

Investigating Pakistani Students' alternative Ideas regarding the Concept of Chemical Bonding

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Abstract

Acknowledgement of prior students' conceptions by science teacher has proved a significant tool for effective science teaching/learning. So the major objective of this research study is to investigate students' alternative ideas (misconceptions) and to develop an understanding about the existence of high frequencies of alternative ideas among science students at secondary level. A random sample of 120 students of 10th class was selected to explore students understanding regarding the concept chemical bonding. Seven instances or non-instances in total about this concept were developed to explore student's misconceptions. Inter-rater reliability was used to determine the reliability of the instrument (IAI) through Cohan Kappa cross tab statistics. Content validity of the instrument was established by experts' judgemental procedures. On the whole high frequencies of alternative ideas and low frequencies of scientific responses were obtained from girls and boys. Although, there was found relatively high frequency of alternative ideas in boys than girls, but overall high proportion of alternative ideas both in girls and boys at secondary level pointed out a big challenge for science educationalist. Further, categorical analysis revealed five categories of alternative ideas. In these alternative ideas many responses were identified as self-centered / human-centered. Similarly, subjects used many scientific terms but explained them incorrectly. There were found three other categories of alternative ideas but comparatively less in numbers. It was notable that less number of scientific ideas could develop despite of teaching chemistry for two years through traditional textbook approach at secondary level.

Key Words: alternative ideas, students understanding, chemical bonding, instances or non-instances, Inter-rater reliability, Content validity, textbook approach

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Introduction

The literature has identified a range of views held by children about particular scientific concepts which were not in accord with the way that scientists understand our world and these scientifically in-correct conceptions have been given numerous names such as misconceptions, alternative conceptions, alternative frameworks or views, mini-theories, common sense conceptions, preconceptions and untutored beliefs (Driver & Easley, 1978; Pfundt & Duit, 2000) but, the most accepted description is 'alternative conceptions' (Wandersee, Mintzes & Novak, 1995). This expression has been selected because it not only refers to experience-base explanations constructed by the learner to make a range of natural phenomena and object intelligible, but it also confers intellectual respect on the learner who hold those ideas.

The aim of chemistry teachers at all levels is to make the subject accessible in such a way that maximum meaningful learning can take place (Sirhan, 2007). This has serious implications for teaching chemistry because this subject is often considered as difficult, which sometimes becomes an obstacle for students to continue with studies in chemistry. Several reasons have been proposed to account for this. They include: i-A linkage between two concepts that leads to a clearly false proposition or by a linkage that misses by key idea relating two or more concepts (Novak & Gowin, 1986), ii-That students' intuitive concepts are grounded in everyday experiences (Osborne & Frey berg, 1985; Driver, 1989; Ross, Laki, & McKechnie, 2010), iii-That students have difficulty in understanding abstract concepts (Murray, Schultz, Brown & Clement, 1990; Brown, 1994), iv-Those students have problems perceiving the invisible molecule (Brook & Brook, 2001; Gabel & Bunce, 1994). Therefore, in the lights of above mentioned reasons, it is imperative to know their impact on students' ideas. Since, researches in many countries indicates that despite many years of formal schooling, students in many instances, not acquiring more scientific ideas about how to interpret their world. Numerous research studies have reported students' alternative ideas as about a range of science concepts and understandings (Pfund & Duit, 2001).

As chemical bonds are central to chemistry which indicates the strength of attractions within molecules and chemists understand the properties of matter in terms of the types of bonds that hold atoms together. Understanding the nature and origin of chemical bonds is an important part of understanding Chemistry, because changes in these bonding forces constitutes the underlying basis for all chemical changes and reactions, old bonds break and new ones form when chemicals react. For instance,

when we digest meat, the bonds that hold the amino acids together in proteins are broken and amino acid molecules are set free. Then processes in our cells recombine them to form the specific protein that we need for survival. But the complex structures of DNA are determined not just by the atoms present, but also by the chemical bonds that binds the atoms to each other with their molecules.

