Pupils' Ideas in Learning Concept of the Chemical Bonding among Pakistani Students

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Abstract

The major objective of this research study is to look into alternative ideas of science students in learning concept of the chemical bonding. 120 students of 10th class were included in randomly selected sample that has learnt chemistry for two years through traditional text book approach. Seven instances or non-instances were used to explore misconceptions of each subject. To determine the reliability of the instrument (IAI), Inter-rater reliability Cohan Kappa cross tab statistics was used. Content validity of the instrument was established through experts' judgemental procedures. Overall high proportion of alternative ideas 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 which many alternative ideas were found in two main categories such as self-centered or human-centered views and incorrect use of scientific terms. There were found three other categories of alternative ideas but comparatively less in numbers. It is notable that their ideas were not improved despite teaching for two years through traditional textbook approach. Thus, this study will guide to change the alternative ideas through more cooperative and interactive approaches of teaching and learning chemistry at secondary and higher secondary level.

Introduction

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 (Stoker, 2006). 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 (Santrock, 2007).

Since, learning is not limited to mere 'conceptual understanding' but now learning is more appropriate to see as 'conceptual change' (Skamp, 2005).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 ideas have been given numerous names such as misconceptions, alternative conceptions, alternative frameworks or views, mini-theories, common sense conceptions, preconceptions and untutored beliefs (Pfundt & Duit, 2001) but, the most accepted description is 'alternative ideas' (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.

It must be noted that it is the textbooks and teachers who fail to present or describe the knowledge needed for shared meaning or construction of ideas. So, major sources of misconceptions are the teachers' methodologies as well as the ways of presentations of knowledge in the textbooks. 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 **naive theories** which very often include misconceptions (Moreno, 2010).

The need for exploration of ideas of science students laid for two reasons. Teachers need to know what stage in their conceptual development their pupils have reached, and pupils need to compare their existing ideas with the new ideas they are being taught (cognitive conflict), thereby enabling these new concepts to be built firmly into their (previous) understanding. Previous research will tell us what we might expect (Ross, Lakin & McKechnie, 2010).

Methodology

The Interview About Instances (IAI) approach was used 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 to probe students' misconceptions for the concept of chemical bonding at secondary level.

Random selection of students of 10^{th} class to explore the students misconceptions was made from a represented equal sample of 120 male and female (30) students from four public high schools was randomly selected. The selected students of class 10^{th} 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

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.

i) What does this diagram/instance explain?
ii) Is it a type of chemical bond?
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. 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 bondings

		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 and IAE research instruments which were developed by Osborne & Gilbert (1979), 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

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); Schultz, Brown & Clement (1998); Brown (1993); Brook & Briggs (1984); Zafar 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 . All the data presented in tables in the form of frequency and percentage was interpreted through typical statements of the subjects about each instance.
Histograms and overall summary of each concept with the help of tables are also given.

Exploration of Students Understandings (Boys)

Sixty boys of class 10^{th} were presented with the following seven instances/ non-instances to explore students understanding of chemical bondings.

In this group only 24 responses of seven instances/non-instances about chemical bondings were categorized correct (scientific) whereas 396 responses were classified into five categories of alternative ideas in the following way:

i) Incorrect Use of Scientific Term

The boys subjects of class 10th hold 72 frequencies of alternative ideas. For example, NaCl is a compound formed by covalent bonding (7). Nitrogen (N_2) molecule is double or triple bond but there is no change in energy (4). Instance of HCl shows ionic bond as positive and negative ions are there. Electronegativity is involved to shifting electrons from one atom to another (18). $NH_3 \rightarrow BF_3$ shows covalent bond and sharing of electrons is equal. Arrow shows chemical reaction. There is no 'electronegativity' (15). Water is formed by an ionic bond where no electronegativity is involved but only dipole moment is acting on it (8). Na+He shows chemical bonding and molecule is formed (16). Mg and Na metals represent covalent bond and both are sharing their electrons (4). Since, in all the above mentioned seven instances all the subjects used the terms such as, covalent bond, ionic bond etc. incorrectly. This shows that these subjects could not apply their knowledge scientifically.

