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Influence of particle theory concepts on preservice science teachers' understanding of osmosis and diffusion

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Abstract

This study investigated understanding of diffusion, osmosis and particle theory of matter concepts among 192 pre-service science teachers in Saudi Arabia using a 17-item two-tier multiple choice diagnostic test. The results suggested that the pre-service teachers understanding of osmosis and diffusion concepts were relatively highly correlated with their understanding of particle theory concepts, while displaying 18 alternative conceptions related to these topics. The findings suggest that greater time and attention needs to be invested in the teaching of particle theory concepts to pre-service teachers to ensure their correct understanding of diffusion and osmosis concepts so that correct understandings can be passed on from teachers to students.

Keywords: diagnostic test; diffusion; osmosis; particle theory concepts

Introduction

Diffusion, osmosis and the particulate nature of matter are among the most investigated concepts in science (Yager et al. 1994). Science educators agree that these concepts are essential for understanding several phenomena in middle and high school science curricula (Singer et al. 2003; Yeany and Miller 1983; Yezierski and Birk 2006). It is therefore important that pre-service teachers acquire a thorough understanding of these concepts so that any alternative conceptions that they may hold are not passed on to their students when they begin their teaching careers.

Understanding the concepts of osmosis and diffusion, particularly in the life sciences, requires understanding of particle theory concepts. In this study, we have investigated how particle theory concepts influence understanding of osmosis and diffusion among preservice science teachers in Saudi Arabian universities.

Theoretical background

The particulate nature of matter is one of the central concepts in science (Singer et al. 2003; Yezierski and Birk 2006; Yeany and Miller 1983). This theory holds that matter is made up of small particles, too small to be seen, and in constant random motion. In most countries the particulate nature of matter is embedded in the middle school curriculum, that is, for adolescent children aged between 13 and 15 years of age depending on the students' aptitude and class level. However, there is repeated mention in the literature of how this concept is difficult for students to grasp (Singer et al. 2003)

One problem is the confusion that students experience between the macroscopic and submicroscopic behaviours of matter (Othman, et al. 2008). The authors have commented that "…students regard particles as small pieces of an object with all its properties, because they have yet to make the distinction between matter (substance) and objects. In addition, students believe that there is no empty space between particles, that there is 'stuff' between molecules and that molecules are in substances rather than a substance is composed of molecules" (p. 1532).

Another problem area for students regarding the particulate nature of matter relates to changes of state. Students appear to have difficulty understanding the role of particles and changes in their behaviour as a substance changes from gas to liquid and then to solid. Instead of a change in the movement of the particles, the students perceived that more profound changes were occurring. For example, according to Othman et al. (2008) the students believed that the bubbles of boiling water consisted of heat, air, oxygen, hydrogen or steam, with air being the most commonly held view.

In a study on 20 primary school students, Valanides (2000) reported that student teachers "had difficulties to relate the observable macroscopic changes to the invisible molecular changes" (p.249). Yezierski and Birk (2006) studied 719 high school students and found that visualisation difficulties were present in the majority of students when it came to understanding the particulate nature of matter at the microscopic level; they concluded that computer animations could help students visualise the submicroscopic concepts. The research conducted thus far suggests that students hold a range of alternative conceptions about atoms and molecules (Singer et al. 2003). Their alternative conceptions include seeing matter as cloud-like, or seeing matter as something which expands or contracts, with the individual particles expanding and contracting at the same time (Singer et al. 2003). Othman et al. (2008) have referred to studies that suggest that students consider matter to be small portions of a continuous substance; they also found in their studies on the particulate nature of matter that most students believed that there was no empty space between molecules.

The literature reports that the difficulty students have with understanding the concepts of the particulate nature of matter stem from the difficulties that teachers themselves have with the concepts (Yeany and Miller 1983; Singer et al. 2003). As Zuckerman (1993) argued, "they may not have had the opportunity to construct this knowledge because their teachers were unaware of some subtle pieces" (p. 5). There is a problem in that not all teachers understand the content they are teaching (Haslam and

Treagust 1987).

