INDIAN STUDENTS' UNDERSTANDING OF PARTICULATE NATURE OF MATTER

Puneeta Malhotra
C.I.E., University of Delhi
puneeta_krm@yahoo.co.in

Understanding of Particulate Nature of Matter is the foundation for learning chemistry. Appreciating this fact, the topic finds space in the school science curriculum across the globe. This topic is abstract so students find it difficult to understand. This paper is an attempt to identify common alternative conceptions related to the particulate nature of matter amongst students in India.

INTRODUCTION

"If, in some cataclysm, all of the scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis that *all things are made of atoms — little particles that move around in perpetual motion, attracting each other when they are a little distance apart but repelling upon being squeezed into one another.* In that one sentence, you will see, there is an enormous amount of information about the world if just a little imagination and thinking are applied."

The above statement by Richard Feynman describes the importance of atomic theory in science. Atomic theory is the foundation of science, thus the foundation of science education as well. For comprehending science whether it is chemical reactions, nuclear behavior, chemical bonding, shapes of molecules; understanding the atom and its structure is indispensable. It is therefore not surprising that the atomic theory is an essential part of the science curriculum across the globe. The need for learners to appreciate the particulate nature of matter drives the inclusion of the topic in the school science curriculum. Not surprising, school curriculum across the globe has given due credit to particulate theory. The theory is introduced to students in the middle school who are in the age group of 11-13 years.

Atomic Theory is a difficult concept with abundant alternative conceptions in the mind of the learner. Alternative conceptions are frequently observed in the student's understanding of atoms. (Nakiboglu, 2003; Park and Light, 2009). Lack of understanding of the theory can be attributed to the abstract nature of the topic. The cognitive readiness of the students is essential to understand abstract topics like atom and the structure of an atom. Therefore until a child reaches the formal operational stage, the introduction of this topic will be a futile exercise. The cognitive preparedness of the child is foremost for curriculum development, it should be cognitively valid (National Curriculum Framework, 2005) [NCF]. Keeping the developmental phase of learners in mind, the National Research Council USA (1996) recommended the introduction of the topic in Grades 9 -12, which is the same in India as well, barring a few exceptions. Following the guidelines of NCF 2005, the Atomic theory is introduced in grade 9 in the CBSE curriculum. The child has attained the age of 14 years when he enters this grade. According to Piaget, this child is now capable of abstract reasoning.

Another problem inherent with microscopic particles is the inability of the students to 'see' the particles leading to association and analogy with a macroscopic system at least initially to understand the abstract topic. The structure of an atom is associated with the 'watermelon and its seeds' as in the case of the Thomson model or 'solar system' in the case of the Rutherford model. The initial engagement with these analogies is so strong that the student falls back to these models time and again.

To add to the problem is the association with the term 'model'. Models used as intellectual tools to aid scientific inquiry are seen as students as a replica of reality. (Grosslight, Unger, Jay, & Smith, 1991, p. 799). Students assume scientists have 'seen' the atom using some sort of special instrument like a special microscope. The colorful 'images of atoms' that are readily available have further strengthened this belief of students. The computer-generated models of atoms appear in different publications of scanning tunneling microscope as 'images of atoms'. These images mislead people. These are assumed to be 'atom' as seen through the scanning tunneling microscope (Harrison & Treagust, 1996). Therefore, the student's belief in being able to see an atom is strengthened.

Molecules are too small to be seen, but these can be seen using some "magnifying lenses". This belief is deep, even after repeated instruction, students feel even if faintly, an atom can be seen. Even after the repeated emphasis on the fact that even with the most powerful microscopes atom is not visible, this alternative conception stands. (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993)

The researcher came across this strong conviction of scientists have seen an atom while an informal conversation with her students. "I have not seen an atom, but scientists have. I saw the images on the INTERNET" a student said. "Like the model of an internal combustion engine or like the model of kidneys and heart, is the model of an atom" she added. The response can be related to the study by Horton (2007). In the study on alternative conceptions in chemistry, he found that none of the students under study understood that models were not depiction of reality. There was a great difficulty encountered by the students in understanding something they were not able to see.

The content and diagrams that appear in the textbooks add on to the woes. Joshi & Sudhir (2017) question the treatment of this important topic in a superficial manner. The diagrams, they write, are misleading. Expansion of solids on heating is greatly exaggerated and decrease in density of liquid on changing to gas is under represented. This leads to alternative conceptions related to densities of the three states of matter. These problems, related to abstractness of the topic, are responsible of mushrooming alternative conceptions amongst students and not surprisingly also amongst pre service and in service teachers (Kikas, 2004; Nakiboglu, 2003; Haidar, 1997).

