Teachers' understanding of the particulate nature of matter: The case of Zambian pre-service science teachers

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Abstract

This study assessed Zambian Junior High School pre-service science teachers' understanding of the particulate nature of matter. A sample comprised 30 pre-service science teachers at a teacher training college. Data was collected through a questionnaire adopted from Ozmen and Kenan (2007). Results show that most teachers had correct views on the effect of phase change on speed, spaces and number of particles in a substance. However, most pre-service teachers had poor understanding about the effect of phase change, cooling and heating on the size of the particles in a substance. Most pre-service teachers erroneously believed that when a substance is cooled it contracts because the sizes of its particles decrease, and when a substance is melting the size of its particles increase. Results have implications on science teaching and learning and teacher education.

Keywords: Pre-service teacher, science, matter, understanding, particle

Introduction

Research studies on chemistry conceptual knowledge indicate that both teachers and students do not have sound understanding of some fundamental concepts that form the basis of the discipline such as atoms and molecules (Nakhleh, Samarampungavan & Saglam, 2005), conservation of matter and chemical equations (Haidar, 1997), chemical equilibrium (Bergquist, & Heikkinen, 1990), particulate nature of matter (Gabel, Samuel & Hunn, 1987; Nakhleh, et al., 2005), chemical bonding (Nicoll, 2001; Ozmen, 2004) and electrochemistry (Sanger &

Greenbowe, 1997). However, the particulate nature of matter stands out to be one of the most difficult concepts for teachers and students to understand (Gabel, Samuel, & Hunn, 1987; Valanides, 2000a; Valanides, 2000b; Nakhleh, Samarampungavan & Saglam, 2005; Ozmen & Kenan, 2007). Yet, the particulate nature of matter provides a basis for understanding the invisible microscopic events underlying natural phenomena (Valanides, 2000b). As such, there is a consensus among chemistry educators that the particulate nature of matter is fundamental to understanding other chemical concepts (Tsai, 1999; Boz, 2006; Yilmaz, & Alp, 2006). For example, teachers or students with poor knowledge about the particulate nature of matter are likely to have difficulties to understand kinetic theory of matter, chemical kinetics, and phase changes.

Several studies have examined and reported students' and teachers' knowledge about the particulate nature of matter. For example, Boz (2006) reported that middle and high school students had difficulties in applying the particulate nature of matter theory to explain phase changes, even after instruction. Similarly, Ozmen and Kenan (2007) found low levels of understanding about the microscopic properties of matter among students in grades 4 to 6. Nakhleh et al. (2005) compared middle school students' ideas about the particulate nature of matter to those of elementary school students. The results showed that most middle school students knew that matter was composed of atoms and molecules and some of them were able to apply this knowledge to explain phase transitions of matter. In contrast, most elementary students did not know that matter was composed of particles such as atoms and molecules. Similarly, a study conducted by Ayas, Ozmen, & Calik, (2010) showed that tertiary level students had a better understanding of the particulate nature of matter than secondary level students.

Research results reported by Nakhleh et al. (2005) and Ayas et al. (2010) summarized above suggest that students' understanding of the particulate nature of matter increase with educational level because students in higher grades demonstrated more knowledge about the particulate nature of matter than those in lower grades. However, Liu and Lesniak (2006) argued that the progression of students' conceptions on matter from lower grades to high school is not automatic but it is multifaceted process, suggesting that there are other factors involved other than the level of education.

