NATURE OF MATTER

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What are some of the most common alternate conceptions students hold about the nature of matter? How do they arise? What level-appropriate approaches can teachers use to build a more scientifically accurate understanding?

The physicist Richard Feynman once said that if only one bit of all the scientific knowledge we have is to be passed on to future generations, then it should simply be this that matter is particulate. Since the atomic theory lies at the heart of modern chemistry, it is usually introduced to children at the beginning of middle school, even before they have engaged with formal chemistry courses.

However, this theory and related concepts are often taught in a superficial manner, and children are not given sufficient time to assimilate ideas about the nature of matter. Neither do we share the evidence for the particulate nature of matter with them, nor do children learn of the implications of the atomic theory in describing chemical changes or changes in the state of matter. This is further complicated by the fact that chemical symbols are also introduced at an early stage and are used to convey different things at different times without adequate clarification. Consequently, children tend to see the atom as a mysterious entity and fail to connect the abstract symbols used to represent them with observed phenomena in the real world.

Prior and alternate conceptions

This lack of understanding is evident in several studies which show that children exhibit a range of prior or alternate conceptions about the particulate nature of matter, which tend to be difficult to unlearn. Children see the properties of these particles as being continuous with their observations of the bulk properties

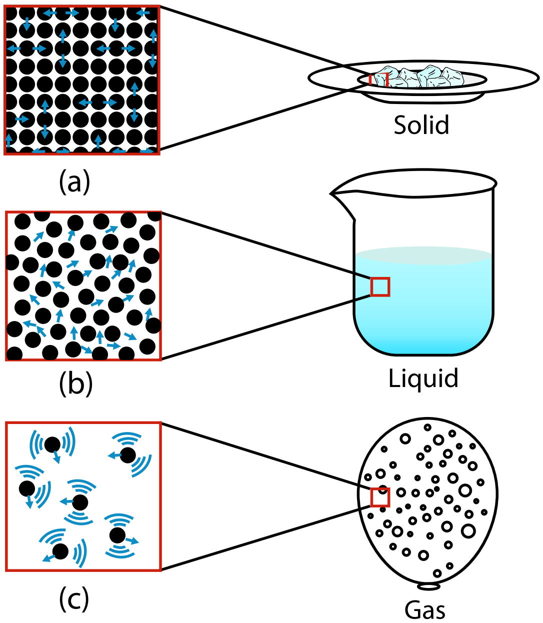

Fig. 1. Misleading illustrations in textbooks can influence student misconceptions about the nature of matter. For example, this is an illustration from the first chapter 'Matter in our surroundings' from the current NCERT science textbook for Grade IX. If students were to believe this depiction to be accurate, then they would believe that the density of the solid would be at least twice that of the liquid form of the same substance, and the density of the liquid would be around four times that of the same substance in the gaseous state. This is obviously not true of any known substance.

of a substance, and do not develop an appreciation for the relationship between bulk phenomenon and the atomic nature of matter. For example, they assume that because chlorine gas is yellow-green in colour, its atoms will be yellow-green in colour too. Similarly, children tend to attribute changes in macroscopic behaviour to changes in the particles. For example, they may believe that a solid expands because its atoms expand, or that a solid melts into a liquid when its atoms 'melt'. Other studies show that even when children associate the correct technical term with an event or phenomenon, they may not be able to give a coherent account of the process involved in it. Like when shown a cube of ice kept at room temperature, children may correctly identify the ice to be 'melting', but have no idea of what melting means at the molecular level.

One factor that contributes to these misconceptions is the inclusion of misleading illustrations and models in textbooks. For example, the decrease in density when (most) solids melt and the extent of their expansion when they are heated are both greatly exaggerated (see **Fig. 1**). Liquids are represented in a way that suggests that they are readily compressible. The decrease in density when a liquid changes to a gas is underrepresented. The number of molecules shown in most diagrams does not convey any idea of how many particles are being talked about. So an appreciation of 'bulk' properties arising out of the combined action of very large numbers of particles is absent. Illustrations often relate the colour of particles to the colour of the bulk material; an atom of carbon is shown to be black. Diagrams also often show 'molecules of water' floating in a blue background (see **Fig. 2**). This gives students the impression that water and its molecules are two independent things.