ii) Self-Contradictory View

The subjects of class 10th hold 21 frequencies of alternative ideas in this category. For example, nitrogen molecule shows covalent bonding. Both atoms are donating their electrons to each other so, it can also be a coordinate covalent bond (2). HCl shows covalent bond – sharing of electron is there. But charges also show that it is an ionic bond (1). $NH_3 \rightarrow BF_3$ is non-polar covalent bond but sharing of electrons occurs so it is a covalent bond (1). Water is a polar covalent bond, when opposite forces act on it, then coordinate covalent bonding may be there (4). Na + He atoms indicating a chemical reaction. But atoms are repelling each other. No change in energy. It looks an ionic molecule (6). Since, mostly the subjects were seemed to confuse and were changing their statement frequently.

iii) Self-centered/Human-centered Views

The subjects of class 10th hold highest 180 frequencies of alternative ideas in this category. For example, NaCl is a compound formed due to a 'chemical process'. Sizes of their atoms and ions are not clear but 'some ionic force' is involved (29). Nitrogen molecule shows a chemical bond in which both atoms are donating their electrons to each other. So it can also be called a 'force' (25). HCl is an acid, having strong dipole moment with a force called electrostatic force (25). There is a no bond between $NH_3 \rightarrow BF_3$. Arrow represents a chemical reaction. No electronegativity is involved (15). Water molecules show a chemical bond. Hydrogen and oxygen atoms are indicated through dipole – dipole bond, not exactly known about dotted lines (31). Na + He atoms indicate a chemical reaction. Both atoms are repelling to each other. No change in energy. It looks like an ionic molecule (22). Mg + Na are reactive metals and used for making utensils. Positive and negative signs shows cathode and anode rays (33). So, subjects used the term like 'force, chemical reaction or chemical processes, acid' etc. in everyday language.

iv) No Scientific Term but Correct Explanation

The subjects of class 10th hold lowest frequencies 10 of alternative ideas in category-4. For example, NaCl is a compound but not a molecule. Variation in sizes of atoms and ions is due to gaining and loosing electrons (4). Both atoms of nitrogen are bonding through sharing of three pairs of electrons (3). Ammonia donates a pair of electrons to Boron trifluride and arrow shows this donation (1). In Na + He atoms He is a noble gas – nonreactive. So, no indication of chemical reaction or formation of a compound (1). In Mg and Na metals, there is non-formal type of bonding shown with positive and negative ions. Mg is stronger than Na because Mg has more free electrons than Na metal (2). Interestingly, subjects correctly explained the instance related to bonds like, ionic/covalent bond or metal bonds but not used the term or name of that bond.

v) Scientific Term but Incorrect Explanation

The subjects of class 10th hold frequencies of 113 alternative ideas in category-5. For example, NaCl shows an ionic bond. Electronegativity is involved in forming this compound (19). Nitrogen molecule shows triple covalent bond. Both nitrogen atoms have equal density and electronegativity make it more stronger (22). HCl is a polar covalent bond. Polarity and electronegativity is involved on both atoms in equal proportion (11).

It is a coordinate covalent bond between $NH_3 \rightarrow BF_3$ but also shows a chemical reaction without electronegativity (21). Water molecule represents hydrogen bonding positive and negative ions are shown but electronegativity is not involved there (17). Na and He is not type of chemical bond and not a compound. Although, there may be some electronic movement but reason is unknown (7). Mg and Na metal shows metallic bond and mutually share their electrons to make it stronger (16). Thus, mostly the subjects explained the chemical terms such as electronegativity, polarity etc. incorrectly.

Table 2: Exploring Students' Understandings (Boys 10th Class) about Major Concept 'Chemical Bondings' (N = 60)

Instances/ non-instances / Categories of Alternative Concept		NaCl	N ≡ N	H-Cl	$NH_3 \rightarrow BF_3$	Two Water Molecules (hydrogen bond)	Na+He	Na + Mg Metals	Total Frequency & Average %
Incorrect use of scientific term	f	7	4	18	15	8	16	4	72
	%	11.66	6.66	30	25	13.33	26.67	6.66	17.14
Self-contradictory views	f	2	1	1	4	4	6	3	21
	%	3.33	1.67	1.67	6.66	6.66	10	5	5
Self-centered or human centered views	f	29	25	25	15	31	22	33	180
	%	48.33	41.67	41.67	25	51.67	36.67	55	43.05
No scientific term but correct explanation	f	3	3	-	1	-	1	2	10
	%	5	5		1.67		1.67	3.33	2.38
Scientific term but incorrect explanation	f	19	22	11	21	17	7	16	113
	%	31.66	36.67	18.33	35	28.34	11.67	26.66	26.90
Total alternative ideas	f	60	55	55	56	60	52	58	396
	%	100	91.67	91.67	93.34	100	86.67	96.67	94.29
Total scientific responses	f	-	5	5	4	-	8	2	24
	%		8.33	8.33	6.66		13.33	3.33	5.71

