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COMPARING MALE AND FEMALE PRE-SERVICE TEACHERS' UNDERSTANDING OF THE PARTICULATE NATURE OF MATTER

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Abstract. *This study compared male and female pre-service science teachers' understanding of the effect of phase changes and physical transformation of matter on the size of particles, spaces between particles, speed of particles, and number of particles. Data were collected using a questionnaire that has 36 items. Both gender groups had sound understanding of the effect of phase change on speed, spaces, and number of particles in a substance, and the effect of compression on speed, number, size and spaces between particles in solids and liquids. However, most female pre-service teachers had low understanding of the effect of phase change on the size of the particles in solids, liquids and gases as most of them incorrectly believed that heating increases the size of the particles and cooling decreases the size of particles. The results have implications for science teaching and learning and teacher education.*

Key words: *gender, matter, particle, pre-service teachers, understanding.*

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Introduction

Research studies show that teachers do not have sound understanding of some fundamental chemical concepts that form the basis of chemistry discipline (Gabel, Samuel, & Hunn, 1987; Haidar, 1997; Onwu & Randall, 2006; Valanides, 2000a; Valanides, 2000b). In particular, teachers have misconceptions on the particulate nature of matter (Nakhleh, Samarampungavan & Saglam, 2005; Ozmen & Kenan, 2007). For example, Gabel et al., (1987) investigated US prospective elementary education teachers' views about the particulate nature of matter using a test in which they were asked to draw the particles after the solid had melted into a liquid. Most pre-service teachers didn't conserve the number of particles in their diagrams, suggesting that teachers lacked the knowledge about the conservation of atoms or molecules in a phase change. Furthermore, their 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 Yemen, Haidar (1997) reported that most prospective teachers had no meaningful understanding of conservation of atoms and mass, the mole, atomic mass, and balancing chemical equations. In Cyprus, Valanides (2000a) found that the majority of the pre-service 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 when a substance is dissolved. In another study, Valanides (2000b) reported that the pre-service teachers exhibited limited understanding of the connection between the observable macroscopic changes and the way molecules in the solutions and vapor moved in relation to one another and how they are held together. Valanides wrote 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. In a similar study, Onwu and Randall (2006) found that South African pre-service science teachers had difficulties to use a particulate model to relate submicroscopic entities and processes to macroscopic events in chemistry.

Although studies have examined teachers' understanding of the particulate nature of matter, no study has compared male and female pre-service science teachers' understanding of this concept. The few studies that have compared gender differences on the particulate nature of matter mainly focused on K-12 students (Bunce & Gabel, 2002; Nitza & Yehudit, 1999; Yezierski & Birk, 2006). In general, these studies reported that female students performed at the same level as male students after receiving instruction on particulate nature of matter; more visual representation of chemical interactions had significant effects on females' representations of matter, including the traditional symbolic chemistry problems; and animations-mediated instruction improved the achievement of female students on particulate nature of matter, closing the gender gap that existed prior to intervention.

It is also evident in the literature that most studies on the particulate nature of matter have mainly focused on teachers in Europe (Valanides, 2000a, 2000b), Middle East (Haidar, 1997) and USA (Gabel, et al., 1987; Gabel, 1993). Only one study has reported South African secondary school pre-service science teachers' conceptions of particulate nature of matter (Onwu, & Randall, 2006). However, Onwu, & Randall did not examine the differences between male and female pre-service teachers' achievement on particulate nature of matter. As such, very little is known about the African pre-service science teachers' understanding of particulate nature of matter and the differences (if any) between male and female teachers' knowledge about this concept. Therefore, this study compared Zambian male and female pre-service science teachers' knowledge about the effect of phase changes, cooling, heating and compression on the size of particles, spaces between particles, speed of particles, and number of particles in a substance.

This study is desirable, not only to Zambian science educators, but also to science educators elsewhere, who have a similar teacher education program. As such, it is anticipated that the results of this study would have some implications on science teaching, learning and teacher education.

Methodology of Research

A Comparative quantitative research method was used in this study. According to Hittleman & Simon (2002) the purpose of a comparative quantitative research study is to examine numerical descriptions of two or more valuables and make decisions about their differences or relationships. These variables might represent characteristics of the same group of subjects or those of separate groups. In this study, a comparative quantitative research method was used to compare male and female pre-service science teachers' understanding of the effect of phase changes and physical transformation of matter on the size of particles, spaces between particles, speed of particles, and number of particles.

