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Identifying Students' Alternative Concepts in Basic Chemical Bonding – A Case Study of Teacher Trainees in the University of Education, Winneba

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Abstract:
The study developed a diagnostic instrument to identify misconceptions that teacher trainees have of chemistry topics in relation to ionic and covalent bonding. Students' initial ideas on these topics were collated through classroom discourse, Treagust's (1988) and Tan and Treagust's (1999) adapted diagnostic tests, concept maps and whole class interviews during the first week of interaction with teacher trainees in 2011. These data were used to produce 20 two-tier multiple choice items in four concept areas. The test had a Cronbach alpha reliability of 0.75. Item difficulties ranged from 0.12 to 0.65. Discrimination values ranged from 0.32-0.60. The diagnostic instrument was administered to 98 undergraduate teacher trainees in their second year of chemistry education at the University of Education, Winneba. The participants' scores on each item were analysed by simple percentages to identify their misconceptions on basic chemical bonding and structure. The identified alternative concepts have been presented and discussed and possible teaching remedies suggested.

Keywords: *Chemical bonding, two-tiered test, multiple choice test, alternative concept*

1. Introduction

Chemical bonding is taught as part of a general chemistry course to first year chemistry education students of the University of Education, Winneba (UEW), Ghana. It is an abstract topic as students do not experience bonding visibly in their daily lives. Yet, chemical bonding is one of the fundamental key concepts in chemistry. It is also one of the areas in the physical sciences where understanding is developed through diverse models and where learners are expected to interpret a wide unrelated range of symbolic representations of chemical bonds (Taber & Coll, 2002). Learning about chemical bonding allows the learner to make predictions and give explanations about physical and chemical properties of substances. According to Taber (1997), many students have difficulty in understanding these concepts so there is the tendency for them to form alternative concepts (ACs). Many researchers have attempted to find out students ACs through various means. Butts and Smith (1987) used interviews and found out that most grade 12 chemistry students associated sodium chloride (NaCl) with ionic bonding since electrons were transferred from sodium to chlorine. However, these students did not understand the three dimensional nature of ionic bonding in sodium chloride. Taber (1994) described the tendency of students to think of the 'ion-pair molecule' as a molecular framework in a study. Students in this stance presume that the atomic electronic configuration determines the number of ionic bonds formed once the octet presentation is observed. The octet rule has proved to be one impediment towards the understanding of chemical bonding in secondary schools. Ghanaian chemistry students often tend to misapply the octet rule by accrediting all bond formations to the octet rule concept, even when it is clearly not possible. Taber (1998) and Treagust (1995) assert that students' use of the octet rule to explain chemical reactions and chemical bonding forms the basis of an alternative conceptual framework for understanding inorganic chemistry. These assertions became evident in a study by Taber (1997)in the UK, when he administered a diagnostic instrument on ionic bonding to A' Level students. These students intimated that bonds are formed only between atoms that donate or accept electrons. Findings from recent studies conducted in Singapore (Tan, Goh & Chia 2010) and Turkey (Al-Balushi, Ambusaidi, Al-Shuaili, & Taylor, 2012) were similar to those founded by Taber (1994; 1997); and Butts and Smith (1987) in the United Kingdom. This suggests that students from different parts of the world, Ghana inclusive, may have similar alternative concepts on chemical bonding. According to Taber (1994) if more than 10% of students showed an alternative view of a concept, then it was significant enough to be considered a misconception which required attention.

Tan and Treagust (1999), Tan, Goh, Chia and Treagust (2002) Chou and Chiu (2004), Wang (2004), Treagust (2006), Chandrasegaran, Treagust and Macerino (2007), Taber and Tan (2007), Tan, Taber, Liu, Coll, Lorenzo, Li, Goh and Chia (2008), have used diagnostic tests to determine students' ACs in various chemistry topics. Other methods which have been used to diagnose students' conceptual understanding of chemical bonding include concept mapping (Novak, 1996), multiple-choice diagnostic instruments, observation, explanations, concept phase diagrams, guesses, diagrams, and question forming. This study will use a 2-tiered diagnostic test (adapted from Treagust, 1988; 1995) to identify possible teacher trainees' alternative concepts in basic chemical bonding in UEW since the formation and transfer of these alternative concepts have been asserted to be global. Two-tiered questions have two main benefits over conventional one-tiered questions as measurement error is minimized. A two-tiered question is considered correct when both tiers are answered correctly. Its format allows for the probing of two aspects of the same phenomenon. Students make a prediction in a first tier and then choose a reason in the second tier to support the answer chosen in tier one. Teachers learn a lot about reasons of students in a two-tier test.

Metallic bonding was not of prime interest in this study but there were brief references to it as some students think of metallic bonding in terms of both ionic and covalent bonding.

2. Purpose of the Study

The purpose of this study was to develop and use a two-tiered diagnostic test to find out misconceptions which Ghanaian chemistry teacher-trainees had about basic chemical bonding.The research questions which guided the study were:

What alternative conceptions do chemistry teacher-trainees of UEW have about basic chemical bonding?

How can chemistry teacher- trainees' alternative concepts about chemical bonding be identified and corrected?

3. Methodology

The study employed a pre-test post-test developmental research design as well as qualitative and quantitative methods.

4. Sample

A total of 98 undergraduate trainees in their second year participated in the research. This comprised 88 males and 10 female trainees from the University of Education, Winneba (UEW) in Ghana. The trainees had learned about chemical bonding in secondary school as well as in their first year at UEW.