Research studies on pre-service teachers' conceptions of the particulate nature of matter have provided evidence that teachers' difficulties on this topic are similar to those displayed by middle and high school students. For example, Gabel et al. (1987) investigated prospective elementary teachers' views about the particulate nature of matter using a test item, in which atoms and molecules of matter were drawn to represent the solid state. These teachers were asked to draw the particles after the solid had melted and became a liquid. The results revealed that many teachers did not conserve the number of particles, suggesting they displayed lack of knowledge about conservation of atoms or molecules. Another misconception Gabel et al. identified among the pre-service teachers was that the diagrams of the atoms got larger as matter changed from liquid to gas state, suggesting that the particles increased in size due to the physical change. In a similar study, Valanides (2000a) studied primary student teachers' understanding of the particulate nature of matter and its transformations during dissolving. Valanides found that a majority of the student teachers exhibited perceptual rather than conceptual understanding of the particulate nature of matter and they had difficulties to relate the observable macroscopic changes to the invisible molecular events such as arrangement and movement of molecules. Haidar, (1997) investigated Yemen's prospective teachers understanding of conservation of atoms and mass, the mole, atomic mass, and balancing chemical equations. The results showed that most prospective teachers depended on memorization of the concepts without meaningful understanding of the concepts. In a separate study, Valanides (2000b) investigated pre-service teachers' understanding of the macroscopic and microscopic changes which would occur when different water solutions were distilled. The results showed that majority of the pre-service teachers exhibited limited understanding of the particulate nature of matter and the connection between the observable macroscopic changes and the way molecules in solutions and vapor moved in relation to one another and how they are held together. Valanides also reported that some pre-service teachers attributed the expansion of a liquid to the expansion of the molecules themselves and were unable to differentiate chemical from physical transformations.

Although several studies have been done on the particulate nature of matter, it is evident in the literature that most of these studies have mainly focused on teachers and students in Europe (Valanides, 2000a, 2000b), Asia (Haidar, 1997; Ozmen & Kenan, 2007, Tsai, 1999; Boz, 2006; Yilmaz & Alp, 2006; Ayas et al., 2010), and USA (Gabel, Samuel, & Hunn, 1987; Gabel, 1993). Very little is known about the

African science teachers' and students' understanding of the particulate of nature of matter. For example, during our literature review we only located one study that examined South African secondary school pre-service science teachers' and Nigerian high school students' conceptions of nature of matter (Onwu & Randall, 2006). In recent times, Harrison and Treagust (2002) also recommended for more research at senior and post-secondary level that would inform practice. As such, there is need for more research on populations that little is known about their knowledge about the particulate nature of matter. In particular, no study has explored Zambian teachers' and students' understanding of the particulate nature of matter. Thus, such research has become necessary in the Zambian context. Therefore, the purpose of this study was to assess Zambian junior high school science pre-service teachers' understanding of the particulate nature of matter. In particular, we assessed the pre-service science teachers' knowledge about effect of phase change, cooling, heating and compression on the size of particles, spaces between particles, speed of particles, and number of particles in a substance.

In Zambia, science is a mandatory subject to all students from grades 1 (elementary school level) to 12 (high school level). From grades 1 to 9 students take general science subject that comprise of chemistry, earth science, biology and physics concepts and skills. The most common instructional mode in science classrooms is structured inquiry-based teaching where students are provided with detailed laboratory instructions but not the answer. The particulate nature of matter cuts across general science, chemistry, physics and biology subjects. The topic matter is first introduced elementary grades. The details on structure of matter are taught in middle and high schools. At high school level, the particulate nature of matter is dealt with in different chemistry and physics lessons. The concepts on structure of matter taught in school form a basis for learning other chemical and physics concepts at tertiary level of education. Therefore, pre-service science teachers' sound understanding of the particulate nature of matter is important if they have to teach correct aspects of matter and other scientific concepts to their students.

This study is desirable, not only to Zambian science teacher educators but also to science educators elsewhere, who have a similar school science curriculum and teacher education program. It was also anticipated that the findings of this study would provide some implications for science teaching, learning and science curriculum design in teacher education where this study was conducted.