Particulate Nature of Matter

Introducing atom, molecule and ion to a child who does not comprehend particulate nature of matter is a futile task. Distinction between the macroscopic properties of matter and the properties of particles is not clear to majority of students. The properties of bulk of matter are transferred to individual particles. The commonly held alternative conceptions in this topic are:

Matter is Continuous

Doran (1972) listed alternative conceptions that commonly occur related to particulate nature of matter. The most common one is considering matter is continuous. The idea of existence of empty space is not internalized by students. They believe there is no space between particles of matter. There is 'nothing' between the particles is not accepted by students. The particles are either in contact (Nakhleh, 1992) or float in some medium (Andersson, 1990; Harrison, 2001) or particles have something like air in between them, (Lee et al., 1993) is a strongly held notion.

According to Lee et al. (1993), this strongly held notion includes 'various kinds of 'stuff [or air] between molecules' (p. 257). Andersson (1990) and Harrison (2001) both found textbooks containing diagrams like Figure 1 where the line across the top tells students that water molecules are floating in some other 'stuff! The students interpret the line on the top in diagrams like figure 1 as water molecules are floating in some other 'stuff!'. Study by Griffiths & Preston (1992) echoes similar results.

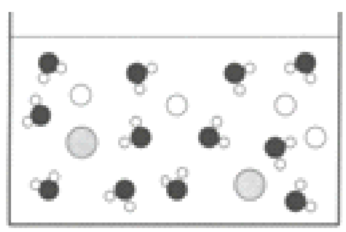

Figure 1: A model of a liquid in a container with surface line implying that the particles are suspended in another substance

Particles of Matter Do Not Move

Many students believe that particles of solid are static. The particles are tightly held and are rigid so no motion is possible in solids. Doran (1972) and Lee et al. (1993) identified students are unable to value the notion of movement at particulate level. The movement of particles in gases is seemingly easily appreciated by students. Though, the belief that when some gas is sucked out of a container, the gas does not fill the container, points at an alternative vision about gas particle. (Nussbaum & Novick, 1982).

Spacing between Particles

Overestimation of distance between particles of liquids is frequently encountered alternative conception. Students however view particles of liquid at a distance that is somewhere intermediate of solid and gas particles. Scientifically, the spacing between solid-solid, liquid- liquid and gas-gas particles is about 1: 1: 10 (Andersson, 1990; de Vos & Verdonk, 1996). Commonly held student view about particles is that: solid particles are in contact, liquid particles about a particles away and gas particles three to four particles away(Harrison, 2001).

The perception of inter-particle distance between different states of matter is directly derived from the textbook representations. Figure 2, shows the depiction of space between particles of solid, liquid and gas from the NCERT Science textbook (class IX). The diagram is misleading. According to this diagrammatic representation, the density of solid would be at least twice that of liquid and that of gas four times the liquid state. This is not true for any known substance. (Joshi & Sudhir, 2017)

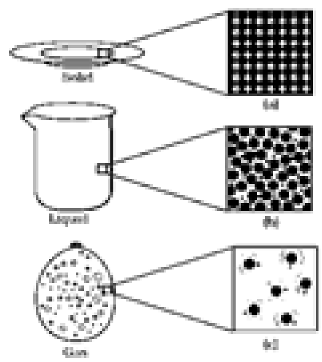

Figure 2: Depiction of distance between particles in solid, liquid and gas.

Properties of Substance are Properties of Particles

Macroscopic properties like colour, malleability, electrical conductivity are considered to be properties exhibited by each individual atom. Ben-Zvi, Eylon, and Silberstein (1986) in their study found nearly 85% students of grade 10 from different schools in Israel thought properties of matter are manifested by an atom. Only 14.9% of the students out of a sample of 288 stated that an atom cannot be isolated or the properties like colour, malleability, conductivity are properties of cluster of atoms.

Atom appears in multicolored images in modern textbooks. These add on to students conceptions of colour of atom. The difference in colour of reactant and products can be used to debate on colour of atom (Albanese & Vicentini, 1997).

Joshi & Sudhir (2017) also reported teachers believe an atom of copper is a better conductor of heat and electricity than an atom of mercury. Also, measurement of temperature of an atom is possible, provided we have the correct instrument. Therefore, teachers attribute bulk properties of matter to properties of the constituent particles. The students are thus likely to develop these alternative conceptions.

A study from Israel conducted by Ben-Zvi et al., (1986), too voices concern about students understanding of atomic theory. Responses of nearly 67% of the students from a sample of 300 high school students, reflected that the 'continuous model' of matter was deep rooted. They knew the particulate model but were not able to internalize the concept. For them, atom has same properties as the substance and atoms of solid and gas are different.