And how do bonds form between atoms of the similar or dissimilar elements. How can we describe the bonds in substances such as HCl, NaCl, H₂, Cl₂, CO₂ (McMurry & Foy, 2006). Therefore, it is a fact that without knowing the nature of different chemical bonds, it is not possible for science students to respond correctly. As artificial blood, new pharmaceuticals, agricultural chemicals and the polymers are used to make modern artifact such as CDs, cellular phones and synthetic fibers have all become possible because chemists understand how atoms link together in specific ways. But, unfortunately, our today's teaching approaches specially in Pakistan at schools /colleges do not address such basic and important topics, therefore students are taught chemistry but they do not learn how to relate chemistry with their daily lives. In other words, students do not learn chemistry (Atkin & Jones, 2000).

For instance, why calcium phosphate has been adopted by nature for the formation of bones? How can we make lighter and stronger airplanes and rockets? Answers to questions like these depend on understanding the different types of bonds. Chemists understand the properties of matter in terms of the types of bonds that hold atoms together (Brady & Holum, 2000). But our traditional teaching approaches are inefficient to develop conceptual understanding in students mind.

Misconceptions are not wrong or bad ideas; they are the 'meanings' in a 'limited' perspective which leads to newer or better understandings about a phenomenon. As, Einstein built on Newton's theories, added to them and took them to new levels of complexity and sophistication. If Newton had been completely wrong, Einstein could not have been right – without Newton, there could not have been Einstein. Therefore, without knowing the misconceptions or alternative ideas of the students, there could not have been possible to make the teaching and learning effective (Alchin, 2003). Alternative ideas are invalid concepts that students construct using their experiences, expectations, beliefs, and emotions. When children start school, they have already developed their own concepts or theories about the world around them (Reiner, Slotta, Chi & Resnick, 2000). Because these theories develop without instruction or with very little guidance from teachers they are also called **naïve theories** which very often include misconceptions (Moreno, 2010).

Some misconceptions are cases of under generalization, where students have a concept often is too narrow because it fails to include relevant objects or events. K-2 children will often under generalize the concept 'animal' by including only mammals. Other misconceptions are cases of overgeneralization, where students have a concept that is too wide because it includes irrelevant objects or events. Students in grades 3-5 tend to overgeneralize the idea that all living things need to eat food to survive, such as thinking that plants obtain their food or 'eat' food through their roots. The origin of misconceptions is believed to be the result of everyday interactions with the world as well as the ways in which culture and its adult members transmit information (Duschl, Schweingruber, & Shouse, 2007). Some misconceptions arise from inappropriate common expressions about natural phenomenon (Duit, 2000). For instance, people say that sun and moon, 'rise' and 'set' suggesting that it is the sun that moves around the earth rather than the opposite. Children are also likely to learn misconceptions from the media or other people who have misconceptions. Many adults believe that Africa is a country (it's a continent) and that dinosaurs and humans co-existed (Nehm & Schonfeld, 2007).

The main objectives of the study were

- To explore students' alternative ideas about the concept chemical bonding of chemistry at secondary school level.
- To find out the alternative ways of thinking, through categorizing the alternative ideas of students regarding the concept chemical bonding.

Methodology

Selection of a random sample yields research data that can be generalized to a larger population. Four public high schools from two towns of Lahore city were selected randomly. Two public high schools from each town of city in which one boy's high school and one girl's high schools were randomly selected. All public schools are bound to implement the textbook of chemistry developed by Punjab Textbook Board. Similarly, the socio-economic status of students, qualifications of the teachers as well as their teaching methodology, administrative style, teaching periods allocated to chemistry, age and grade levels, financial and other facilities were also similar. Therefore, it was useful for the purpose of generalizability of the result of the study at a larger scale. Random selection of students of 10th class to explore the students understanding and elicitation of alternative ideas was made from a representative equal sample of 120 male and female (30 students from four public high schools) was randomly selected. The selected students of 10th class had studied

this concept during their academic session of two years. Therefore, it was assumed that all the students had no problem in the understanding of that concept.