Sample

A sample comprised 30 Junior high school pre-service science teachers at a teacher training college in Zambia. There were 15 females and 15 males. All the participants were trained 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 courses 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 [Country name] high schools. Participants were in the first-year of the three-year teacher education program. The teacher education program requires these pre-service teachers to take content courses in biology, physics and chemistry. In addition, pre-service teachers take science teaching methods, educational psychology, sociology of education, 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.

Data Collection and Analysis

Data were collected using a questionnaire that was developed by Ozmen and Kenan (2007). The questionnaire has 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 change, cooling, heating, and compressing – *Increase (I), Decrease(D)*, or *Constant(C)*. Data were analyzed by coding participants' responses on each item. Then, the number of participants choosing each of the three possible responses was converted into a percentage. Reliability value of the instrument was 0.83, indicating the high reliability of the data collection instrument.

Results of Research

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

Table 1. Male and female responses on the effect of phase change.

		Items	% Male (N=15)			%Female (N=15)		
			I	D	C	I	D	C
Meltingg	1	Size of particles when a solid is melted.	53.3	26.7	***20.0***	40.	53.3	***0.0***
	2	Spaces between the particles when a solid is melted.	***86.7***	13.0	0.0	***80***	7.0	13.0
	3	Speed of the particles when a solid is melted.	***86.7***	0.0	13.0	***93.3***	0.0	0.0
	4	Number of particles when a solid is melted.	6.7	6.7	***80.0***	13.3	46.7	***40.0***
Freezing	5	Size of particles when a liquid freezes.	26.7	40.0	***33.0***	26.7	53.3	***20.0***
	6	Spaces between the particles when a liquid freezes.	20.0	***73.3***	0.0	6.7	***93.3***	0.0
	7	Speed of the particles when a liquid freezes.	6.7	***80.0***	0.0	0.0	***73.3***	26.7
	8	Number of particles when a liquid freezes.	0.0	20.0	***73.3***	40.0	13.3	***46.7***
Vaporizingng	9	Size of particles when a liquid is vaporized.	46.7	40.0	*13.**0***	20.0	53.3	***20.0***
	10	Spaces between the particles when a liquid is vaporized.	***93.3***	6.7	0.0	***67***	20.0	13.0
	11	Speed of the particles when a liquid is vaporized.	***86.7***	0.0	6.7	***80.0***	6.7	6.7
	12	Number of particles when a liquid is vaporized.	13.0	6.7	***80.0***	0.0	66.7	***26.7***
Condensing	13	Size of particles when a gas is condensed.	20.0	33.3	***40.0***	27.0	40.0	***26.7***
	14	Spaces between the particles when a gas is condensed.	6.7	***86.7***	0.0	20.0	***73.3***	6.7
	15	Speed of the particles when a gas is condensed.	0.0	***86.7***	6.7	33.3	***60.0***	6.7
	16	Number of particles when a gas is condensed.	6.7	13.3	***80.0***	13.3	13.3	***46.7***

Bold *= Correct responses; I=Increase; D= Decrease; C= Constant*

*Melting a Solid***:** As shown in Table 1 above, most males and females correctly believed that spaces between particles and speed of the particles increase when a solid is melted. Most males correctly believed that the number of particles remains constant when a solid is melted. In contrast, most females erroneously believed the number of particles increase or decrease when a solid is melted. Males incorrectly believed that the size of particles increase when a solid is melted. On the other hand, most females incorrectly indicated that the size of particles decreases when a solid is melted.

Freezing a Liquid: Table 1 above shows that most males and females correctly indicated that spaces between particles and speed of the particles decrease when a liquid is frozen. More males than females said the number of particles remains constant when a liquid is frozen. On the other hand, more females than males erroneously believed that the size of particles decreases when a liquid is frozen.

Vaporizing a Liquid: Table 1 shows that more males than females correctly believed that spaces between particles and speed of the particles increase, and when the number of particles remain constant when a liquid is vaporized. On the other hand, most females erroneously believed the number of particles decrease when a liquid is vaporized.

Condensing a Gas: Most females believed that the condensation process increases or decreases the size of gas particles. Most males and females correctly indicated that spaces between particles and speed of particles decrease when a gas is condensed. Most males correctly subscribed to the idea that the number of particles remains constant when a gas is condensed. In contrast, very few females correctly believed that the number of particles remains constant when a gas is condensed.

