

STUDENTS' MISCONCEPTIONS IN LEARNING BASIC CONCEPT 'COMPOSITION OF MATTER' IN CHEMISTRY

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ABSTRACT

The main objective of this research study is to probe students' misconceptions and to provide qualitative descriptions of the existence of high frequencies of alternative conceptions in science students at secondary level. The sample of the study was consisted of 120 subjects of class 10th randomly selected to explore students understanding in the concept composition of matter which is big idea in the field of learning chemistry. Total seven instances or non-instances about this concept were used as IAI (interview about instances) instrument to investigate student's misconceptions of each subject. The reliability of the instrument was determined by Cohen Kappa through inter-rater reliability. Content validity was established by experts. High frequencies of misconceptions rather than scientific responses were obtained from the boys and girls subjects of class 10th in spite of teaching for two years through traditional textbook approach. Further, the qualitative analysis conducted through categorical analysis which explored five categories of misconceptions which indicates the five alternative ways or frameworks of thinking. It may guide science teachers for applying active learning approaches towards promoting conceptual change. More misconceptions were found in category-3 (self-centered/human-centered view) and category-5 (scientific term but incorrect explanation) as compared to other three categories.

Key Words: Misconceptions, Alternative conceptions, Students' understanding, Learning, Basic concept, Composition of matter, IAI (interview about instances), non-instances Content validity, Reliability,

INTRODUCTION

Matter is anything that has mass and occupies space, which exists in three forms – solid, liquid or gas. In a way, matter is the substance of everything. Chemists, however, are especially interested in matter; they study it and attempt to understand it from nearly every possible point of view. So, matter can be described at the level of individual particles that make it up. Therefore, modern chemistry is based on an understanding and exploration of the behaviour and nature of substances at atomic level (Kotz, Treichel & Harman, 2003; Caret, Denniston & Topping, 1997). Learning of isolated science facts, without any sense of how they fit together, is all too common at both the elementary and secondary grade levels. Rote memorization and cramming of such factual information about scientific knowledge has become a routine. In the past, science teachers were used to practice a specified set of teaching methods clearly aligned with any of the existing principles of learning like behaviorism or cognitivism. Traditional lectures were based on the assumption that knowledge is simply transmitted from teacher to student. But in present day schools, more and more emphasis is laid to develop understanding of scientific concepts in students.

Memorization of facts will not suffice in future, due to explosion of scientific knowledge at exponential rate (Peter & Gega, 2002) and also due to changes in society, and what we know about how students learn has changed (Feden & Vogel, 2003). Now the students are not content with just listening to the teacher, doing book reports, taking multiple-choice tests and completing worksheets, or doing their science practicals without relating to any concept in science textbooks. They are doing well on the tests, but unfortunately demonstrated little evidence of remembering the information a week or two later. Thus, conceptual understanding is key aspect of learning. An important teaching goal is to help students understand the main concepts in a subject rather than just memorizing isolated facts (Sanrock, 2007). Research indicates that students of all ages hold quite stubbornly to their alternative conceptions, even after considerable instruction that explicitly contradicts those alternative conceptions (Cary, 1995; Ormrod, 2002).

Atoms are the smallest particles of an element and building blocks of everything seen around us and atoms retain the characteristics of that element and are responsible for the combinations of elements found in molecules and compounds. New experiments show that atoms are composed of even smaller bits of matter called sub-atomic particles. Much of the chemistry of an element depends upon the sub-atomic particles like electrons, protons, and neutrons that are the building blocks of the atoms (Timberlak, 1996). Today, there are 116 different elements. Of these, 92 occur naturally and are found in different combinations, providing the great number of compounds and mixtures that make up our world. Therefore, it is imperative to understand that how the combination of these elements in the form of molecules, compounds mixtures determine the composition of matter. Learning the names and chemical symbols of elements is pre-requisite for learning chemistry.