Methodology

Sample

A sample of this study consisted of 30 Junior high school pre-service science teachers at a teachers training college in Zambia. There were 15 female and 15 male pre-service science teachers. All the participants were training to teach general science, composed of physics, chemistry, earth science and biology concepts and skills, at Junior high school level, from grades eight to nine. All the participants had taken physics, biology, and chemistry subjects for three years at high school (i.e. grades 10-12) before entry into the teacher education program. These three science courses are mandatory in Zambian high schools. Participants were in the first year of the three-year teacher education program. The teacher education program requires the pre-service teachers to take content courses in biology, physics and chemistry. In addition to these content courses, pre-service teachers take science teaching methods, educational psychology, sociology of education, and history and philosophy of education courses. Pre-service teachers do their teaching practice (student teaching) in public schools twice in three years of the teacher education training program. The first teaching practice is done in the second year and the second teaching practice is done in the third year of their training program. Each teaching practice is one school term (about 4 months) long. During the teaching practice pre-service teachers are mentored by experienced science teachers. Lecturers from the teacher training college also assess pre-service teachers' performance during teaching practice through lesson observations.

Data Collection Instrument and Analysis

Data was collected using a questionnaire that was developed by Ozmen and Kenan (2007). The questionnaire had 36 items related to changes of microscopic properties of a solid, liquid, and gas after phase changing, cooling, heating, and compressing. The four microscopic properties investigated were size of particles, spaces between particles, speed of particles, and number of particles. Participants had three alternative answers to choose from about what happens to size of particles, spaces between particles, speed of particles, and number of particles in a substance after phase changing, cooling, heating, and compressing – increase (I), decrease(D), or constant(C). As you can see in Tables 1-3 in the results section, items 1 to 4 focused on melting a solid, 5 to 6 on freezing a liquid, 9 to 12 on vaporizing a liquid, 13 to 16 on condensing a gas, 17 to 20 on heating matter, 21 to 24 on cooling matter, 25 to 28 on compressing a solid, 29 to 32 on compressing a liquid, and 33 to 36 on compressing a gas. Data was analyzed by coding participants' responses (increase, decrease or constant) on each item. Then, the number of participants choosing each of the three possible responses was converted into a percentage.

Results

Effect of Phase Change on Size, Speed, Number and Spaces between Particles

Solid melting: Table 1 below shows that most pre-service teachers correctly believed that spaces between particles (83.3%) and speed of the particles (93.1%) increase when a solid is melted. They also correctly viewed that the number of particles remain constant when a solid is melted (62.1%). In contrast, 89.7% of the pre-service teachers exhibited poor understanding of the effect of melting on size of particles. For example, 48.3% of the teachers erroneously subscribed to the idea that the size of particles increase when a solid is melted while 41% said the size of particles decrease when a solid is melted. Only 10.3% said the size of particles remain constant when a solid is melted.

Table 1: Percentage of Responses on Effect of Phase Change

Physical Change	*Items*		*I*	*D*	*C*
Melting	1	Size of particles when a solid is melted	48.3	41.4	**10.3***
	2	Spaces between the particles when a solid is melted	**83.3***	10.0	6.7
	3	Speed of the particles when a solid is melted	**93.1***	00.0	6.9
	4	Number of particles when a solid is melted	10.3	27.6	**62.1***
Freezing	5	Size of particles when a liquid freezes	26.6	46.7	**26.7***
	6	Spaces between the particles when a liquid freezes	13.8	**86.2***	0
	7	Speed of the particles when a liquid freezes	3.6	**82.1***	14.3
	8	Number of particles when a liquid freezes	20.7	17.2	**62.1***

Vaporizing	9 10 11 12	Size of particles when a liquid is vaporized Spaces between the particles when a liquid is vaporized Speed of the particles when a liquid is vaporized Number of particles when a liquid is vaporized	34.5 **80.0*** **89.3*** 6.9	48.3 13.3 3.6 37.9	**17.2*** 6.7 7.1 **55.2***
Condensing	13 14 15 16	Size of particles when a gas is condensed Spaces between the particles when a gas is condensed Speed of the particles when a gas is condensed Number of particles when a gas is condensed	25.0 13.8 17.2 10.3	39.3 **82.8*** **75.9*** 24.2	**35.7*** 3.4 6.9 **65.5***

*% of correct responses; I=increase; D= decrease; C= constant

Liquid freezing: As shown in Table 1 above, most pre-service teachers correctly agreed that the spaces between particles (86.2%) and the speed of the particles (82.1%) decrease when a liquid is frozen. However, this is not always true for water at below 4°C where ice start expanding resulting into increased spaces between its molecules. Most pre-service teachers (62.1%) also held a scientifically correct idea that the number of particles remain constant when a solid is frozen. However, almost half of the participants (46.7%) erroneously believed that the size of particles decrease when a liquid is frozen, and only about a quarter of them (27%) correctly indicated that the size of particles remain constant when a liquid is frozen.

