquid (or solid).	(2.1.D, 2.2.G, 2.3.A), (8.1.B, 8.2.E, 8.3.A)
5. Vapor or gas has no weight.	(2.1.A, 2.2.A, 2.3.A), (8.1.A, 8.2.A, 8.3.A)
6. When the gas pressure increases, the weight of the gas increases.	(2.1.D, 2.2.F, 2.3.A)
7. In a closed container filled with a gas the volume of a gas always decreases when the temperature decreases.	(4.1.A, 4.2.C, 4.3.A), (6.1.A, 6.2.A, 6.3.A)
8. When air is compressed, the particles stick together.	(7.1.C, 7.2.A, 7.3.A), (9.1.A, 9.2.A, 9.3.A)
9. When air is compressed, the particles are all pushed to the end of the syringe.	(7.1.D, 7.2.D, 7.3.A), (9.1.A, 9.2.C, 9.3.A)
10. When air is compressed, the particles change its shape.	(7.1.A, 7.2.B, 7.3.A), (9.1.A, 9.2.B, 9.3.A)
11. When water boils/evaporates, it breaks into its components hydrogen and oxygen molecules.	(8.1.B, 8.2.B, 8.3.A), (11.1.B, 11.2.B, 11.3.A)
12. In order for evaporation to take place, a liquid has to take heat from its environment.	(12.1.B, 12.2.D, 12.3.A), (13.1.B, 13.2.D, 13.3.A)
13. Vaporization starts with boiling.	(12.1.B, 12.2.C, 12.3.A), (13.1.B, 13.2.A, 13.3.A)
14. Condensation or evaporation requires a temperature gradient.	(12.1.B, 12.2.A, 12.3.A), (13.1.B, 13.2.B, 13.3.A), (16.1.A, 16.2.B, 16.3.A)
15. Condensation is when air turns into a liquid.	(12.1.C, 12.2.E, 12.3.A), (13.1.C, 13.2.E, 13.3.A), (16.1.B, 16.2.C, 16.3.A)
16. The cold surface of the closed container and dry air react to form water via the combination of hydrogen and oxygen on the surface.	(14.1.A, 14.2.A, 14.3.A), (16.1.A, 16.2.A, 16.3.A)
17. When water boils and bubbles come up, the bubbles are oxygen and hydrogen, air, or heat.	(10.1.C, 10.2.A, 10.3.A), (10.1.A, 10.2.B, 10.3.A)
18. Boiling liquids at atmospheric pressure have different vapor pressures.	(17.1.C, 17.2.A, 17.3.A), (17.1.B, 17.2.B, 17.3.A)
19. Vapor pressure increases/decreases with height and this cause the water boil at lower/higher temperatures.	(19.1.A, 19.2.D, 19.3.A), (19.1.C, 19.2.E, 19.3.A)
20. At constant temperature, the value of the vapor pressure changes with changes in the volume of the vapor in equilibrium with its liquid and in the amount of liquid.	(15.1.C, 15.2.A, 15.3.A), (15.1.C, 15.2.C, 15.3.A), (15.1.B, 15.2.B, 15.3.A), (18.1.A, 18.2.A, 18.3.A), (18.1.C, 18.2.B, 18.3.A)