Methodology

The Interview About Instances (IAI) approach was used as research instruments in this research which was earlier developed by Osborne and Gilbert (1980). This method of exploring students understanding and revealing the current concept of students can be traced back to the clinical interviews developed by Piaget in 1920's and 1930's. It is based on the idea that a particular concept held by a person can be explored by asking the person to distinguish between instances and non-instances of the scientifically accepted concept and by asking them to give reasoning behind their action. Therefore for this research seven instances / non-instances were developed as IAI instrument to probe students' misconceptions for the concept composition of matter at secondary level. To explore the students' misconceptions a represented sample of 120 male and female students from four public high schools was randomly and equally selected. The selected students of class 10th had studied these concepts during their academic session for two years. Therefore, it was assumed that all the students had no problem in the understanding of those concepts.

Development of Research Instrument

Seven instances / non-instances were developed as a research instrument, IAI (Interview about Instances) to explore student understanding about the concept composition of matter in chemistry. These instances are given below.

- i) Distilled water (instance about compound)
- ii) Carbon dioxide (CO₂) (instance about compound)
- iii) Milk (instance about mixture)
- iv) Flame (non-instance or non-example)
- v) Sun-light (non-instance or non-example)
- vi) Wooden chair (instance about composite mixture)
- vii) Copper wire (instance about element).

The following three general questions about each instance were asked.

- i) Do you know, what is this (instance name)?
- ii) Is it a kind of matter?
- iii) Why do you think so?

The most generalized type of content analysis in qualitative research is the Categorical Analysis which has been applied to many other researches to both written and oral production of individuals as well as that of groups. Five categories of alternative conceptions emerged through analysis of the responses of the subjects about the concept composition of matter. The qualitative nature of data in the form of typical statement in each category will be presented in tabular form and also represented by bar graphs about each instance followed by critical analysis.

Reliability of the Instrument

Reliability of the instrument IAI was determined. Female and male students understanding were assessed with both research instruments. Cohen Kappa was used to identify the inter-rater reliability of the instrument. There were six categories of students conceptions identified separately for male and female for the four concepts of chemistry in which five categories were about the alternative conceptions and one category was about the scientific responses. SPSS output has been given in table 1:

Table 1: Inter-rater reliability of the IAI (interview about instances) instrument

		Value	SE(a)	T(b)	Sig.
Measure of Agreement	Kappa	.823	.019	39.064	.000
N of Valid Cases		520			

a Not assuming the null hypothesis.

b Using the asymptotic standard error assuming the null hypothesis.

It is indicated in the above Table 1 that the Cohen Kappa Inter-rater reliability coefficient of the IAI (interview about instances) instrument is 0.823, which is high reliability.

Validity of the Instruments

The content validity of research instrument was established with the consultation of the experts having Doctoral degree in chemistry as well as master degree in Science Education and related experience.

Exploration of Boys

Total 420 responses were obtained from 60 boys subjects in which only 14 responses were scientific whereas 406 misconceptions were assigned into anyone of the five categories which are represented through typical statements as follows:

i) Incorrect Use of Scientific Terms

The subjects of class 10th hold 101 frequencies of alternative conceptions in this category. The responses which were classified in this category the boys subjects applied/used the scientific terms like, mixture, compound or element incorrectly or alternatively to different instances. The subjects used the terms 'mixture' instead of 'compound' for distilled water. For example, distilled water is not a matter but non-living thing made by Almighty Allah. It's a 'mixture' of hydrogen and oxygen" (11). Similarly it was replied that Co₂ is a matter – 'mixture', formed through ionic bonding of the atoms (18). Milk is a complex 'compound' of matter. It is full of protein. When solute is dissolved in solution...its precipitates are visualized in the beaker. White colour is due to bonding force (17). Flame is a 'mixture' of fire, wood and gases. Heat is observed in the form of orange colour. Fire and many other components, emit from the flame (16). Sunlight is a 'mixture' of various gases which is formed by earth, air and water. Light is emitted in the form of heat and fire packet (115). Wood is a 'compound' ... a kind of matter. Its major constituents are water and glucose (4). Copper wire is a 'compound'. It's a metal which is, used in electrical appliances. It is formed by an alloy of Zn and Cu (24). Since, in the above mentioned responses, subjects used the chemical/scientific terms incorrectly.

