Children's Misconceptions about the Nature of Matter:

The Atomic Theory lies at the heart of modern Chemistry and hence is usually imparted to children in the very beginning, even before they enter formal Chemistry courses. However, this theory and related concepts are never dealt with in any detail, nor is the evidence for the particulate nature of matter ever gone into. Moreover, the children never get an idea of the implications atomic theory has in terms of describing chemical change or even change of state. Matters are further complicated by the introduction of symbols at an early stage and their being used to convey different things at different times without any clarifications. Several studies have shown that children exhibit a range of alternate concepts and confusions which are difficult to unlearn.

What kind of confusions do children (and some adults too) have? Researchers have found that children accept the particulate nature of matter at a superficial level, so that the properties of these particles are continuous with the bulk properties of the substance (a solid expands because the atoms expand, the particles melt and turn the solid into a liquid, etc.).

One major problem arises due to the fact that we teach these concepts in a very casual manner. Thus, for a child an atom remains a mysterious entity and she never develops a relationship between the observed bulk phenomenon and the atomic nature of matter. Children also fail to make a mental picture of the reality represented as abstract symbols.

For example, the ease with which the chemist shifts between different levels when talking about matter – the macroscopic (reacting substances), the sub-microscopic (the atoms and molecules taking part in the reaction) and the symbolic (formulae and equations) – without making it explicit to the learner that such shifts have taken place, also creates confusions. As children do not get enough experience of conducting chemical reactions and seeing the mass relationships among the reactants and products, they find it difficult to make connections between events taking place at the bulk scale and their description at the atomic level in the form of formulae and equations.

Or, it may be that we, as teachers, tend to make inaccurate statements, perhaps as short-cuts. For example, we may say that water consists of hydrogen and oxygen. This is imprecise; water consists of water molecules with no trace of any property of hydrogen and oxygen to be seen. The water *molecule* is made up of two atoms of hydrogen and one atom of oxygen.

Other than the direct applications of the particulate nature of matter, children also have difficulties in recognising gases as matter. Hence, they do not take into account the gases that may be used up or produced in a reaction. This leads to a confusion about what exactly a chemical reaction is. For example, if the role of oxygen and atmospheric moisture in the rusting of iron is not recognised, children will tend to think it a property of iron that it turns red and crumbly after some time. They also have difficulty in comprehending the idea of the large amount of empty space between the particles in gases.

ALTERNATE CONCEPTIONS FOUND AMONG STUDENTS

Various studies have been done to find out what children understand about the nature of matter and whether their ideas are consistent with the views of scientists. It is interesting to see the kind of concepts that children develop. These concepts may arise because of the following reasons:

1. Sufficient time is not given to the children to assimilate ideas about the nature of matter. These ideas are often counter-intuitive.
2. Teachers and textbooks move between descriptions about the macroscopic properties, the sub-microscopic properties and the symbol-system used to denote them without making it clear to the children what aspect is being discussed and how they are inter-related.

Children often say things like N2O5 cannot be prepared from N2 and O2 because it would need three more atoms of oxygen for the product to be formed. Here, one of the causes of confusion is that they don't realise the relation between the element and its depiction in the form of a symbol / formula. Since they have no appreciation of how formulae have been arrived at, they also tend to change the numbers of various atoms in formulae in order to balance equations (an activity which they see as a mathematical exercise instead of something that reflects the exact quantitative nature of any reaction taking place).

3. The illustrations or the models used are misleading. Some of the common deficiencies of textbook diagrams are as follows:

- The extent of expansion of solids when heated is greatly exaggerated, and also the decrease in density when (most) solids melt.
- Liquids are represented in a way which suggests that they are readily compressible.
- The decrease in density when a liquid changes to a gas is under-represented.
- The number of molecules shown in most diagrams do not convey any idea of how many particles are being talked about – so the impression 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 – would an atom of carbon be black?!!

Insert Figure 1.5 from the class IX NCERT Science textbook.	A factor which could be influencing misconceptions is the nature of misleading illustrations in the textbooks (for example, look at the diagram from the current NCERT textbook for class IX); if this depiction is correct, then the density of the solid will be at least twice that of the liquid form of the same substance, and the density of the liquid would be only around four times that of the same substance in the gaseous state. This is obviously not true of any known substance. Diagrams also often show 'molecules of water' floating in a blue background. So it gives a feeling that water and its molecules are two independent things.

4. Where children have prior concepts about substances, they do not easily substitute 'scientific' ideas for their pre-concepts.

For example, it was found that children use the particulate nature of matter to describe gases because they do not have any prior ideas about the nature of gases, but they resist the idea that solids and liquids are also made up of particles. So they tend to think of the properties of solids and liquids being continuous with their bulk properties.