The views about particulate nature of matter of 54 prospective elementary teachers of Indiana University, Kokomo, Indiana were studied by Gabel, Samuel and Hunn (1987). The examination of students drawings depicting what happens to particles after physical and chemical change, revealed distorted understanding of particulate nature of matter. The diagrams show change in size of constituent particles when the phase changes and gaseous particles in an ordered arrangement rather than random arrangement. After decomposition reaction, the molecules were still intact as if in a physical change. The misconceptions (author uses this term) related to change of size, no change in inter-particle distance and arrangement as well as poor understanding of physical and chemical change is prevalent.

Study of perceptions about particulate nature of matter in the United States also hints at the struggle of students in comprehending the topic. A sample of 87 high school and middle school students, of schools ranked for their academic performance in US was assessed for their conceptual understanding of particulate nature of matter. Aydeniz & Kotowski (2012) reported the following misconceptions (term used by authors) held by significant number of students: (i) During phase change, chemical composition of the substance changes. The author cites example of students stating boiling of water involves breaking of bonds between hydrogen and oxygen. They visualize phase change as a chemical change rather than a physical change. (ii) Nearly 70% students think a gas formed during change of state (boiling or sublimation) weighs less than the liquid or solid. The “law of conservation of mass” is not internalized by the students. The analysis reported possible reason for such a misconception was students’ belief that the size of molecules changes during phase change.

Students (sample of 20) at the Education Department of the University of Cyprus who opted for a compulsory science course had conflicting views regarding particles of matter. Valanides (2000) cited lack in understanding of empty space between particles, constant motion of particles in all states of matter, particles do not expand or contract during phase change and particles do not melt during the process of melting.

Looking at studies from Africa, similar problem in understanding of particulate matter have been reported. A study of 30 high school pre service teachers, showed lack of understanding of effect of phase change on size of particles. The study was conducted by Banda, Mumba, Chabalengula and Mbewe (2011) which reported 89.7% of the sample associated melting and freezing result in change in size of the particles. Similarly, more than 75% associated vaporization and condensation involves change in size of particles. However, the understanding of distance between the particles, speed and number of particles was in accordance to scientific understanding for nearly 70% of the sample.

The only study from India, which the researcher came across was by Chakraborty & Mondal (2012). The sample was 189 students of grade 9 of four schools situated in Murshidabad district of West Bengal, India. The students were reported to have difficulty in the understanding of mass number, atomic nucleus and shells. No other study was available from India. The researcher decided to conduct a study to find out the alternative conceptions related to particulate nature of matter held by students of grade XI in India.

METHODOLOGY

The study was conducted in two private schools in National Capital Region. The students, who chose science stream in grade XI, were chosen as sample. These students have studied particulate nature of matter in detail in grade IX. The sample of 60 students was selected on basis of section allocation done by school.

A questionnaire was prepared to test the understanding of particulate nature of matter. The questionnaire consisted of 15 multiple choice questions (MCQ) and 4 open ended questions. Out of the 15 MCQ 11 were taken from Particulate Nature of Matter Assessment (ParNoMA) Yezierski & Birk (2006) and rest from Merritt (2010).The open ended questions were taken from studies by Merritt(2010) and Ben-Zvi et al. (1986) and Kokkotas, Vlachos and Koulaidis (1998)**.** 10 students of class XI were part of pilot stage. Responses of students were studied. Open ended interviews were conducted for all 10 students to understand their responses. Questions were changed or re-framed based on the students' responses.

Questions which intended to assess clarity of inter particle distance in different states of matter were re-framed. During interviews it was realized that the problem area is inter-particle distance in liquid state, so questions were re-framed. The changed question tested understanding of particles in liquid state. In another question, student's seemed to understand evaporation as breaking of water molecules away from other water molecules, but clarity of what this 'breaking away' meant was missing. Interviews showed, it was majorly thought as breaking of covalent bond, so this question was re-framed. Diagram showing hydrogen bonds and covalent bonds was given asking about which bond(s) are broken during evaporation.

Question on what lies between particles of matter, many students answered 'nothing', which was the correct option. Interview revealed that students thought amongst the options provided, only nothing fits, which actually means something. Like when we see an empty glass, it has nothing that we can see but it actually has air.

All open ended questions were re-framed after getting an initial feeler of possible gaps in Understanding of Particulate Nature of Matter.

Following the pilot stage, questionnaire was sent to experts for their comments. The questionnaire was vetted by experts Dr Uma Sudhir and Dr Arvind Sardana from Eklavya. The questionnaire was then administered to the sample.

Data Analysis

The data was analysed to draw out the alternative conceptions if any held by the students. 1 mark was allotted for each correct answer and 0 for incorrect answer in MCQ. The open ended question correct answer was awarded 1 mark and correct reason 1 mark. To understand the answers better interviews of students were also conducted.