ii) Self-Contradictory Views

The subjects of class 10th hold 32 frequencies of alternative conceptions in this category. The subjects used the scientific terms for an instance about their views were self-contradictory. For example, distilled water is a clear 'mixture'. But, actually it is a 'compound' of hydrogen and oxygen with definite proportion (5). Milk is a 'compound' in liquid state. It is very energetic and used as diet. However, it also looks like a 'mixture' when its all constituents have definite proportion (2). Flame is a 'matter' it has mass and occupies space. It also produces heat. Although heat is not matter but flame is matter because it is produced from material things (4). Sunlight is energy – a kind of 'matter' because we feel it and occupies space and has mass. Its combination of seven colour (16). Thus, it is clear that they used both terms such as compound and mixture for the same instance in a contradictory way.

iii) Self-centered/Human-centered Views

The subjects of class 10th hold the highest 164 frequencies of alternative conceptions in this category-3. The subjects could not use the scientific terms like compound, mixture, atoms or element to describe the composition of matter instead explained their observations on the basis of their everyday lives or societal terms. For example, water is liquid type matter, which occupies space and have mass, free from all germs (27). Co₂ is not a kind of matter but a gas. It does not occupies space because its constituents have no definite proportion (26).

Milk is a liquid state of matter. Cows are basic source of producing milk for humanity, therefore it can't be prepared chemically. Ca, Fe and glucose are naturally mixed through chemical bonding (26). Flame is a 'gas'. It produces fire and light for us. Flame is a solid thing because it is produced from solid wood and it is gas when formed by natural gas (methane gas) (9). Sunlight is a combination of 'atoms'. There are dust particles in light. It is major source of heat and gives many other benefits to human kind (2). Wood is a useful solid matter for everyone. It is made up of plants cells. Different atoms in solid state form wood. After burning each wood produces similar kind of flame (50). Copper wire is solid...beautiful brown colour. It has 'two types of atoms and electrons'. Good conductor of electricity (24). So, in the above mentioned responses each instance was explained in human or personal context and subjects were not interested to look the instance I a scientific way.

iv) No Scientific Term but Correct Explanation

The boys subjects of class 10th hold 13 frequencies of alternative conceptions in this category. The subjects did not use the terms compound, mixture or element but explained correctly. For example, flame is a kind of energy. It is produced by burning the fuel with oxygen (5). Since, one can see in the case of non-instance flame where subjects did not use the term 'non-matter' or not a kind of matter but explained correctly. Similarly, they explained correctly that copper wire is a metal and matter made up of one type of atoms of copper only and its atoms expand when pressed(8).

v) Correct Use of Scientific Term but Incorrect Explanation

The subjects of class 10th hold alternative conceptions in this category with total frequencies of 96 for the concept composition of matter. For example, "distilled water is a compound.... pure substance. It is useful for 'drinking' because it is a filtered water"(14). CO₂ is a compound, which is colorless, tasteless gas. It is unreactive and can not chemically change into other products (12). Milk is a colloidal solution – liquid in liquid state. Proteins, fats and carbohydrates are found in it. 'Hydrogen bonding' is found in milk, so it is similar to water (13). Flame is not matter produced from burning of oxygen. When it releases smoke and light, becomes injurious to health. 'Hydrogen gas' is around the flame (22). Sunlight is a kind of energy it is not a matter. There are 'ionic particles' in light with the help of them, we can visualize it (28). Wooden chair is matter. Atoms and molecules are its basic unit. Both 'physical and chemical' changes can separate these particles from each other (5). Copper wire is a metal, solid type of matter. It is an element which combine to form 'molecule' by chemical reaction (2). In this category, subjects used the terms compound atoms, metal, molecules, ionic particles, but when it was asked to explain why do you think so? They explained these terms incorrectly.