The particulate nature of matter concepts have implications for the understanding of biology concepts as students are better equipped to understand the processes of osmosis and diffusion once the principles of the particulate nature of matter are understood. Diffusion and osmosis refer to the movement of particles in and out of cells and tissues throughout the body. Both processes are vital for ongoing good health and survival of the body. Diffusion is a broader term which refers to the movement of particles from areas of high concentration to areas of lower concentration. However, diffusion involves underlying processes that are random and spontaneous. Many students and teachers misunderstand this aspect of diffusion particularly when it is discussed in relation to the body. According to Garvin-Doxas and Klymkowsky (2008), the response that "*diffusion occurs because of a random event due to thermal motion* was one of the very few responses that acknowledged the role of random molecular motion. The majority (95% of approximately 100) of responses are typified by the other examples, where diffusion is viewed as directional movement that takes place *only* when some kind of gradient exists. There is no apparent appreciation displayed that random processes can give rise to emergent behavior, such as net directional movement of molecules" (p.231). In contrast, osmosis refers to the specific movement of water particles in and out of cells depending on the concentration of salts in the cells. Diffusion and osmosis are taught as part of most high school science curricula.

Some spatial aspects of the theory have been found to be troublesome for students. The body of literature on the teaching and learning of these biological concepts has often mentioned the difficulties that students experience. Abdo and Taber (2009) commented that if students miss this vital stepping stone, they later struggle with the whole field related to molecular biology concepts. Diffusion and osmosis lie at the core of the fundamental knowledge of life sciences (Yager et al. 1994). Johnstone and Mahmoud (cited by Odom and Kelly 2000) found in their study that high school biology students perceived diffusion and osmosis to be among the most difficult topics in biology. Five areas of alternative conceptions were found relating to the students' understanding of the particulate nature of matter. These were concentration, toxicity, life forces, diffusion and the processes of the actions (Odom and Kelly 2000). Odom developed and tested the Diffusion and Osmosis Diagnostic Test in 1995. Diffusion is another concept which is problematic for students of science. Diffusion is the primary method of short distance movement in cells and the greater cellular systems (Odom and Kelly 2000). Osmosis, a biological phenomenon, is a concept based on diffusion of which students need to have an understanding in order understand water intake, water balance in plants and animals, as well as other more physically based concepts such as turgor pressures and transport in living organisms (Odom and Kelly 2000). The issue with misunderstanding diffusion and osmosis, is that when students miss the foundations, understanding more complicated biological processes becomes more difficult (Duit and Treagust 2003; Treagust 2006).

Recently, Tomažič and Vidic (2012) used a modified 12-item version of Odom and Barrow's (1995) two-tier multiple-choice diagnostic test to evaluate 168 first- second- and third-year preservice teachers' understanding of diffusion and osmosis concepts. The study showed that the first- and second-year students had very superficial knowledge of the concepts. In addition, the preservice teachers who were more actively engaged in learning about the concepts in high school, for example by conducting experiments, achieved significantly better test scores.

Objectives of the study

This research aimed to determine the understanding of osmosis, diffusion and particulate theory concepts as well as correlations between understanding of the former two concepts and particle theory concepts among preservice science teachers in Saudi Arabia using modified versions of the two-tier multiple choice diagnostic instrument on osmosis and diffusion (Odom and Barrow 1995) and on chemical bonding and particle theory (Othman et al. 2008). Specifically, this study sought to answer the following research questions:

Research question 1: What is the nature of diffusion and osmosis conceptions among Saudi Arabian pre-service science teachers?

Research question 2: What is the nature of the particle theory of matter conceptions among Saudi Arabian pre-service science teachers?

Research question 3: What are the relationships between Saudi Arabian pre-service science teachers' conceptions of diffusion and osmosis and those of the particulate nature of matter?

Methodology

Research design

This study incorporated a quantitative design (Cohen et al. 2005). Detailed quantitative data were gathered using a diagnostic test to elucidate the preservice teachers’ scientifically understandings as well as their alternative conceptions about diffusion, osmosis and particle theory concepts.

