Exploring Pakistani Students' Alternative Conceptions about Composition of Matter in Chemistry

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Abstract

This study develops an awareness 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. Total seven instances or non-instances were developed as interview about instances (IAI) instrument about this concept to explore student's misconceptions of each subject. The reliability of the instrument was determined by Cohan Kappa through inter-rater reliability. Content validity was established by experts. High frequencies of alternative conceptions and lower frequencies of scientific responses were obtained from the boys and girls subjects. Although, there is relatively low frequency of alternative conceptions in girls than boys, but overall high proportion of alternative conceptions in boys/girls at secondary level indicates a big challenge for science educators. Further, categorical analysis revealed five categories of alternative conceptions. In which many alternative conceptions were found in catetory-3 (self-centered/human-centered view) and category-5 (scientific term but incorrect explanation) as compared to other three categories. This will guide to apply some interactive approach of teaching for conceptual understanding at secondary level, as these subjects were taught for two years through traditional textbook approach but hold huge alternative conceptions.

Keywords: Alternative conceptions, content validity, composition of matter, student's misconceptions, conceptual understanding, Interview about instances (IAI), Self-centered/human-centered view, textbook approach, interactive approach

Introduction

There is much evidence that students often struggle to learn chemistry but do not correctly understand fundamental concepts (Gopal, Kleninsmidt & Case, 2004). If we want students to understand and use scientific ideas their existing beliefs need to be changed through challenging or extending them (Ross, Lakin & Mckechnie, 2010). The major drawback found was that the students have difficulty relating what they learned in class to the world outside. Indeed, schools and the way teachers teach have not changed substantially in modern times. And surprisingly, there is compelling evidence that learners proceed successfully through formal education but without changing their naïve level of understanding (Feden & Vogel, 2003). If that is true, students can go through school, being taught, but not having learned. Therefore it has been observed that the students at secondary level don't understand the basic

concepts of chemistry such as composition of matter. Due to this deficiency they cannot describe their surroundings in the context of chemistry that how the basic terms such as elements, compounds, molecules, ions, and mixtures are used in different situations to represent the matter.

Literature Review

All the matter that surrounds us and from which all other things are built is composed of primary substances called elements. 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. Atoms are the smallest particles of an element and building blocks of everything we see 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).

Above discussion indicates that all substances are made of certain combination of atoms and molecules and enormous diversity in substances around us is due to different possibilities by which atoms are arranged (Salloum & Boujaoude 2008). But it is a dilemma that students are neither guided, nor facilitated to learn chemistry that how the common objects around us for example, pencil or penny's are made up of common elements like carbon and copper respectively.

Sirhan (2007) as cited in Bodner (1991) that Chemistry by its very nature , is highly conceptual while much can be acquired by rote learning in a non-meaningful way. Although students show some evidence of learning and understanding in examination papers, researchers find evidence of alternative conceptions and abuses of rote learning and of certain areas of basic chemistry which are not understood even at degree level. Students' alternative conception is a universal phenomenon and research in science education has identified a vast catalogue of such beliefs held by students which are at odds with orthodox science (Novak, 1978; Iqbal, 2003; Taber, 2002).

Osborne, Bell & Gilbert (1983) pointed out that school students understand little about the nature of matter or about other chemical phenomena in their everyday lives. Surprisingly, after formal school instruction students gave incorrect explanations even about the common phenomena. Many countries revised syllabuses in 1960 to 70s in a logical order but now it is felt that this may not be psychologically accessible to the students. These findings indicated that non-scientific explanations persist for some graduate students with major in chemistry. It was concluded by Ross, Latkin & McKechnie (2010) that students have much problem in

applying their knowledge and they do not extend their knowledge into the real world. For instance, many of our science graduates do not understand that our teeth and bones are built from the element of calcium and phosphorous. The hemoglobin that carries oxygen in our blood contains the element Iron(Fe) and the element Carbon, Hydrogen, Oxygen and Nitrogen derived from the digesting of food are used by the cells of our body to build protein. Similarly, our science students are unable to give the reasons that why Sodium Chloride (Table salt) an ionic compound is a white crystalline solid and Hydrogen chloride, a molecular compound is a gas at room temperature (Stoker,2006).
Peacok, Sharp, Johnsey & Weright (2009) cite that students at higher secondary stage, rarely use terms such as atoms and molecules when explaining chemical reactions and do not easily distinguish between such terms as atoms, elements, molecules o compounds. This is in spite of an apparent understanding of such terms previously in a different context.