Exploration of Students Understandings

Same sixty girls of class 10th were explored students understanding of the third concept **'Chemical Bondings'** whom were already probed other concepts 'chemical bonding' and 'solution'. The same seven instances/non-instances of chemical bonding were presented to girls subjects which were presented to boys. In this group only 35 responses about seven instances/non-instances of chemical bondings were scientific while 385 responses were placed under the five categories of alterative ideas in the following way.

i) Incorrect Use of Scientific Term

The subjects of class 10th hold frequencies of 69 alternative ideas in category-1. For example, NaCl shows covalent bonding and it is not a compound but an acid (6). Nitrogen molecule (N ≡ N) is formed through coordinate covalent bond. Both atoms have no dipole moment (3). $NH_3 \rightarrow BF_3$ formed through covalent bonding sharing of electrons is shown. Compound formation is represented by an arrow (10). HCl is formed by coordinate covalent bond as well as polar bond (18). Mg and Na metal represents an ionic bonding because positive and negative charges are shown (3). Na + He atoms designate covalent bonding as Na and He atoms are sharing their electrons (20). Thus, in all these instances, subjects could not recognize the type of correct chemical bondings.

ii) Self-Contradictory View

The subjects of class 10th hold frequencies 26 of alternative ideas self-contradictory view. For example, NaCl represents no chemical bonding but there is also a chemical reaction in which ionic bond formed (3). Nitrogen (N ≡ N) molecule shows covalent bond but actually it represents coordinate covalent bond (1). HCl is formed by covalent bond. As there are positive and negative charges on it so, it shows ionic bonding also (2). Water molecule shows hydrogen bonding. There are also charges which are showing ionic bonding (4). Na and He atoms are not chemically bonding although, formation of a compound can be observed between them (10). Here, girls subjects were more confused as compared to boys and changed their statements alternatively.

iii) Self-centered/Human-centered Views

The subjects of class 10th hold highest frequencies 131 of alternative ideas as self-centered view. For example, NaCl is not a type of chemical bond, as a diet and this compound is not formed due to a chemical reaction (11). Nitrogen molecule (N≡N) formed through covalent bond and they are chemically reactive and used in urea (27). HCl is formed by single covalent bond. No compound is formed. As much energy is produced in it chemical reaction. No electronegativity is involved in this bond (26). $NH_3 \rightarrow BF_3$ is not a chemical bond but two groups are attracting each other. Arrow shows chemical equation (23). Water molecule shows hydrogen and oxygen molecules. They are also helpful in dissolving. Dipole moment is shown (20). Na + He atoms are bonding mutually and showing change of energy. There is some change of sizes of the atom when they approach each other (9). Mg and Na metals are good conductor of electricity and both chemical reactive and blast other(15). The girl subjects explained these instances in everyday language such as diet, blast, chemical reaction but could not explain in a scientific way.