Liquid vaporizing: Table 1 shows that most pre-service teachers had a scientifically correct understanding of what happens to the spaces between particles (80%), speed of the particles (89.3%) and the number of particles (55.2%) when a liquid is vaporized. On the other hand, most pre-service teachers erroneously believed the particle size decrease (48.3%) or increase (34.5%) when a liquid is vaporized.

Gas condensing: Table 1 below shows that most pre-service teachers held a scientifically correct idea that space between particles (82.8%) and speed of the particles (75.9%) decrease when a gas is condensed. Furthermore, more than half of the pre-service teachers (65.5%) also correctly indicated that the number of particles remain constant when a gas is condensed. However, some pre-service teachers erroneously believed that when a gas is condensed the size of particles increase (25%) or decrease (39.3%).

Effect of heating, and cooling on Size, Speed, Number and Spaces between particles

Heating matter: Table 2 below shows that most pre-service teachers had scientifically correct views about spaces between the particles (76.7%), speed of the particles (80.0%), and number of particles (70.0%) when matter is heated. Very few teachers (17.9%) correctly indicated that the size of particles remain constant when matter is heated. Majority of the pre-service teachers (71.4%) erroneously believed that the size of particles increase when matter is heated.

Table 2: Percentage of Responses on the effect of Heating and Cooling

	Items		I	D	C
Heating	17	Size of particles when matter is heated	71.4	10.7	**17.9***
	18	Spaces between the particles when matter is heated	**76.7***	16.7	6.6
	19	Speed of the particles when matter is heated	**80.0***	16.7	3.3
	20	Number of particles when matter is heated	20.0	10.0	**70.0***
Cooling	21	Size of particles when matter is cooled	20.7	58.6	**20.7***
	22	Spaces between the particles when matter is cooled	7.9	**80.6***	11.5
	23	Speed of the particles when matter is cooled	6.7	**83.3***	10.0
	24	Number of particles when matter is cooled	24.1	13.8	**62.1***

*% of correct responses; I=increase; D= decrease; C= constant

Cooling matter: As shown in Table 2 above, most pre-service teachers correctly indicated that both the speed of the particles (83.3%) and spaces between particles

(80.6%) decrease when matter is cooled. They also correctly indicated that the number of particles remain constant (62.1%) when matter is cooled. As such, majority of the pre-service teachers exhibited sound views on the effect of cooling on the number of particles, spaces between particles and speed of the particles in a substance. However, teachers displayed poor knowledge on the effect of cooling on the size of particles as most of them indicated that the size of particles increase (20.7%) or decrease (58.6%) when matter is cooled.

Effect of Compression on Size, Speed, Number and Spaces between particles

Compressing a solid: As shown in Table 3 below, most of the pre-service teachers had scientifically correct views on the effect of compressing a solid on the four microscopic aspects of matter. For example, 57.1% said the size of particles remains constant and 73.3% said the number of particles remain the same when a solid is compressed. They also correctly believed that the speed of the particles decrease (51.7%) when a solid is compressed. Most pre-service teachers (66.7%) believed the spaces between the particles decrease when a solid is compressed. This implies that this group of teachers believed a solid can be compressed and the speed of its particles will decrease when it is compressed because such physical change will result into more reduction in spaces between particles. It is scientifically correct to say that most solids can be compressed, though the extent to which they can be compressed varies from substance to substance, and is often minute. As such, students in lower grades are likely to be taught or read in science textbooks that solids can't be compressed. On the other hand, students in advanced college science courses, including those offered in teacher education programs, are likely to learn that solids can also be compressed. As such, teachers are expected to know that solids are compressible.