Piaget & Inhelder (1974) work describes two main misconceptions:

1. Atomistic, that is, that matter is made up from particles whose properties resemble those of atoms.
2. That matter is continuous, that is, it isn't made of discrete particles, even though pupils accept a particle model in a very limited context.

Similarly children are unlikely to accept the concept that molecules of air are moving in a empty space. Johnson (2002) states that pupil need to have a basic particle model before they can begin to understand the idea of atom and bonding.

Children's alternatives conceptions include the following;

- Particles are different according to their state i.e. gas molecules are round, molecules of liquid have an irregular form and molecules of solids are cubic or cuboids (Haider & Abraham, 1991).
- The size of molecules is determined by the state of matter, i.e. molecules are largest in solids and smallest in gases (Pereir & Pastano, 1991).

Purpose of the study

The main objective of the study was to explore students' alternative conceptions about concept, composition of matter in the subject of chemistry at secondary school level.

Following null hypotheses were devised to explore the study.

- There is no difference of alternative conceptions as compared to scientific responses that students of class 10^{th} hold.
- There is no association between gender and obtained responses.
- There is no association between gender and categories of alternative conception about the concept composition of matter.
- There is no significant difference between, no scientific term but correct explanation and scientific term but incorrect explanation.

Methodology

A sample of 120 students of 10th class from four public high schools of boys and girls were randomly selected. To collect the data seven instances/non-instances were developed to explore students' alternative conceptions for the concept 'composition of matter'. To probe understanding, each subject was invited individually for interview. Open-ended questions were asked while using the IAI research instruments. The Interview about Instances (IAI) approach was developed by Osborne and Gilbert (1980). This method of exploring students understanding and revealing the current concepts of students can be traced back to the clinical interviews developed by Piaget in 1920's and 1930's. This method 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. In IAI technique, pupils are presented with a series of pictures that will illustrate a particular event or context of the instance and then asked if the scientific idea in question applies to this. If they will say 'yes' they will be then asked to explain why? This technique works best when the idea being explored can be expressed in a word or short phrase such as 'energy' or 'chemical' bonding.

The detail of seven instances about the concept composition of matter is given below.

i) Distilled water (instance about compound)
ii) Carbon dioxide (CO_2) (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?

Reliability of the Instrument

Reliability of the instrument IAI and IAE was determined. Female and male students understanding were assessed with both research instruments. There were six categories of students conceptions identified separately for male and female for the concept composition of matter in chemistry. During analysis five categories were identified as the alternative conceptions and one category was of the scientific responses. Cohen Kappa was used to identify the inter-rater reliability of the instrument and its values are given in following table:

Table 1: Inter-rater reliability of the instrument (N=520)

Measure	Test	Value	SE(a)	T(b)	Sig.
Measure of Agreement	Kappa	0.823	0.019	39.064	0.000

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.

Validity of the Instruments

In the light of IAI and IAE research instruments which were developed by Osborne & Gilbert (1980), seven instance were developed about the concept with open-ended questions which were related to the local curriculum of chemistry. Its content validity was established with the consultation of the experts having Doctoral/M.Phil degree in chemistry as well as master degree in Science Education and related experience. Three experts have established the content validity of the instrument.

Data Analysis

The most generalized type of content analysis 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.

After collecting the data from 120 subjects of class 10^{th} from four public high schools of Lahore, the data was audio-recorded. A specially designed paper-sheet for transcription of summary of the responses of the subjects of study was prepared by synthesizing into a coherent description for each instance of each concept to each subject. A simple formula "one instance = one response = one frequency" (and one score) was devised keeping in view the nature of data. This sheet had four columns; (i) name of instance, (ii) knowledge level responses, (iii) reasoning level responses, and (iv) name of category, this part was assigned for writing the expected category after reading the responses. A sample for one instance is given as follows:

Concept: Composition of Matter

Name of the Instance (I)	Knowledge Responses (II)	Reasoning Responses (III)	Name of Category (IV)
Distilled Water			

All the alternative conceptions identified about all instances of this concept were classified into five categories which have been mentioned as follows: (i) Incorrect use of scientific term (ii) Self-contradictory views (iii) Self-centered/human-centered view (iv) No scientific term but correct explanation (v) Correct use of scientific term but in correct explanation. The above mentioned five categories have been deduced through in-depth observation study analysis of the subjects responses and review of the previous studies such as, Novak & Gowin (1986); Osborne & Freyberg (1985); Driver (1989); Brown (1993); Brook & Brook (2201); Iqbal (2003).The frequencies of alternative conceptions of each instance were tallied and then presented in tabular form. The total frequencies of each instance with respect to different categories of this concept are given along with the average percentage in tables.