iv) No Scientific Term but Correct Explanation

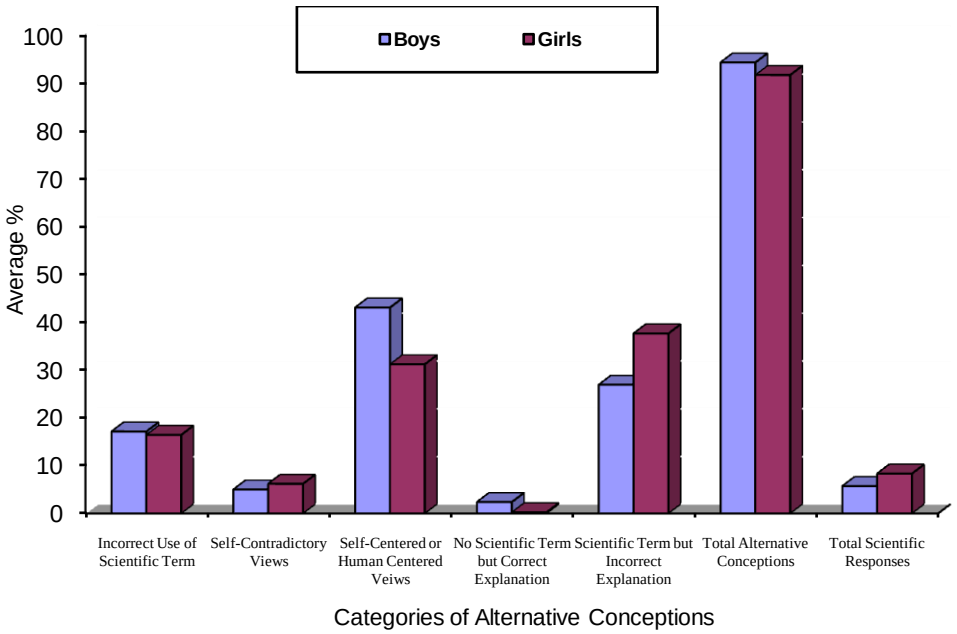
The subjects of class 10th hold 1 frequency of alternative conception. For instance, HCl is a representing chemical bonding, which signify a polar molecule and electronegativity is involved in sharing of electrons (1).

v) Scientific Term but Incorrect Explanation

The subjects of class 10th hold frequencies 158 and emerged as biggest category of alternative ideas in chemical bonding. For example, NaCl shows ionic bonding. Both atoms share their electrons when Na metal react to chlorine gas. They mutually bond together through sharing of electrons (35). Nitrogen molecule (N_2) is a non-polar/triple covalent bond and a compound is formed. Molecules and compounds are same thing (27). HCl is a polar covalent bond in which sharing of electrons between two atoms occurs. There is dipole moment but no electronegativity (11). $NH_3 \rightarrow BF_3$ coordinate covalent bonding. Electrons are mutually shared by them. Arrow shows a chemical equation(16). Water molecule represents hydrogen bonding and dipole moment. There are special kind of charges which dissolves everything in water (25). Na + He atoms do not represent a chemical bond, no change in energy but both atoms approach each other and some changes occur (10). Mg and Na metal is representing metallic bonding. A chemical reaction takes place among both metals (34). Surprisingly, subjects identified the correct instances relevant to covalent bond but explained them incorrectly.

Table 3: Exploring Students' Understandings (Girls 10th Class) about Major Concept 'Chemical Bondings' (N = 60)

Instances/ non-instances / Categories of Alternative Concept		NaCl	N ≡ N	H-Cl	$NH_3 \rightarrow BF_3$	Two Water Molecules (hydrogen bond)	Na+He	Na + Mg Metals	Total Frequency & Average %
Incorrect use of scientific term	f	6	3	18	10	7	20	8	69
	%	10	5	30	16.67	11.67	33.33	8.33	16.42
Self-contradictory views	f	3	1	2	4	4	10	2	26
	%	5	1.67	3.33	6.66	6.66	16.67	3.33	6.19
Self-centered or human centered views	f	11	27	26	23	20	9	15	131
	%	18.33	45	43.33	38.34	33.34	15	25	31.18
No scientific term but correct explanation	f	-	-	1	-	-	-	-	1
	%			1.67					0.24
Scientific term but incorrect explanation	f	35	27	11	16	25	10	34	158
	%	58.34	45	18.33	26.67	41.67	16.67	56.67	37.62
Total alternative ideas	f	55	58	58	53	56	49	56	385
	%	91.67	96.67	96.67	88.33	93.34	81.67	93.34	91.67
Total scientific responses	f	5	2	2	7	4	11	4	35
	%	8.33	3.33	3.33	11.67	6.66	18.33	6.66	8.33



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 catetory-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 (cateotry-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 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 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.

1. Almost all the subjects of class 10^{th} holding alternative ideas could not differentiate between molecule and compound or molecule of an element and molecule of a compound.
2. 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).
3. Majority of the subjects could not explain why sodium chloride (NaCl) is called a compound instead of a molecule.
4. Majority of the subjects could not explain the difference between the electro-negativity in HCl and electrostatic force of attraction in NaCl.
5. HCl instance was mostly confused with NaCl and termed as ionic bond due to its partial positive and negative ends.

Discussion

Taber (1998) reported that undergraduates do have an alternative theory of chemical bondings. Similarly, this research study also confirms that subjects taught through traditional textbook approach do have more than 90% alternative ideas of the chemical bondings.

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.

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