Research sample

The study involved 192 male preservice science teachers from 15 Saudi Arabian teachers’ colleges who were in the second and third year of a 4-year course leading to a bachelor degree in science education. The participants used the same national curriculum in their course. The majority of the pre-service science teachers were from families with earnings in the middle and upper segments of society; commonly listed occupations of respondents' parents were teachers, lecturers, business people, and other skilled white-collar workers.

Research instrument

A 17-item conceptual diagnostic instrument consisting of two-tier multiple-choice items was administered to the preservice teachers who had previously been instructed on osmosis and diffusion. The teachers were also familiar with the particulate nature of matter. Diagnostic instruments consisting of two-tier multiple-choice items have been found to be convenient to administer as paper-and-pencil tests that can be readily marked before being analysed (Treagust 1988, 1995). Several such instruments have been developed and administered involving a variety of science concepts (Treagust and Chandrasegaran 2007). More recently Sesli and Kara (2012) have developed and validated a similar diagnostic instrument to assess high school students' understanding of cell division and reproduction. The *Diffusion, Osmosis and Particle Theory (DOPT) Diagnostic Instrument* consisted of 8 items about diffusion and osmosis concepts and 9 items about particle theory concepts. The contents covered by the items in the *DOPT* diagnostic instrument are summarised in Table 1.

Table1 Contents of the 17 items in the *DOPT* diagnostic instrument

Concepts	Items
Differentiation between osmosis and diffusion	Items 1 and 4
Concentration gradient and amount of solute	Items 2, 3 and 5
Process of osmosis	Item 7
Partially permeable membrane	Item 8
Effect of temperature on solubility	Item 6
Change of state	Items 9, 10 and 11
Process of dissolution	Item 12
Macroscopic and submicroscopic properties	Item 13
Particle arrangement in solids, liquids and gases	Items 14 and 16
Diffusion in gases and liquids	Items 15 and 17

The items on diffusion and osmosis were adapted from a previously-developed instrument by Odom and Barrow (1995), while five of the particle theory items were adopted from Othman, Treagust, and Chandrasegaran (2008) and the remaining four were developed by the last two authors. Examples of an item about diffusion, osmosis and particle nature of matter are provided in Figures 1, 2 and 3, respectively. The complete instrument may be obtained from the second author.

Item 2

During the process of diffusion, particles will generally move from:

A. high to low concentrations.

B. low to high concentrations.

The reason for my answer is:

1. There are too many particles crowded into one area; therefore, they move to an area; with more room.
2. Particles in areas of greater concentration are more likely to bounce toward other areas.
3. The particles tend to move until the two areas are isotonic, and then the particles stop moving.

Figure 1 Example of an item about diffusion from the *DOPT* diagnostic instrument

Item 7

Figure 4 is a picture of a plant cell that lives in freshwater. If this cell were placed in a beaker of 25% saltwater solution, the central vacuole would:

A. increase in size.

B. decrease in size.

C. remain the same.

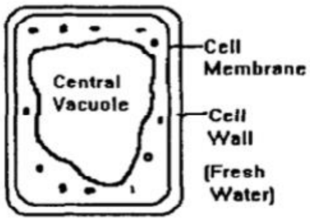


Figure A4.

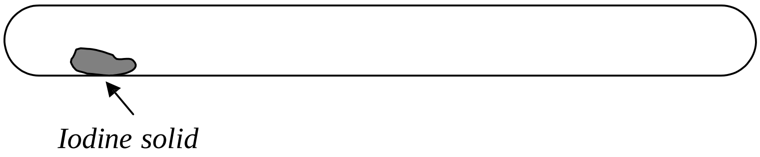
The reason for my answer is:

1. Salt absorbs the water from the central vacuole.
2. Water will move from the vacuole to the saltwater solution.
3. Salt solution outside the cell cannot affect the vacuole inside the cell.

Figure 2 Example of an item about osmosis from the *DOPT* diagnostic instrument

Item 10

1.0g 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 27.0g.