Table 3: Percentage of Responses on Compressing a Solid, Liquid and Gas

		Items	*I*	*D*	*C*
Solid	25	Size of particles when a solid is compressed	28.6	14.3	**57.1***
	26	Spaces between the particles when a solid is compressed	3.3	**66.7***	30.0
	27	Speed of the particles when a solid is compressed	24.1	**51.7***	24.2
	28	Number of particles when a solid is compressed	10.0	16.7	**73.3***

Liquid	29	Size of particles when a liquid is compressed	3.4	34.5	**62.1***
	30	Spaces between the particles when a liquid is compressed	16.7	**80.0***	3.3
	31	Speed of the particles when a liquid is compressed	46.7	**43.3***	10.0
	32	Number of particles when a liquid is compressed	7.1	21.5	**71.4***
Gas	33	Size of particles when a gas is compressed	30.0	26.7	**43.3***
	34	Spaces between the particles when a gas is compressed	20.0	**66.7***	13.3
	35	Speed of the particles when a gas is compressed	40.0	**46.7***	13.3*
	36	Number of particles when a gas is compressed	6.6	26.7	**66.7***

*% of correct responses; I=increase; D= decrease; C= constant

Compressing a liquid: Table 3 above shows that most pre-service teachers correctly believed the spaces between particles decrease (80.0%) when a liquid is compressed. They also held correct views on size of particles (62.1%) and number of particles (71.4%) remaining constant when a liquid has been compressed. On the other hand, they had an erroneous idea about the effect of compression on the speed of particles when a liquid is compressed. About 47% believed the speed of particles increase when a liquid is compressed.

Compressing a gas: As shown in Table 3 above, most pre-service teachers held correct views on spaces between particles, and number of particles when a gas is compressed. Most pre-service teachers agreed that the spaces between particles decrease (66.7%), the number of particles remain constant (66.7%), and speed decrease (46.7%) when a gas is compressed. On the other hand, 20% of the pre-service teachers believed the speed increase when a gas is compressed. Furthermore, 56.7% subscribed to an erroneous idea that the size of particles increase (30%) or decrease (26.7%) when a gas is compressed. Only 43.3% said the size of particles remain the same when a gas is compressed.

Discussion

The purpose of this study was to assess Zambian Junior High School pre-service science teachers' understanding of the particulate nature of matter. The results of this study show that most pre-service science teachers had good understanding about the number of particles, spaces between particles, and speed of particles when matter has been heated, melted, condensed, frozen, cooled, vaporized or compressed. This group of teachers also exhibited sound knowledge about the effect of compression on the size of particles as most of them correctly believed that the size of particles remain the same when a solid, liquid is compressed. However, less than half believed the size of particles remain the same when a gas is compressed. These findings are opposite of those reported in previous research studies (Gabel, Samuel, & Hunn, 1987; Valanides, 2000a; Valanides, 2000b; Nakhleh, Samarampungavan & Saglam, 2005; Boz, 2006; Yilmaz & Alp, 2006; Ozmen & Kenan, 2007). For example Ozmen & Kenan (2007) and Valanides (2000a) reported low levels of understanding of these aspects of particulate nature of matter among students and pre-service teachers, respectively. This group of Zambian pre-service science teachers' better understanding of these four microscopic aspects of particulate nature of matter may be attributed to a longer period of instruction in chemistry and physics at high school level, grades 10-12. Chemistry and physics are among the compulsory subjects in Zambian national high school curriculum. Furthermore, the pre-service teachers took chemistry, physics, and biology courses in teacher education program before responding to a questionnaire for this study. However, we are making this attribution with caution because such a claim does not seem to be consistent with one previous study. For example, Boz (2006) reported that students had difficulties in applying the particulate nature of matter theory to explain phase changes even after instruction.