Table 1: Exploring Students' Understanding (Boys 10th Class) about Major Concept 'Composition of Matter' N = 60

Instances		Distilled Water	CO ₂	Milk	Flame	Sun light	Wooden Chair	Copper Wire	Total Frequency & Average %
Categories of Alternative Concept									
Incorrect use of scientific term	f	11	18	17	16	11	4	24	101
	%	18.33	30	28.33	26.66	18.33	6.66	40	24.06
Self-contradictory views	f	5	2	4	5	16	-	-	32
	%	8.33	3.33	6.66	8.33	26.66	-	-	7.61
Self-centered or human centered views	f	27	26	26	9	2	50	24	164
	%	63.33	43.33	43.33	15	3.33	83.33	40	38.9
No scientific term but correct explanation	f	-	-	-	5	-	-	8	13
	%	-	-	-	8.33	-	-	13.33	3.11
Scientific term but incorrect explanation	f	14	12	13	22	28	5	2	96
	%	23.33	20	21.66	36.67	46.66	8.33	3.33	22.85
Total alternative conceptions	f	57	58	60	57	57	59	58	406
	%	95	96.67	100	95	95	98.33	96.67	96.65
Total scientific responses	f	3	2	-	3	3	1	2	14
	%	5	3.33	-	5	5	1.67	3.33	3.35

Exploration of Students Understanding (Girls)

Sixty girls subjects from class 10th of the two girls high schools were presented same instances/non-instances which were used to explore students understanding of boy subjects. Their total alternative conceptions were 406 and 14 scientific responses. Their responses in different categories are in the following way:

i) Incorrect Use of Scientific Terms

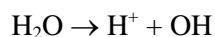
The girls subjects of class 10th hold less alternative conceptions in this category with total frequencies of 83 about all seven instances/non-instances as compared to boys with 101. For example, distilled water is a 'hard water'...carbon and nitrogen particles also mixed. It is apparently not a matter, because it is not H₂O but D₂O (9). Co₂ is a gas – not a matter. It is formed by carbon and oxygen with fixed ratio (14). Milk is a liquid, type of matter, homogeneous solution with fixed ratio (13). Flame is a 'matter' – a mixture of different gases. It is formed by different things, like carbon, methane, heat or smoke (15). Sunlight is a kind of 'matter', there are different gases in it (constituents). The source of its reaching at earth is air and space (8). Wood is a solid and hard like a matter (4). Copper wire is a matter, solid type. It is made up of copper and 'plastic'. It is used for electric circuit (18). Since, in the above responses girls used the terms like 'matter' where it was not desired.

ii) Self-Contradictory Views

The girl subjects of class 10th hold alternative conceptions with 33 frequencies similar in quantity and quality as compared to the boys in this category. For example, distilled water is a type of matter. It is a compound made up of hydrogen and oxygen but it is also a 'mixture' of both gases and some other particles, that is why it changes into ions when electric current is passed through it (3). Co₂ is a matter made up of carbon and oxygen, but it is gas, cannot be visualized so it should 'not be a matter' (2). Milk is liquid, used as soft drink. It is a mixture of water, proteins and other fatty acids. It is also 'compound' because covalent bond is present (2). Flame is not a matter but similar to gas particles, so it may also be called a 'matter' in this sense (93). Sunlight is not a matter but energy. Although, some dust/material particles are its constituents. Waves are the source of light to reaching at earth (17).

iii) Self-centered/Human-centered Views

The girl subjects of class 10th hold 194 (46.16%) alternative conceptions in this category. The girls are more self-centered than boys subjects (164) but quality of responses of girls seemed better in using scientific terms. For example, distilled water is crystallized and pure water when high temperature is reached, its converts into its ions, as following (32):



Co₂ is a gas, a kind of matter. It is formed by carbon and oxygen with ratio 1:2 but its constituents vary in composition so it may be decomposed by some physical means (13). Milk is a complete diet with white colour used as source of energy and vitamins. It is formed through internal chemical process within cows/goats (35). The major components of flame are match and wax. Smoke is also a part of flame. Co, Co₂ are also its constituents (10). Wood is a solid matter made up of atoms. Major constituent is wood itself. Different woods have different nature(54). Copper wire is not a matter, as it is used as electric wires. It is a special type of iron with two kinds of atoms (28). Since, girls mentioned the scientific terms like matter, energy, atoms, to describe the composition of matter in all the seven instance but their self-centered views are more prominent.

iv) No Scientific Term but Correct Explanation

The subjects of class 10th hold alternative conceptions with total 13 frequencies similar to boys in quality and quantity in this category. For example, flame is formed by burning of CH₄ with oxygen. It is warm, so, heat is produced. There is also heat, air and fire particles around it 4). Copper wire is a matter, only one kind of atoms are present in it, so cannot be decomposed into simpler atoms (7).