Development of Research Instrument

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 ideas or 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. Interviews are carried out preferably with individual or with small group (depend upon the nature of instance).

As a research instrument, IAI (Interview about Instances) seven instances were developed to explore student understanding about the concept chemical bonding in chemistry. These instances are given below.

- | | |
|--|------------------------------|
| (i) NaCl | (ii) $N \equiv N$ |
| (iii) H – Cl | (iv) $NH_3 \rightarrow BF_3$ |
| (v) Two Water molecules (non-instance) | |
| (vi) Na + He (non-instance) | (vii) Na + Mg metals |

Chemical Bondings

The following three general questions were asked during interview about each instance under this concept.

- What does this diagram/instance explain?
- Is it a type of chemical bond?
- Why do you think so?

Some of the following questions were asked with reference to each instance for further exploration:

- Is there any change in the size of atom before and after approaching each other?
- Why charges produced/not produced?
- Is there any force involved?
- Is there a formation of compound/molecules?
- What is formed due to this process?

Reliability of the Instrument

Reliability of the instrument IAI and IAE 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 ideas identified separately for male and female for the four concepts of chemistry in which five categories were about the alternative ideas and one category was about the scientific responses. SPSS output has been given in the appendix C and its values are given in following table:

Table 1: Inter-rater reliability of the instrument to identify alternative ideas about the concept of chemical bonding

		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.

Validity of the Instruments

In the light of IAI research instrument which was developed by Osborne & Gilbert (1979), seven instances were developed about the concept chemical bonding with open-ended questions. The content validity was established by the experts both in chemistry and Science Education with related experience. Three experts have established the content validity of the instrument.

Data Analysis

After collecting the data from 120 subjects of class 10th 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: Chemical bonding

Name of the Instance (I)	Knowledge Responses (II)	Reasoning Responses (III)	Name of Category (IV)
H – Cl			

All the alternative ideas 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); Brook & Briggs (1984); Iqbal (2003). The frequencies of alternative ideas 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. Chi-Square test was used for statistical analysis

Table 2: Comparison between alternative ideas & scientific responses of class 10th

Concept	Alternative ideas		Scientific responses		χ^2
Chemical Bonding	781	(92.97%)	59	(7.031%)	620.576***

*** P < 0.001

The results of the concept chemical bonding $\chi^2(df=1, N=840)=620.576, p=0.000$ shows that they are not equally distributed. This provides evidence that majority of students at secondary level hold many alternative ideas.

Table 3: Gender Comparison between alternative ideas & scientific responses of Class 10th

Name of Concept	Alternative Ideas		Scientific Response		χ^2
	Boys	Girls	Boys	Girls	
Chemical Bonding	396	385	24	35	2.206
	%	94.29	91.61	5.71	

There is big difference between alternative ideas 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 ideas & Scientific response) of the concept Chemical bonding.

The results of the concept chemical bonding's χ^2 (df=1, N=840)=2.206, p=0.137 shows that there is no association between gender and obtained responses for the selected concepts of chemical bonding's. It is also evident with respect to girls scientific responses frequencies or percentages 121 (7.92%) as compared to 90 (5.93%) of boys.

Table 4: Gender Comparison of Five Categories on Alternative ideas of class 10th

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
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	
Chemical Bonding	72	69	21	26	180	131	10	1	113	158	23.002

Overall similar trend of alternative ideas can be observed in class 10th of both boys and girls in each category which indicate some common patterns 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 ideas (Incorrect use of scientific term, Self-contradictory views, and Self-centered / human centered view, No scientific term but correct explanation & scientific term but incorrect explanation) of chemical bonding. The results of χ^2 test on chemical bonding χ^2 (df=4, N=781)=23.002, p=0.000 show that there is association between gender and categories of alternative conception about the concept chemical bonding.