The results of this study also showed that most pre-service teachers displayed misconceptions on the size of particles because most of them believed that the size of particles in a substance increase when heat is applied and decrease when heat is removed. They also believed that the size of particles (molecules) increase or decrease when a gas is compressed. Similarly, Valanides (2000b) reported that the pre-service teachers attributed the expansion of a liquid to the expansion of the molecules themselves. Gabel et al (1987) also reported that pre-service teachers said atoms get larger as matter is changed from liquid to gas state. Such erroneous ideas suggest that most pre-service teachers in this study were unable to differentiate physical changes from chemical changes. Only a chemical change can affect the size of particles (atoms and molecules) of a substance. For example, the radius of an atom decreases after a loss of an electron. The cations (formed by the loss of electrons from the valence shell of the parent atom) are invariably smaller than their parent atoms. In some cases, the difference can be considerable (i.e. more than 50 percent). As cations have less number of electrons, the effective nuclear charge increases and as such, the remaining electrons are more tightly bound by the nucleus and, subsequently the radius of the cation is that of the compact atomic core. On the other hand, anions, which are formed by the gain of electrons by an atom—most commonly into the incomplete valence shell—are invariably larger than the parent atoms. In this case, the additional electrons repel the electrons that are already present, and the entire atom inflates.

This study also confirmed that misconceptions on the effect of physical change on the size of particles in a substance exist among all levels of students – from elementary to tertiary level. Such pre-existing beliefs are likely to influence how teachers learn new scientific knowledge that requires them knowing the particulate nature of matter. Such beliefs play an essential role in teachers' instructional practice and subsequently in student learning. As such, the results of this study have implications for science teaching and learning and teacher education. For example, our results show that the pre-service teachers' believed the size of the particles change (increase or decrease) when matter is heated, cooled, vaporized, condensed, frozen or compressed. Such a revelation of the pre-service teachers' conceptions has direct bearing on the possible promotion of misconceptions among many generations of students they will teach. Furthermore, this group of teachers is likely to have difficulties to learn and understand gas laws and kinetic theory of matter because these topics require sound background knowledge about the particulate nature of matter.

Research shows that addressing teacher misconceptions seem to help eradicate students' misconceptions in chemistry (Valanides, 2000a). Therefore, based on the results of this study and those reported in previous studies we recommend that chemistry teacher educators should identify misconceptions among the pre-service teachers before instruction on topics that require sound knowledge of particulate nature of matter. This will reveal the nature of misconceptions the pre-service teachers have on this topic. Then, teacher educators can take them into consideration when planning for instruction. We also recommend that teachers' misconceptions should be addressed through learner centered teaching strategies. For example, the misconceptions held by the pre-service teachers in this study can be addressed by using interactive computer simulations and animations on particulate nature of matter. Computer simulations and animations would enable teachers to see that the size of particles and number of particles don't change when there is a phase change. They would also see the effect of physical change on speed and spaces between particles in a substance. Similarly, teachers can be encouraged to discuss the particulate nature of matter in their classrooms using computer simulations and animations in order to help their students develop scientifically accepted concepts on the particulate nature of matter. However, a better intervention on the particulate of nature in schools would be more effective if teachers have sound knowledge about this topic and technological skills.

Conclusions

The purpose of this study was to assess Zambian junior high school science pre-service teachers' understanding of the particulate nature of matter. The findings of this study were also compared to those reported in previous studies on teachers' conceptions of the particulate nature of matter. The results show that most teachers had correct views on the effect of phase change on speed, spaces and number of particles of a substance. They displayed better understanding on number, speed, size of particles and spaces between particles when solids and liquids are compressed. This group of teachers correctly believed that matter can be compressed including solids and liquids though the extents to which different solids can be compressed vary. However, most pre-service teachers had poor understanding about the effect of phase change on the size of the particles in solid, liquid and gas. Furthermore, this study confirmed some findings reported in previous studies. For example, the pre-service teachers in this study also believed that heating a substance cause the size of its particles to increase while cooling it makes the particles decrease in size. As such, we can conclude that this group of teachers believed that when a substance is heated it expands due to the expansion of its particles [atoms or molecules], and when a substance is cooled it contracts because the size of the particles [atoms or molecules] decrease.

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