5. Children generally think of properties as being continuous, i.e., they think of chlorine atoms as being green in colour, this could also be because of the models or illustrations used. And they attribute changes in macroscopic behaviour to changes in the particles, i.e., they think that the particles 'melt' when a solid turns into a liquid.

6. Because of the casual nature of instruction, children often do not know which concepts are useful or relevant in the explanation of a given phenomenon. Thus, children tend to be affected by irrelevant inputs when asked to describe phenomena.

For example, children who have seen the electrolysis of water to give hydrogen and oxygen are likely to say that water turns into hydrogen and oxygen (both gases) when it boils. The confusion could also arise because of what seems to be a high energy process like boiling while electrolysis seems to happen on supplying what appears to be a small amount of energy from batteries. This means that, for some reason, they can not judge which categories apply where.

7. We often look towards analogies for understanding various phenomena. Children seem to be doing the same at times.

For example, children think that iron remains iron even after rusting, that rusting is in the nature of iron which continues unchanged within the dusty brown product. It is as if they are drawing parallels with ageing – an infant named Nirjuli grows up, its height, weight, shape, almost everything changes, but it still is Nirjuli!!

Such alternate ideas are discovered only on probing, because children quickly learn to give, and we tend to accept, the expected answers without any concrete understanding. This is also because of the lack of adequate probing to check whether learning has taken place. For example, it was found that children can correctly associate the correct technical term with the event or phenomenon, but they cannot give a coherent account of the process. Like when shown a piece of ice kept at room temperature, children correctly said that it was melting, but had no idea of what melting meant.

It must be mentioned that even some adults, including teachers, have some of these difficulties. For example, in a small study, several teachers were shown the picture given above (from the NCERT textbook) and were asked: 'What is present in the spaces between the molecules in the case of gases?' Some of them did respond by saying that there is air between the molecules of the gas. Some teachers felt that there is inter-molecular force between the molecules while only a few said that there is nothing between the molecules.

Similarly, several teachers felt that an atom of copper would be a better conductor of electricity and heat than an atom or mercury. Interestingly, many teachers also felt that given proper instruments, one would be able to measure the temperature of an atom.

It appears that even some teachers think that the bulk properties like temperature, conductivity, etc., are also properties of atoms / molecules.

Hence, it is felt that for children to internalise the particulate nature of matter, they have to appreciate how these ideas developed. Moreover, they must get some exposure to the following ideas / concrete experiences before they move on to theoretical issues:

A. Chemical change vs. physical change : how does one know that a chemical change has taken place and a new substance has been formed?

Very often, one is given some seemingly straight-forward clues to recognising that a chemical change has taken place. But the students need to perform experiments where they can distinguish between a chemical change and a physical change, and the conditions under which these changes take place too. For this, they need to be able to perform simple tests for the properties of substances, and how the properties of the starting materials and products are different.

B. Specific properties of substances : simple tests which show that different chemical substances have different properties which can be tested and observed.

They need to have some experiences of distinguishing substances on the basis of their chemical properties, for example, metals may appear similar, but they differ markedly in their reaction with acids and this can easily be studied.

C. The different states of matter, their properties and change of state.

As mentioned earlier, the students learn very early how to associate the correct terms with the processes taking place, but they have no conception of what is happening at the sub-microscopic level during change of state, and how change of state can be brought about. The supply of energy during the process of boiling water might also be more apparent than when ice melts. The reverse processes of condensation and freezing release the same amount of energy, but this is never stressed or understood. Similarly, the cooling caused by evaporation is never internalised.

One way to do this might be to observe changes during different seasons more closely. It is folk wisdom in cold areas that the weather is warmer after it snows, and that it is colder when the snow is melting. What are the situations that people living in warmer places can use? The problem with the evaporation of water being a cooling process is that on large scales, we often feel 'hotter' because the humidity makes us sweat more. Maybe condensation of water-vapour could be studied in detail to appreciate the same process in reverse.

D. The idea of elements, compounds and mixtures and how they are different from each other, how do we identify any sample as one of these categories?

Here, it is important to go into the twin question of separation and purity also. Our classification of a substance as pure would depend on the techniques of separation available to us as also the methods for testing for the purity of the sample. Till isotopes were recognised, the mixture of Cl-35 and Cl-37 found in nature was taken to be 'pure" (which it still is for purposes of studying chemical changes!).

Some simple experiments that will cover the above areas are given in the third part of the module. It is suggested that the students get a chance to perform such and other similar experiments before they are asked to grapple with the atomic theory and related abstract ideas.