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 27.0g
B. 27.0g
C. more than 27.0g

The reason for my answer is:

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.

Figure 3 Example of an item about particle theory from the *DOPT* diagnostic instrument

The internal consistency of the 17 items in the *DOPT* measured by Cronbach's alpha reliability coefficient was found to be 0.54. This result, however, fell short of Nunnally's (1978) recommended reliability coefficient of 0.60 or greater. One reason for this low value may be attributed to the limited understanding of the items in the instrument.

Results and discussion

Analysis of responses to the Diffusion, Osmosis and Particle Theory (DOPT) diagnostic instrument

A response to each *DOPT* item was considered correct if a pre-service science teacher first selected the correct answer from three or four content options in the first tier and then also selected the most scientifically correct justification from a range of three or four reason options in the second tier. Correctly answered items were scored '1' while incorrect items were scored '0'. The results are summarised in Table 2.

Table 2 Percentages of students who correctly answered the first tier only and both tiers of the items in DOPT diagnostic instrument (N = 192)

Item nos.	Percentage of students correctly answering		Item nos.	Percentage of students correctly answering	
	First tier	Both tiers		First tier	Both tiers
1	93.8	70.5	10	56.8	41.9
2	81.9	64.8	11	55.9	55.9
3	91.6	84.6	12	79.7	52.9
4	72.7	65.2	13	72.2	56.4
5	65.6	57.3	14	88.5	63.0
6	85.9	71.4	15	52.4	52.4
7	68.7	44.9	16	52.9	41.0
8	88.5	73.1	17	70.5	53.3
9	79.7	62.1			

(Note: Items 1-8 are about diffusion and osmosis; Items 9-17 are about particle theory)

The results show that the percentage of students who provided correct responses to the first tier was higher than that of the combined tiers for 15 items. For the remaining two items (Items 11 and 15) these percentages were the same. The former trend suggests limited understanding of the concept involved as the students were not able to provide a justification for their selection in the first tier.

Comparing responses to items related to osmosis and diffusion (8 items) with items related to particle theory (9 items)

In the items involving osmosis and diffusion (Items 1 – 8), the percentage of students who provided correct responses to both tiers of the items ranged from 64.8% to 84.6% for six of the eight items. For the remaining two items (Items 5 and 7) the correct responses to both tiers were 44.9% and 57.3%, respectively. However, of the nine items on particle theory, the percentage of students who provided correct responses to both tiers of the items ranged from 62.1% to 63.0% in only two instances (Items 9 and 14). This range of correct responses to both tiers was less than that for the items on osmosis and diffusion. For the remaining seven items on particle theory the percentage of correct responses to both tiers of the items ranged from 41.0% to 56.4%.

Correlations between correct responses to both tiers of the items on diffusion and osmosis with the items on particle theory

Associations between students' understanding of osmosis and diffusion concepts and particle theory concepts were determined by computing the Pearson product-moment correlations. The correlations between the scores were highly positively correlated with a value of 0.42 ($p < 0.01$), suggesting that the scores on osmosis and diffusion items increase with the scores on particle theory items. Hence, it is vital that students have good understanding of particle theory concepts to be able to better understand osmosis and diffusion concepts.

Alternative conceptions on diffusion and osmosis

Six major alternative conceptions about diffusion and osmosis concepts that were held by more than 10% of the preservice teachers were identified in the analysis (Peterson, Treagust & Garnett, 1989). A cut off figure of 10% was selected to ensure that no alternative conceptions were omitted. These alternative conceptions are summarised in Table 3.