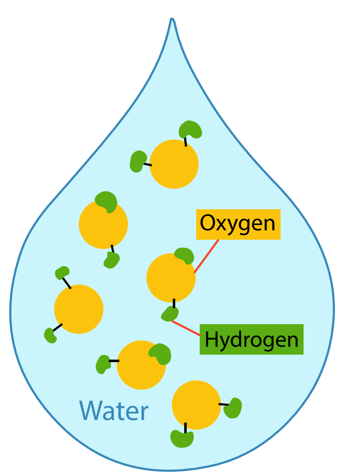

Fig. 2. Each water molecule is made up of two atoms of hydrogen and one atom of oxygen. What is the blue background in which these molecules of water float?

Some misconceptions may arise from inaccurate statements that we, as teachers, share in class, perhaps as short-cuts. For example, we may say that water consists of hydrogen and oxygen. This is imprecise—the water **molecule** is made up of two atoms of hydrogen and one atom of oxygen. Water consists of water molecules and no trace of any property of hydrogen and oxygen atoms can be seen in it.

Other misconceptions may arise from the ease with which teachers and textbooks shift between different levels when talking about matter. For example, they may both move between descriptions of the macroscopic properties of the reacting substances, their submicroscopic properties (the atoms and molecules taking part in the reaction), and the symbol system (formulae and equations) used to denote a reaction. Neither may make explicit to the learner what shifts have taken place, what aspect is being discussed, and how these are interrelated. As children do not get enough experience in conducting chemical reactions and seeing mass relationships between reactants and products, they find it difficult to connect events occurring at these three levels. Thus, for example, children often say things like N_2O_5 cannot be prepared from N_2 and O_2 because three more atoms of oxygen would be needed. This suggests that they don't understand the relationship between the element and its depiction in the form of a symbol or a formula. Since they have no appreciation of how these formulae have been arrived at, they also tend to change the numbers of various atoms in the formulae in order to balance equations (an activity that they see as a mathematical exercise instead of one that reflects the exact quantitative nature of the reaction).

Due to the casual nature of instruction, children often do not know which concepts are useful or relevant in describing or explaining a certain phenomenon. For example, children who see the electrolysis of water molecules produce hydrogen and oxygen molecules are likely to say that boiling also causes water to split into hydrogen and oxygen (both gases). This may be due to the fact that they give undue importance to the observation that both boiling and electrolysis seem to need energy.

Children may also have difficulties in recognising gases as matter. If so, they may not take into account the possibility that gases may be used up or produced in a reaction. This leads to confusion about what exactly a chemical reaction is. For example, if children do not recognise the role of oxygen and atmospheric moisture in the rusting of iron, they tend to believe that it is a property of iron to turn red and crumbly after some time. They may also believe that the iron remains unchanged in spite of rusting. It is as if they are drawing parallels with aging—as an infant named Nirjuli grows up, her height, weight, shape, and almost everything else changes, but she is still Nirjuli!! They also have difficulty comprehending the idea that a large amount of empty space exists between the particles in a gas.

Where children have prior concepts about substances, they do not easily substitute them with more 'scientific' ideas. For example, studies suggest that children may use the particulate nature of matter to describe gases because they do not have any prior ideas about the nature of gases. Since this is not the case with solids and liquids, children resist the idea that these forms of matter are also made up of particles. This is also why they tend to think of the properties of atoms in solids and liquids as being continuous with their bulk properties. Such alternate ideas are discovered only on probing because children quickly learn to give, and we tend to accept, expected answers without having any concrete understanding of what these answers signify.