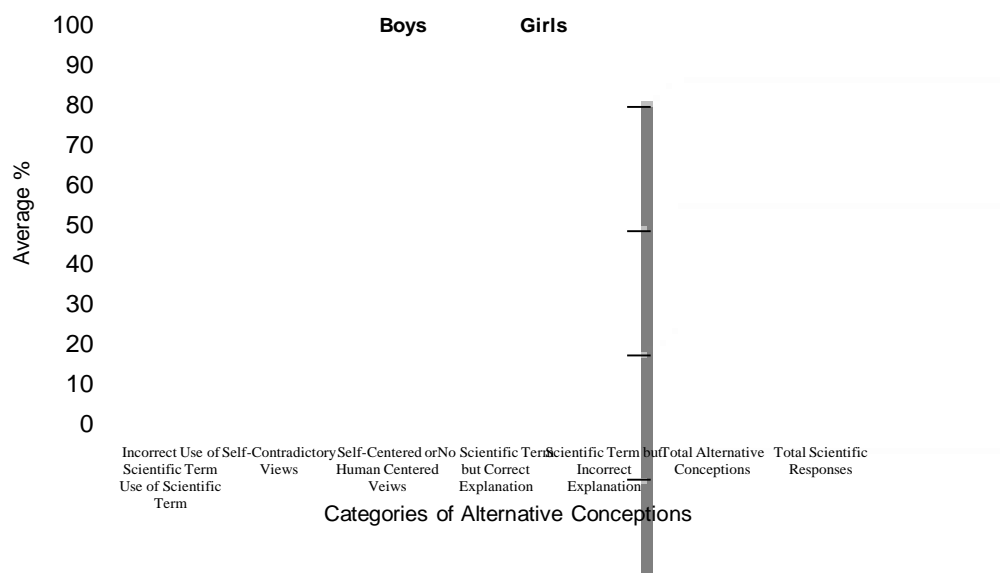
v) Scientific Term but Incorrect Explanation

The subjects of class 10th hold alternative conceptions with 83 frequencies. For example, distilled water is a molecule, formed by oxygen and hydrogen with fixed proportion. When it is heated up then H⁺ and OH⁻ formed. It is a filtered water and useful to drink (13). Co₂ is a compound in gaseous state. But its components have no fixed ratio, thus, it can't be seen (8). Milk is a mixture, a colloid and liquid proteins, fats. There are some chemicals which are taken by cows to chemically produce milk (10). Flame is not a matter. It is not solid, liquid or gas. It is warmer due to H₂ gas. There is nothing around it (20). Sunlight is a type of heat not a matter. Its major source is sun. Dust particles present in it, whereas some gases are its major constituents (28). Wood is a composite mixture. Flame and heat is produced same from all the trees. It can't be changed through chemical reaction (2). Copper wire is formed by a copper element but under high pressure its constituents will be destroyed (2). Since, girl subjects used the terms like molecule, compound, colloid or atoms to describe the composition of matter, but explained them non-scientifically.

Table 2: Exploring Students' Understandings (Girls 10th Class) about Major Concept 'Composition of Matter' N = 60

Instances		Distilled Water	CO ₂	Milk	Flame	Sun light	Wooden Chair	Copper Wire	Total Frequency & Average %
Categories of Alternative Concept									
Incorrect use of scientific term	f	9	16	13	15	8	4	18	83
	%	15	26.67	21.67	25	13.33	6.66	30	19.76
Self-contradictory views	f	3	2	2	9	17	-	-	33
	%	5	3.33	3.33	15	28.34	-	-	7.85
Self-centered or human centered views	f	32	31	35	10	4	54	28	194
	%	53.33	51.67	58.34	16.66	6.67	90	46.67	46.16
No scientific term but correct explanation	f	1	1	-	4	-	-	7	13
	%	1.66	1.66	-	6.67	-	-	11.67	3.01
Scientific term but incorrect explanation	f	13	8	10	20	28	2	2	83
	%	21.67	13.33	16.66	33.33	46.67	3.33	3.33	19.76
Total alternative conceptions	f	58	58	60	58	57	60	55	406
	%	96.67	96.67	100	96.67	95	100	91.67	96.67
Total scientific responses	f	2	2	-	2	3	-	5	14
	%	3.33	3.33	-	3.33	5	-	8.33	3.33