Effect of Heating, and Cooling on Size, Speed, Number and Spaces between Particles

Heating Matter: As shown in Table 2 below, both gender groups held scientifically correct views about spaces between the particles, and speed of the particles after a substance has been heated. Most males correctly believed that the number of particles remains the same when matter is heated. In contrast, most females indicated that the number of particles increases or decrease when matter is heated. Both gender groups speciously believed that the size of particles increases when matter is heated.

Table 2. Males' and females' responses on the effect of heating and cooling.

		Items	% Male (N= 15)			%Female (N=15)		
			I	D	C	I	D	C
Heating	17	Size of particles when matter is heated.	73.3	0.0	***20.0***	60.0	20.0	***13.3***
	18	Spaces between the particles when matter is heated.	***73.3***	20.0	6.7	***80.0***	13.3	6.7
	19	Speed of the particles when matter is heated.	***73.0***	20.0	6.7	***86.7***	13.3	0.0
	20	Number of particles when matter is heated.	7.0	0.0	***93.0***	33.0	20.0	***47.0***
Cooling	21	Size of particles when matter is cooled.	6.7	73.3	***20.0***	33.3	40	***20.0***
	22	Spaces between the particles when matter is cooled.	6.7	***66.7***	13.3	6.7	***86.7***	6.7
	23	Speed of the particles when matter is cooled.	13.0	***80.0***	7.0	0.0	***86.7***	13.0
	24	Number of particles when matter is cooled.	6.7	20.0	***66.7***	40.0	6.7	***53.3***

Bold *= Correct responses; I=Increase; D= Decrease; C= Constant*

Cooling Matter: As shown in Table 2 above, most females and males correctly believed that spaces between particles and speed of the particles decrease when matter is cooled, and the number of particles remain constant when matter is cooled. However, both males and females displayed poor knowledge about the effect of cooling on the size of particles when matter is cooled.

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

*Compressing a Solid***:** Table 3 below shows that both gender groups correctly indicated that the number of particles remain constant when a solid is compressed. More females than males correctly believed the space between particles decrease when a solid is compressed. Similarly, more females than males correctly believed that the speed of particles decrease when a solid is compressed.

Table 3. Percentage of responses on compressing a solid, liquid and gas.

		Items	%Male (N=15)			%Female (N=15)		
			I	D	C	I	D	C
Solid	25	Size of particles when a solid is compressed.	13.3	13.3	***26.7***	13.3	0.0	***26.7***
	26	Spaces between the particles when a solid is compressed.	6.7	***53.3***	40.0	0.0	***80.0***	20.0
	27	Speed of the particles when a solid is compressed.	20.0	***40.0***	33.3	26.7	***60.0***	13.3
	28	Number of particles when a solid is compressed.	13.0	13.3	***73.3***	6.7	20.0	***73.3***
Liquid	29	Size of particles when a liquid is compressed.	7.0	20.0	***73.0***	0.0	47.0	***47.0***
	30	Spaces between the particles when a liquid is compressed.	7.0	***93.0***	0.0	27.0	***67.0***	7.0
	31	Speed of the particles when a liquid is compressed.	20.0	***67.0***	13.0	73.0	***20.0***	7.0
	32	Number of particles when a liquid is compressed.	0.0	26.7	***66.7***	13.0	13.3	***66.7***
Gas	33	Size of particles when a gas is compressed.	20.0	26.7	***53.3***	40.0	26.7	***33.3***
	34	Spaces between the particles when a gas is compressed.	13.0	***80.0***	6.7	26.7	***53.3***	20.0
	35	Speed of the particles when a gas is compressed.	46.7	***46.7***	6.7	33.0	***46.7***	20.0
	36	Number of particles when a gas is compressed.	0.0	20.0	***80.0***	13.0	33.3	***53.0***

***Bold = ****Correct responses; I=Increase; D= Decrease; C= Constant*

Compressing a Liquid: Table 3 above, shows that more male pre-service teachers than female teachers correctly believed that spaces between particles decrease when a liquid is compressed. About half of the females correctly believed that the size of particles remains the same when a liquid is compressed. Most males had correct views on the speed of particles when a liquid is compressed. On the other hand, most females erroneously believed that the speed of particles increases when a liquid is compressed. Both gender groups correctly believed the number of particles remain the same when a liquid is compressed.