Table 3 Alternative conceptions about diffusion and osmosis concepts identified in the study (N = 192)

No.	Alternative conceptions	Item no.	Choice combination	% of preservice teachers
1.	Diffusion cannot occur without the presence of a semi-permeable membrane.	1	B1	14.1
2.	The movement of particles between two solutions stops when the concentrations of the solutions become equal.	2	A3	10.6
3.	When a small amount of soluble solid is added to water without stirring, the solution at the bottom will become more concentrated after some time because the denser solute particles sink to the bottom.	4	A2	18.5
4.	After a substance has evenly diffused through water, the molecules of the substance stop moving.	5	A1	21.6
5.	Diffusion of a substance in water occurs faster at a higher temperature because the substance is more stable at high temperatures.	6	B1	11.0
6.	The vacuole of a plant cell placed in salt solution decreases in size because the salt absorbs water from the vacuole.	7	B1	21.6

Diffusion/concentration gradient and amount of solute (Items 2 and 5)

In this study, pre-service teachers' ability to determine that diffusion is the best explanation of the random interaction of particles was limited (as measured by each of items 2 and 5). For example, only 64.8% of them provided the correct answer for Item 2, which is related to the process of diffusion of particles moving from a higher concentration to a lower concentration as the result of random interaction of particles.

The most common alternative response for Item 2 may have resulted from a misunderstanding about the terminology used. For example, many of the preservice teachers selected "particles generally move from high to low concentrations because they tend to move until the two areas are isotonic and then stop moving altogether". In this case, preservice teachers might have memorised the prefix *iso*, to mean *the same thing* and thus interpreted this item to mean that particles would continue to move until they are of the same concentration throughout. for Item 5, 21.6% of them made their selections that indicated they believed that "After a substance has evenly diffused through water, the molecules of the substance stop moving".

Differentiating between osmosis and diffusion (Items 1and 4)

The preservice teachers' understanding of the process of diffusion was assessed through two items. In Item 1, a single drop of blue dye was placed in a container of clean water. Over time the dye became evenly distributed throughout the water. In total, 70.5% of the preservice teachers selected the correct answer combination, that is, the process responsible for the dye becoming evenly distributed throughout the water is the movement of particles between regions of different concentrations. The most common alternative conception for the phenomenon was displayed by 14.1% of respondents who suggested that "the lack of a membrane means that osmosis and diffusion cannot occur".

In Item 4, a small amount of sugar was added to a container of water that was allowed to stand for one to two hours without stirring. The correct response combination was: "the sugar molecules will be evenly distributed throughout the container because there is movement of particles from a high to a low concentration". In this case, the most common alternative conception, held by 18.5% of respondents, was that "the sugar molecules will be more concentrated on the bottom of the container" because "the sugar is heavier than water and will sink".

Effect of temperature on solubility (Item 6)

This concept was assessed by Item 6 which considered the effect of temperature on molecules. The majority of pre-service teachers (71.4%) selected the correct answer combination that "if a drop of green dye is added to beakers with equal amounts of clear water at two different temperatures (beaker 1: 25°C and beaker 2: 35°C), beaker 2 becomes light green first because the dye molecules move much faster at a higher temperature". Eleven percent of the preservice teachers held the conception that diffusion of a substance in water occurs faster at a higher temperature because the substance is more stable at high temperatures.

Process of osmosis (Item 7)

The process of osmosis in a plant cell was evaluated utilising Item 7. It showed a picture of a plant cell normally living in fresh water that was placed in 25% salt-water. Students were asked to determine what would happen to the size of the central vacuole of the cell as a result of immersing in saline. The correct response was that “the central vacuole would decrease in size because the water will move from the vacuole to the salt water solution”. Only 44% of the preservice teachers gave the correct combination for the answer to Item 7. The most common alternative conception was that, “salt absorbs water from the vacuole” as indicated by 21.6% of respondents.

Alternative conceptions on particle theory

Many more alternative conceptions (12) about particle theory concepts that were held by more than 10% of the preservice teachers were identified in the analysis. These alternative conceptions are summarised in Table 4.