Introducing properties of substances

How do we convey such complicated theories to children? We believe that students do not need to learn an overarching theory about the nature of matter till they are familiar with the properties of various substances and how they react with one another. Thus, at Eklavya, we introduce children to the physical and chemical properties of various substances in middle school (in Grades VI, VII, and VIII) and strongly recommend that abstract theories be taught only in high school (Grades IX and X). This means that our focus in middle school is to offer children some exposure to the following ideas or concrete experiences before they move on to theoretical issues:

1. Specific properties of substances: Children need to be familiar with simple experiments which show that different chemical substances have different properties that can be tested and observed. Also, they need to have some experience in distinguishing between substances on the basis of their chemical properties. For example, many metals may look similar but differ markedly in their reaction with acids, and this can be easily studied.

2. Physical versus chemical changes: Often, teachers share seemingly straightforward indicators to help students recognise that a chemical change has taken place and a new substance has been formed. But students are only able to appreciate this when they perform experiments where they have to distinguish between a chemical and a physical change, and the conditions under which these changes take place. Thus, they must learn to perform simple tests to identify differences in the properties of the starting materials of a reaction and its final products.

3. Different states of matter: As discussed before, while students may learn how to use the correct terms for the processes involved in a change in states, they have no conception of the submicroscopic processes that occur during these changes or how these changes can be brought about. For example, the external source of energy that causes the boiling of water and its conversion to vapour may be more apparent to students than the energy involved in the melting of ice. Similarly, they may not understand that the reverse processes of condensation and freezing release the same amounts of energy, or that evaporation causes cooling. One way to help students understand these processes is to encourage them to closely observe seasonal changes in states of matter. For example, students living in cold areas could be encouraged to test the folk theory that the weather becomes warmer after it snows, and gets colder when the snow starts melting. Similarly, students living in warm areas could be asked to test if the evaporation of sweat from their skin feels cooling or heating. Since the rate of large-scale evaporation reduces with a resulting rise in humidity, it is possible that students may feel 'hotter' as their sweat takes longer to evaporate. In such cases, encouraging students to study the condensation of water vapour on a cold surface could help them appreciate the same process in reverse.

4. Elements, compounds, and mixtures: The usual route of teaching this starts with introducing the idea that atoms of different elements combine to form compounds. Due to the manner in which this is taught, students are often confused about the difference between compounds and mixtures, and why molecules of elements exist. At Eklavya, we start with the purification of mixtures instead. We also introduce students to the twin questions of separation and purity. This helps them appreciate how our classification of a substance as 'pure' depends on the techniques of separation available to us and the methods we use to test the purity of a sample.

Parting thoughts

How do we introduce students to the abstract concepts and theories related to the particulate nature of matter? We believe that the tradition of diving directly into Dalton's postulates does not work. Instead, it would be helpful if we were to introduce students in middle school to the bulk properties of substances and help them identify changes in their physical and chemical properties through simple experiments. In high school, students can be taken through all the convoluted paths and by-lanes that various theories about the nature of matter gave rise to, and how these debates were resolved. Rather than disguising history as chemistry, this approach would help them appreciate the cumulative work done by Berzelius, Guy-Lussac, Avogadro, and Cannizzaro. It would also help them assimilate the ultimately simple resolution given by Dalton's atomic theory, and become familiar with the contributions of Lavoisier and Boyle. In addition, an awareness of the historical sequence of the development of ideas in the field of chemistry will help students understand and appreciate the nature and process of science.

Key takeaways

- Various alternate conceptions about matter make it hard for students to grasp its particulate nature or use this idea to explain observed phenomena.
- Students often confuse the bulk properties of matter with the properties of its constituent atoms.
- Some of these confusions arise because of problematic illustrations in textbooks, while others arise because of the casual nature of instruction.
- Exposing students to different 'chemical' experiences in middle school may help lay the necessary foundations to introduce abstract theories in high school.

Notes:

1. This article was first published in Sandarbh, Issue 83, pg 13-21. This version is restructured and revised for conciseness. URL: https://www.eklavya.in/magazine-activity/sandarbh-magazines/192-sandarbh-from-issue-81-to-85/sandarbh-issue-83/560-children-s-misconceptions-about-the-nature-of-matter-by-uma-sudhir.
2. Source of the image used in the background of the article title: Rusting iron. Credits: Logan King, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Rusty_Barbed_Wire.jpg. License: CC-BY-SA.

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