*Compressing a Gas***:** As shown in Table 3 above most male pre-service teachers held correct views on spaces between particles, and number of particles when a gas is compressed. In contrast, about half of females correctly believed that spaces between particles decrease or the number of particles remain the same when a gas is compressed. Very few teachers in each gender group believed that the speed of particles decreases when a gas is compressed. More males than female teachers correctly indicated that the size of particles remains the same when a gas is compressed.

Discussion

Results show that both male and female pre-service science teachers had a good understanding of the effect of phase changes and physical transformation of matter of spaces between particles and speed of particles in a substance. This outcome may be attributed to longer period of chemistry instruction in Zambia high schools, from grades 10-12. Chemistry is one of the compulsory subjects in the national high school curriculum. Furthermore, the pre-service teachers took chemistry courses in teacher education program before responding to a questionnaire for this study. Similarly, Bunce and Gabel (2002) found that female students who were taught the particulate nature of matter scored significantly higher than those who were not. However, this attribution of longer period of chemistry and physics instruction is being made with caution because most females in this study subscribed to incorrect idea that phase changes and physical transformation of matter cause an increase or decrease in the size of particles. They believed that the size of particles in a substance increase when heat is applied and decrease when heat is removed, and that the size of particles (molecules) increase or decrease when a gas is compressed. Similarly, Boz (2006) reported that some students had difficulties in applying the particulate nature of matter theory to explain phase changes even after instruction. Valanides (2000b) also reported that pre-service teachers attributed the expansion of a liquid to the expansion of the molecules themselves. Gabel et al (1987) reported that pre-service teachers indicated that atoms get larger as matter is changed from liquid to gas state. However, both Valanides and Gabel et al did not compare males' to females' understanding of the particulate nature of matter. Nevertheless, the revelation of these erroneous ideas suggests that most female pre-service science teachers in our study were unable to differentiate physical changes from chemical changes. From a scientific viewpoint, it is only a chemical change that may affect the size of particles (atoms and molecules) of a substance. For example, the radii of atoms decrease after the loss of electrons. Such cations formed by the loss of electrons from the valence shell of the parent atom are invariably smaller than their parent atoms (Silberberg, 2013). 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.

These findings have implications for science teaching and learning and teacher education. For example, results in this study show that most female 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 has direct bearing on the possible transfer of misconceptions from teachers to students in schools. Furthermore, this group of female teachers is likely to face difficulties in learning and understanding certain science topics (e.g. gas laws and kinetic theory of matter) that require learners to have a good understanding of the particulate nature of matter.

Based on the results presented in this study and those reported in previous studies, it is recommended that science teacher educators should identify misconceptions among pre-service teachers before instruction on topics that require prior knowledge of particulate nature of matter. Such an effort will help reveal the nature of misconceptions among pre-service teachers on the structure of matter or related chemical concepts. Then, science teacher educators can take their pre-service teachers' misconceptions into consideration when planning for a course or instruction on structure of matter and other related chemical concepts. This study also recommends that pre-service teachers' misconceptions on the particulate nature of matter should be addressed through emerging technologies and learner centered instructional strategies. For example, the misconceptions held by most female 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 do not change during a phase change or when a substance is heated, cooled, or compressed. For example, Yezierski and Birk (2006) used computer animations of molecular-level water to remediate particulate nature of matter misconceptions held by students from middle school through college. Yezierski and Birk concluded that the use of animations improved the achievement of female students, closing the gender gap that existed prior to the intervention. Such intervention would also encourage pre-service teachers to teach the particulate nature of matter in their classrooms using computer simulations and animations, and subsequently promote scientifically correct concepts of the particulate nature of matter among their students.

Future research should examine teachers' chemical reasoning on particulate nature of matter, and also compare their ability with the assessment items difficulty using a Rasch model statistical analysis. Such approach would provide more information on whether teachers' low performance on this topic is due to their low chemical reasoning or the difficulty level of the items in the measurement.

Conclusions

The purpose of this study was to compare male and female pre-service science teachers' understanding of the particulate nature of matter. Results show that both gender groups had correct views on the effect of phase change on speed, spaces and number of particles of a substance. Furthermore, both gender groups displayed better understanding on number, speed, size of particles and spaces between particles when solids and liquids are compressed. They correctly believed that matter can be compressed including solids and liquids though the extent to which different solids can be compressed vary. However, most female pre-service teachers had poor understanding of the effect of phase change on the size of the particles in solid, liquid and gas. For example, most female pre service teachers subscribed to the incorrect idea that heating a substance causes the size of its particles to increase while cooling causes the particles to decrease in size. As such, most female teachers strongly believed in the idea 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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