Table 4 Alternative conceptions about particle theory concepts identified in the study (N = 192)

No.	Alternative conceptions	Item no.	Choice combination	% of preservice teachers
1.	The bubbles in boiling water contain the gases hydrogen and oxygen that are produced by the decomposition of water molecules.	9	A1	15.0
2.	Heat energy is absorbed by boiling water and released as bubbles.	9	B2	11.0
3.	The mass of a substance in the gaseous state is less than that of an equal amount of the same substance in the solid state.	10	A1	20.7
4.	The mass of a given amount of a solid increases in the gaseous state because the particles have become more widely-spaced.	10	C3	14.1
5.	Water vapour consists of hydrogen and oxygen molecules.	11	A2	10.1
6.	When crystals of a soluble substance are added to water, the molecules of the solid absorb heat from the surroundings and melt before diffusing throughout the water.	12	A1	19.4
7.	When crystals of a soluble substance are added to water, the solid dissolves only on stirring to break up the solid into smaller particles.	12	B3	16.3
8.	A single atom of an element exhibits the same properties as the element itself.	13	A1	12.8
9.	States other than solids do not have strong attractive forces holding the particles together.	14	B4	14.1
10.	The molecules of a dense gas will sink rapidly to the bottom of the container in a partial vacuum because the particles are heavy.	15	A2	12.8
11.	When a gas is compressed the volume and mass of the gas decrease because the molecules of the gas become compressed.	16	A2	11.0
12.	A liquid that is miscible with water but denser than water will not diffuse uniformly because the heavier particles will sink to the bottom.	17	B2	19.8

Change of state (Items 9 and 11)

Items 9 and 11 revealed alternative conceptions regarding changes of state: 15% of respondents believed that "the bubbles in boiling water contain the gases hydrogen and oxygen that are produced by the decomposition of water molecules" and 11% held the belief that "heat energy is absorbed by boiling water and released as bubbles". In the case of evaporation in Item 11, 10.7% of respondents believed that oxygen and hydrogen molecules are produced in the vapour.

Dissolving (dissolution) (Item 12)

Two alternative conceptions were identified from the preservice teachers' answers to Item

12 relating to the dissolving process. This result indicated that the preservice teachers had not clearly understood this concept. Nine preservice teachers (19.4%) held the conception that when sugar dissolves, “it melts forming a liquid that mixes with water”. Another alternative conception identified among the preservice teachers was that “sugar only dissolves when stirred as stirring causes the crystals to break into smaller particles that will spread in the water and can no longer be seen” (16.3% of respondents).

Macroscopic and submicroscopic properties (Item 13)

The most common alternative conception that was identified regarding Item 13 was that “a single atom of an element exhibits the same properties as the element itself when in fact the properties are determined by the interaction between individual particles of the element” (12.8% of respondents).

Particle arrangement in solids, liquids and gases (Items 14 and 16)

The preservice teachers’ overall performance in Items 14 and 16 indicated that they had not yet acquired sound understanding of the arrangement of particles in matter. In the case of Item 14, the most common alternative conception identified was that “states other than solids that do not have strong attractive forces holding the particles together” (held by 14.1% of respondents). For Item 16 the most common alternative conception was that “when a gas is compressed the volume and mass of the gas decrease because the molecules of the gas become compressed” (11% of respondents).

Diffusion in gases and liquids (Item 15)

The concept of diffusion in gases and liquids was evaluated by Item 15. Only 52.4% of the respondents chose the correct combination. The most common alternative conception was that the molecules of a dense gas will sink rapidly to the bottom of the container in a partial vacuum because the particles are heavy.

Conclusion and implications

The results indicate that based on the first tier of the *DOPT* diagnostic test alone, the preservice science teachers possessed better understanding of diffusion and osmosis concepts compared to the particle theory of matter concepts. When responses to both tiers were considered, there was further support for stronger understanding that preservice teachers had on diffusion and osmosis concepts compared to those of the particle theory of matter. Also, there were fewer alternative conceptions regarding diffusion and osmosis compared to the particle theory of matter, for which multiple alternative conceptions were found to exist (e.g. in Items 9, 10, 12). The results suggest that the preservice science teachers in general experienced difficulty in understanding the principles of the particle theory of matter. Hence, priority needs to be given to instruction about the particle theory of matter as inaccurate understandings of these principles are most likely to be passed on from teachers to students if not addressed at the preservice stage.