Histograms and overall summary of each concept with the help of tables are also given.



Conclusions

1. Majority of the subjects (90%) of class 10th could not distinguish among distilled water, filtered water or sea water.
2. Majority (97.04%) of the subjects of class 10th taught through traditional textbook approach for the concept 'composition of matter' could not categorize the general examples and non-examples of daily life in terms of atoms, elements, compound, molecules, ions and mixtures.
3. Generally the basic terms like physical and chemical properties of matter were not described correctly by the subjects of control group when asked to distinguish between the mixtures and compounds.
4. Majority of the subjects (could not distinguish between states (solid, liquid or gas) of matter and classification or composition (element, compound, molecule or mixture) of matter.
5. Majority of the students did not recognize CO₂ as a kind of matter. The students used the term 'molecule' for carbon dioxide but the molecules of CO₂ were not matter according to them.
6. Majority of the subjects were unable to discriminate between the terms 'molecule' and 'compound' when the relevant instances of the concept 'composition of matter' were presented.

- Majority of the subjects are of the view that milk was a chemical compound, formed by chemical reactions within cows/goats/buffalos. They consider it similar to the milk which was prepared at plants.

Discussion

This research study exposed the major drawback of traditional textbook approach in teaching of chemistry at secondary level. The extensive data obtained through exploration of students' understanding about the concept, composition of matter in chemistry give strong evidence about the existence of misconceptions. Some other studies like, Sharp, et al. (2009) also shown that the ideas held by the pupils are very resistant to change. This research study agrees due to the fact that traditional textbook approach was applied for two years at secondary level but had made no effect on the construction of scientific concepts. As this group hold 94% alternative conceptions which is a worst situation for science educators. The main cause for the existence of misconceptions seemed to be the use of traditional textbook approach. It transfers only information about science processes such as observing, inferring, and predicting, without relating it to the science content or applying it to solve the real issues or problems of the society that is why students understanding reflected learning as 'scientific truths' making little linkage to core concepts of chemistry. As a result, students learn chemistry but could not understand their ideas towards those accepted by the chemists and did not make better sense of the way in which their environment works. The five categories which emerged through qualitative analysis of the students responses have an important implications for teaching/ learning of chemistry at secondary or higher secondary level. The most prominent category of alternative conceptions emerged from the analysis of data was self-centered/human-centered views with 856 frequencies in the concept composition of matter.

The cause of the origin of alternative conceptions lies somewhat here, when subjects attributed human properties to the instances and adopted ignorant attitude towards their studies was surprising. The self-centered views recognized with the fact that students understandings about the basic concepts of chemistry were strongly influenced by their everyday life experiences and oftenly conflict with scientific views. So, major problems were faced by the subjects of such behaviour during the treatment to the experimental groups. The findings of this research are consistent with the previous research studies in many ways. The research conducted on the concept composition of matter; by Pozo (2001) about the composition of matter, more than 70% prospective teachers could not even describe the relationship between related concepts. Similarly, it was found out as a result of research work that science teachers as well as students hold similar alternative conceptions and there is some evidence that teachers and textbooks might also be serving as sources of alternative conceptions (Gunston as cited in Gilbert, 1982). The present research also agrees that subjects have similar misconceptions. This fact can be perceived in the sense that textbooks present scientific knowledge in the form of isolated facts, or concepts in different chapters which are often missing the sequence or link. Teachers follow the same pattern and transmit information in the same way without linkage of different concepts to each other. Thus, it is not surprising if secondary school students hold more than 90% alternative conceptions about this concept.

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