Table 2: Comparison between alternative conceptions & scientific responses of class 10th (N=840)

Concept	Alternative conceptions		Scientific Responses		χ^2
Composition of matter	812	(96.67%)	28	(3.33%)	731.73***

*** P < 0.001

Above table shows that majority of the students of class 10th hold alternative conceptions with total frequencies 812 (96.67%) of this concepts as compared to scientific responses of total frequencies 28 (3.33%) only. Since χ^2 test was conducted to find out the equal distribution of obtained responses (alternative conceptions & Scientific responses) about the concept composition of matter. The results of χ^2(df=1, N=840)=731.733, p=0.000 shows that they are not equally distributed. This provides evidence that majority of students at secondary level hold many alternative conceptions.

Table 3: Gender Comparison between alternative conceptions & scientific responses of class 10th (N=840)

Name of concept		Alternative Conceptions		Scientific Response		Sig
Gender		Boys	Girls	Boys	Girls	χ^2
Composition of Matter	f	406	406	14	14	0.00
	%	99.66	96.67	3.34	3.33	

There is big difference between alternative conceptions and scientific responses of class 10th. But, there is no gender difference in students understanding. χ^2 test was conducted to find out association between gender and obtained responses (alternative conceptions & Scientific response) of the concept Composition of Matter. The results of χ^2 (df=1, N=840)=0.00, p=1.

shows that there is no association between gender and obtained responses. It is concluded that boys and girls are equally distributed on alternative conceptions and scientific responses.

Table 4: Gender Comparison of Five Categories on Alternative conceptions of class 10th (N=840)

Concept	Incorrect use of scientific term		Self-contradictory views		Self-centered/ human centered view	No scientific term but correct explanation		Scientific term but incorrect explanation		Sig
Gender	Boys	Girls	Boys	Girls	Boys Girls	Boys	Girls	Boys	Girls	χ^2
Composition of Matter	101	83	32	33	164 194	13	13	96	83	5.23

Overall similar trend of alternative conceptions can be observed in class 10th of both boys and girls in each category which indicate some common patterns of alternative thinking in students understanding. However, above tables shows, higher frequencies of alternative conception is found in category-3 self-centered/human centered view for boys and girls and then category 5 (scientific terms but incorrect explanation) and then in category-1 (Incorrect use of scientific terms) for boys and girls almost equally. Self-contradictory views are also prominent.

However, χ^2 test was conducted to find association between gender and five categories of alternative conceptions(Incorrect use of scientific term, Self-contradictory views, Self-centered/ human centered view, No scientific term but correct explanation & Scientific term but incorrect explanation) of composition of matter The results of χ^2 (df=4, N=812)=5.234, p=0.264. shows that there is no association between gender and categories of alternative conception about the concept composition of matter. Although association between gender and categories of alternative conceptions did not consistent about all the conceptions but distribution of huge numbers of alternative conceptions about this concept of chemistry into only five categories clearly shows 'five alternative frameworks' or ways of alternative reasoning among both boys and girls.

Table 5: Categorical analysis of alternative conceptions of class 10th (N=840)

Concept	Incorrect use of scientific term	Self-contradictory views	Self-centered/ human centered view	No scientific term but correct explanation	Scientific term but incorrect explanation	χ^2
Composition of Mater	184	65	358	26	179	413.13***

*** P < 0.001

Chi-square was conducted to find out the difference in frequencies of alternative conceptions in five categories (Incorrect use of scientific term, Self-contradictory views, Self-centered/ human centered view, No scientific term but correct explanation & Scientific term but incorrect explanation) the results of chi square shows that there is significant difference between these categories. The results of chi-square on composition of matter is χ^2 (df=4, N=812)=413.135, p=0.001. The result shows that there is a significant difference of these categories. Therefore, it is concluded that there was found five different alternative frameworks or ways of alternative reasoning because all alternative conceptions are not equally distributed in all these five categories which means five alternative frameworks do not guarantees the equal distribution of alternative conceptions in all categories.