With respect to research question 1 (What is the nature of diffusion and osmosis conceptions among Saudi Arabian pre-service science teachers?), The *DOPT* two-tier diagnostic instrument revealed that the preservice teachers' understanding of diffusion and osmosis was satisfactory with only six alternative conceptions identified in the eight items. The best performance was in Item 3 where 84.6% correctly answered both tiers of the item about diffusion and osmosis. Item 5 on diffusion and osmosis was the most difficulty for the preservice teachers with only 57.3% answering it correctly.

The results indicated that based on the first tier alone of the *DOPT* diagnostic test, the preservice science teachers had better understanding of diffusion and osmosis concepts than of particle theory of matter concepts. When responses to both tiers were considered, there was further support for their better understanding of diffusion and osmosis concepts than of particle theory concepts.

Referring to research question 2 (What is the nature of particle theory of matter conceptions among Saudi Arabian pre-service science teachers?), the responses to the items in the diagnostic instrument revealed that the preservice science teachers' understanding of particulate theory of matter concepts was unsatisfactory. For example, while for Item 13, 56% of the preservice teachers were able to answer both tiers correctly, while only 41% were able to do so for Item 16.

To answer research question 3 (What are the relationships between Saudi Arabian pre-service science teachers' conceptions of diffusion and osmosis and those of the particulate nature of matter?), a correlation analysis indicated that the preservice teachers' understanding of diffusion and osmosis concepts correlated highly with their understanding of particle theory concepts. The results highlighted that the preservice teachers had a better understanding of diffusion and osmosis than of particle theory concepts which they had difficulty in understanding. Hence, priority needs to be given to instruction in particle theory of matter as inaccurate understandings of these principles are most likely to be passed on from teachers to students if not addressed at the preservice stage of teacher education.

The research was subject to a number of limitations. First, it was not ascertained whether or not all the concepts and principles that were covered in the *DOPT* diagnostic test were included in the preservice science teaching curriculum. Second, the sample size of 192 is considerably smaller than that of comparable studies. For example, in the study by Othman et al. (2008) on students' understanding of the particulate nature of matter and chemical bonding in Singapore, data were obtained from 260 respondents. Likewise, the sample size in this study was also much smaller than that the 915 respondents in the study by Tan et al. (2012) on Singapore students' understanding of qualitative analysis concepts.

Third, there is likelihood of the high demands that are placed by multiple-choice items on the reading/comprehension skills (Taber 1999) of the preservice teachers. Finally, the interpretation of the translated version of the *DOPT* diagnostic instrument could have skewed results for two reasons. First, even though the overall document was translated into Arabic, there were a number of English terms that were retained in the Arabic version. These terms were limited to isolated words and phrases directly related to and in close proximity to the diagrams on the test that could not be changed. Nonetheless, even though it may be worthwhile to mention that the preservice teachers who completed these tests in teacher colleges in Saudi Arabia were third and fourth year college students and were presumably familiar with the English terms, the presence of these English terms in the diagrams may have had a negative impact on their understanding. The second reason that interpretation of the translated version of the assessment instrument could have skewed results was that inconsistencies could have resulted during the translation process. The need for accurate use of vocabulary in science instruction is very important. The procedure in this research involved the diagnostic instrument to be translated from English to Arabic, and then back translated from Arabic to English to identify areas where there might have been inconsistencies in translation. Although the researcher did not identify significant areas of inaccurate or ambiguous translation, the existence of slightly different meanings for each word would have undoubtedly affected the respondents’ word-by-word understanding. The diagnostic instrument is highly dependent on the selection of chunks of words and phrases which indicate the best answer. Therefore, the results need to be viewed with some caution.

In conclusion, the findings of this study involving preservice Saudi Arabian science teachers' understanding of diffusion, osmosis and particle theory concepts have provided useful guidelines for improving the science education curriculum of preservice teachers in Saudi Arabia. It is anticipated that the dissemination of these findings will encourage academics in Saudi Arabia to extend this study to other topics in the curriculum. The findings from these studies would serve as a valuable component of workshops for the purpose of enhancing the pedagogical content knowledge of science instructors from teachers' colleges.

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