Although association between gender and categories of alternative ideas did not consistent about all the ideas but distribution of huge numbers of alternative ideas 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 ideas of class 10th

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
Chemical Bonding	141	47	311	11	271	450.581***

*** P < 0.001

Chi-square was conducted to find out the difference in frequencies of alternative ideas 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 no significant difference between these categories. The results of chi-square on chemical bonding is χ^2 (df=4, N=781)=450.581, p=0.000. These results support the above discussion. Therefore, it is concluded that there was found five different alternative frameworks or ways of alternative reasoning because all alternative ideas are not equally distributed in all these five categories which means five alternative frameworks do not guarantees the equal distribution of alternative ideas in all categories.

Discussion

Taber (1998) reported that undergraduates do have an alternative theory of chemical bonds. This research study also confirms that subjects taught through traditional textbook approach do have more than 90% alternative ideas of the chemical bonds. The present research study also demonstrated the limitations of traditional textbook approach in teaching of chemistry at secondary level. The extensive data obtained through exploration of student understanding of chemical bonding in chemistry give strong evidence about the existence of alternative ideas. These 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 used to teach chemistry for these subjects but had made no effect on conceptual change. As this group hold 94% alternative ideas which is an

alarming situation for science educators. The main cause for the origin of alternative ideas seemed to be the use of traditional textbook approach. It emphasises only to transfers factual 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 change 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 have important implications for teaching/ learning of chemistry at secondary or higher secondary level. The most prominent category of alternative ideas emerged from the analysis of data was self-centered/human-centered views with 311 frequencies. The cause of the origin of alternative ideas 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 concept of chemistry were strongly influenced by their everyday life experiences and often conflict with scientific views.

The category-V (correct scientific term but incorrect explanation) has also many alternative ideas with frequencies 271 and it was apparently opposite but was closely aligned to category-IV (more scientific term but correct explanation) with 11 frequencies. Both these categories represented the alternative ideas with 'partial understanding'.

In the category-I (incorrect use of scientific terms) there were 141 frequencies. In this category the subjects used incorrect terms or made incorrect explanations. Feden & Vogel (2003) declared it the major problem, where learners can succeed in formal education without changing their naïve levels of understanding. In this problem students do not shed their erroneous beliefs/ alternative ideas and not replace them with deeper and less naïve understanding of important facts, events, concepts and ideas. The category-2 self-contradictory view was at fourth stage with respect to frequencies of 47 alternative ideas. Although many researches have called it a major problem but the present research partially disagrees to this finding. It is due to the fact that the subjects only seemed to confuse or less confident due to which they were self-contradictory.

Conclusion

On the basis of research findings, it can be concluded that majority of science students at secondary level hold alternative ideas in the area of chemical bonding in chemistry. Further, categorical analysis revealed highest frequencies of alternative ideas in category-3 (self-centered/human-centered view). Many alternative ideas were also found in category-5 (scientific term but incorrect explanation) and 1 (incorrect use of scientific terms) respectively. Self-contradictory views (category-2) were also found, but comparatively in less number of frequencies as compared to other categories. However, lowest frequencies of alternative ideas were observed in category 4 (no scientific term but correct explanation). It is notable that these subjects 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 in this concept of chemistry. However, after comparing the cumulative percentages of all the concepts girls hold slightly less percentage of alternative ideas than boys but there is no significant difference between them. Some major alternative ideas are given below.

- Almost all the subjects of 10th class, holding alternative ideas could not differentiate between molecule and compound or molecule of an element and molecule of a compound.
- Majority of the subjects could not give logical reasons about the smaller atomic size of chlorine (17) as compared to bigger atomic size of sodium (11).
- Majority of the subjects could not explain why sodium chloride (NaCl) is called a compound instead of a molecule.
- Majority of the subjects could not explain the difference between the electronegativity in HCl and electrostatic force of attraction in NaCl.
- HCl instance was mostly confused with NaCl and termed as ionic bond due to its partial positive and negative ends.

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