Conclusion

On the basis of research findings, it can be concluded that majority of science students at secondary level hold alternative conceptions about the concept composition of matter in chemistry.

Further, categorical analysis revealed highest frequencies of alternative conceptions in catetory-3 (self-centered/human-centered view). Many alternative conceptions were also found in category-5 (scientific term but incorrect explanation) and 1 (incorrect use of scientific terms) respectively. Self-contradictory views (cateotry-2) were also found, but comparatively in less number of frequencies as compared to other categories. However, lowest frequencies of alternative conceptions were observed in category 4 (no scientific term but correct explanation).

The above categorization of alternative conception has an important implication as a source of guidance to apply some interactive approaches of teaching and learning for conceptual understanding at secondary level.

It is notable that these groups were taught for two years through traditional textbook approach. Therefore, this study has many implications, as it tends to indicate that conventional instructional practices do not promote meaningful, conceptual understanding of the content of chemistry. Instead, these students were promoted from lower grade to higher grade without fully understanding the basic concepts of chemistry. This research study also indicates no gender effect because understanding elicited from both boys and girls was almost equivalent to all the four selected concepts of chemistry. However, after comparing the cumulative percentages of all the concepts girls hold slightly less percentage of alternative conceptions than boys and there is no significant difference between them.

1. Majority (97.04%) of the subjects of class 10^{th} taught through traditional textbook approach for the concept 'composition of matter' could not categorize the general examples/non-examples of daily life in terms of atoms, elements, compound, molecules, ions and mixtures.

2. Majority of the subjects (90%) of class 10^{th} could not distinguish among distilled water, filtered water or sea water.
3. Majority of the subjects (class 10^{th} could not distinguish between states (solid, liquid or gas) of matter and classification or composition (element, compound, molecule or mixture) of matter.
4. 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.
5. 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.
6. Majority of the students did not recognize CO_2 as a kind of matter. The students used the term 'molecule' for carbon dioxide but the molecules of CO_2 were not matter according to them.
7. 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 prepared at plants.

Discussion

A number of research studies, such as Wood-Robinson (1991) as cited in Bennett (2003) and Pfund & Duit (2001) on students' understandings have reported students alternative conceptions about a range of science concepts and understandings. Now it is known as Alternative Conceptions Movement (ACM). The present research study also confirms it and demonstrated the reality of traditional textbook approach in teaching of chemistry at secondary level. The extensive data obtained through exploration of student understanding about the concept, composition of matter in the discipline of chemistry give strong evidence about the existence of alternative conceptions. 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 with reference to traditional textbook approach which was applied for two years at secondary level but had made no effect on the formation of scientific concepts. As this group hold 94% alternative conceptions which is an alarming situation for science educators. The main cause for the origin of alternative conceptions 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.

These five categories which emerged through 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 often conflict with scientific views. The findings of this research are consistent with the previous research studies in many ways. The null hypothesis that there is no significant difference between, no scientific term but correct explanation and scientific term but incorrect explanation was not supported. 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. There is some evidence that teachers and textbooks might also be serving as sources of alternative conceptions (Gilbert, 1982). The null hypothesis that there is no difference of alternative conceptions as compared to scientific responses that students of class 10^{th} hold was not supported. The null hypothesis that there is no association between gender and obtained responses was not supported. The present research study 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. The null hypothesis that there is no association between gender and categories of alternative conception about the concept composition of matter was not supported.

Following recommendations has been made based on the findings of the present study.

- Students prior conceptions and experiences must be taken into consideration in every teaching and learning environment to promote conceptual change through persuading learners to adopt a scientific framework which is more acceptable in understanding chemical phenomena.
- The exploration of science teachers' understanding about different concepts of chemistry is basic need to raise the standard of science education generally at the globe and specifically in developing countries like Pakistan.
- Present curriculum and textbooks of chemistry do not fulfill the need of present time. Therefore, it is necessary to develop new science curricula in the context of constructivist approach in coherent way to show the linkage of concepts within the discipline of chemistry as well as to other science disciplines.

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