On analyzing the data, it was found that 50% students assumed solids are immobile. Students associate mobility with particles of liquids and gases as these two states are fluids. Solids are seen as fixed, so the students face difficulty in understanding motion at particulate level.

Nearly 50% students assume distance between particles of liquids is intermediate of solids and gases. The reason that came out on the basis of interviews was the diagrams given in textbooks show space between liquid particles more than solid and less than gas particles.

Particles change in size and melt or boil when state change occurs, is assumed by nearly 45% of the students. Daily experience of comparative densities of solid, liquid and gas is responsible for students' assumption that particles of gas are lighter than liquid while that of solid heavier. On probing further, it was found students do mention that the inter-particle distance changes on state change but macroscopic observation is a barrier to understanding what happens at particle level. Similarly students' understanding that particle of a shiny substance shines, of a grey substance is grey and of a conductor is a good conductor shows bulk properties are properties of the particles too. This was observed in 70% of the responses.

Another alternative conception which was found in 60% of the students was matter is continuous. There is something, maybe air between particles of matter. As when we say the glass has nothing, it means glass has air, said one of the students during the interview.

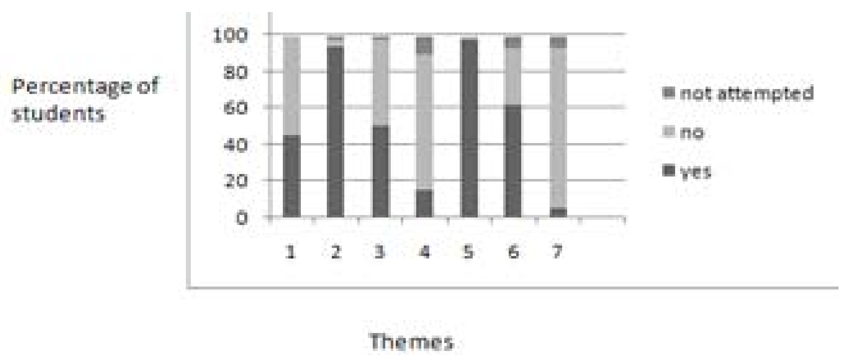

Figure 3: Percentage responses of students on themes 1 to 7 (1: decomposition occurs on boiling, 2:atom conducts electricity 3: atom has colour 4: size of particle changes on state change, 5: overestimation of distance between liquid particles, 6: solid particles are immobile and 7:particles melt.)

CONCLUSION AND IMPLICATIONS

Nearly 50% students who have chosen science stream in class XI are found to have alternative conceptions related to particulate nature of matter. The students have studied the atomic theory in detail in class IX. Also in class X they have studied chemical reactions, periodic classification and types of bonds. The data analysis is a striking revelation about understanding of basic concepts in chemistry. These alternative conceptions will impede their understanding of chemistry at senior school level. Students who associate breaking of covalent bonds with state change actually have little understanding of physical and chemical changes. The idea that size and weight change with change of state will affect their understanding of periodic classification. The overestimation of inter-particle space in liquids is also responsible for the understanding that liquids are compressible to some extent. Inability to appreciate compressibility of gases is due to under estimation of distance between its particles. Poor understanding of evaporation and boiling can be associated with the alternative conception that temperature of a substance is same as temperature of each of its particles and not dependent on its average kinetic energy.

More than 95% students assume atom to have same colour as the substance. From this study, for example, it came out that students assume sulfur atom to be yellow as sulfur is yellow in colour. Making note of alternative conceptions (as represented in figure 2) teachers can plan their lessons in a manner that these conceptions are hit upon. While teaching atomic theory, a teacher can question students about colour of carbon atom. They may reply black as graphite is black. Initiate a debate, why black? Will it be a conductor? Why do you think carbon atom will conduct or not conduct electricity? Let them compare graphite atom to atom of diamond, which is also carbon, and now explain what will be colour of atom, or conductivity. Create a confusing situation and let students resolve the confusion and arrive at scientifically correct conception. Teacher can also weave in historical development in understanding of atom. Starting with initial thoughts that atoms of iron have hooks and that of cheese are cheesy and correlate it to student's idea of atom of carbon being black.

Chemistry teachers often face difficulties in teaching topics like chemical bonding, evaporation, boiling, periodicity of properties of elements to name a few. The cause of these can be traced back to poor understanding of particulate nature of matter. Therefore, it is essential for teachers to be aware of alternative conceptions of students and to find out means to reduce these. Use of historical narratives, computer simulations and philosophical debates are a few methods which can be used to reduce these alternative conceptions.

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