5. Instruments

Information for the construction of the two-tiered test was collected from trainees' answers to questions through interviews, concept maps as well as pen and paper tests. Trainees were required to make concept maps about basic chemical bonding. There were two whole class interviews (brainstorming) on the trainees' ideas about chemical bonding where students' own ideas (ACs) were compiled. Some of these wrong answers were used as detractors in the diagnostic test. A paper and pen multiple choice tests were conducted a week later to get a confirmation or second opinion of what students thought about chemical bonding. A 2-tier multiple choice diagnostic instrument was developed using procedures defined by Treagust (1995) and adapted to suit Treagust's (1988, 1999) instruments. In the instrument, the first tier of each item consisted of a factual content question with four choices of answers. The second tier of each item contained a set of four justifications for the answers chosen in the first tier. The first tier, was evaluated as a traditional multiple choice test (MCT) while both the first and second tiers (comprising explanations for the first tier) were together evaluated as a two-tier test (TTT). One point was awarded for a correct score in the MCT as well as the TTT. This is because the justification answer was tied to the first-tiered factual answer. The25-item draft diagnostic test was administered during the second week of the research to 120 students in a field trial at the University of Cape Coast, Ghana, from which the best 20 were selected and administered to the study sample at UEW. A post –test was administered after the intervention and trainees' gains in conception assessed. The reliability of the diagnostic test was 0.75.The pre- and post-test results were analysed with SPSS 16.0 to obtain descriptive means. The MCT and TTT were also compared to elicit changes which occurred in the administration of tests at different levels

6. Intervention

Multimedia and pictorial representations by trainees were the main instruments used during a four week treatment period to correct and enhance trainees' conceptions about chemical bonding. The effect of Multimedia representations was not a strong factor in causing conceptual change and so was not discussed in this paper. Trainees' correct scores on the test have been presented as percentages in Table 1, together with some identified alternative conceptions.

7. Results and Findings

Item	Pre-test	Post-test	Some alternative conceptions
1	68	73	Attraction between all oppositely charged ions in an ionic compound (30) (17)
2	72	72	Chemical bonding terms applied wrongly (28) (14)
3	51	54	Poor understanding of bond strength (49) (13)
4	44	60	Equal sharing of electron pairs in entities (48)(12)
5	76	80	Wrong choice of chemical bond in entities (22)(5)
6	54	53	Concept off melting and boiling point (47)(13)
7	55	56	Bond polarity (45)(11)
8	56	58	Bond polarity (43)(10)
9	85	90	Misapplication of chemical bonding terms (13)(4)
10	60	64	Poor interpretation of shapes of molecules (38)(9)
11	40	52	Inter & intra forces within molecules (54)(15)
12	73	77	Nature of the atom (25)(7)
13	58	60	Poor interpretation of shapes of molecules (44)(11)
14	39	49	Formation of ionic bond (56)(8)
15	43	58	Forces within a compound (50)(13)
16	46	49	Coordinate covalent bond (53)(21)
17	52	60	Misunderstanding about bond strength (24)(10)
18	53	72	Formation of covalent bond (38)(16)
19	61	69	Interpretation of chemical bonding terms (35)(8)
20	33	45	Metallic bond (61)(11)
Mean Score	56.20	62.55	

Table 1: Percentage scores of trainees' performance and identified ACs in the pre and post-MCT

From Table 1,it appears as if trainees performed credibly well on the test regardless their many alternative concepts. Trainees scored between 44 and 85 marks out of a total of 100. Their post-test scores are also quite high and so there was not much gain in scores. This suggests that guessing might have been used in the pre-test to obtain almost as high marks as they did in their post-test. Their initial misconceptions however reduced grossly (shown in italics) in the post-test. This implies that the MCT was not been able to distinguish between the trainees' true performance nor elucidated their misconceptions and was therefore not a good discriminatory tool to find out about students' conceptions. Other alternative concepts which became evident in the second tier of the test which were different from the first tier are presented in Table 2, together with the trainees' performance in the 2-tiered test (TTT).

Item	Pre-test	Post-test	Identified alternative concepts (%)
1	38	45	Particles such as ions must be charged before bonding (62)
2	23	36	Indiscriminate use of the terms elements, atoms, compounds (31)
3	32	40	Ionic bonds are stronger than covalent bonds(68)
4	27	45	Electrons are shared equally in covalent bonds (51)
5	22	60	Ionic bonding established in sugar and iodine crystals (29)
6	14	38	Ionic compounds have higher melting points than covalent compounds due to ionic bond strength (69)
7	24	49	All ionic compounds are polar so LiCl is highly polar (57)
8	40	58	All covalent compounds are non-polar (49)
9	29	59	Polarity means ability to conduct electricity (63)
10	15	28	Shapes of molecules depend on bonding (72)
11	18	36	Valence electron determine bond strength and force in matter (68)
12	33	60	Nature of an atom depends on its valence electrons (42)
13	21	43	Shapes of molecules depend on bonding caused by electrons (59)
14	12	40	All transfer of electrons cause ionic bonds (69)
15	21	32	Ionic bonds are difficult to break; covalent ones break easily (66)
16	17	26	Coordinate covalent bonds are weak and break easily (70)
17	23	39	Only ionic molecule bonds are strong. All others are weak (59)
18	28	51	Covalent bonds are easily broken as overlaps are weak (61)
19	18	42	Inability to differentiate between particulate matter (59)
20	05	28	Metallic bonding is strong because each electron bonds strongly with a positive ion. Thus strong ionic bond is formed (84)
Mean score	23.00	42.75	

Table 2: Percentage of trainees' pre- and post TTT scores and identified ACs

Table 2, shows how trainees performed in the second part of the diagnostic test. Many more misconceptions were identified from the second tier of the test. The percentage correct scores are lower as compared to their MCT scores because trainees had to score both the multiple choice answer as well as its accompanying conceptual explanation in order to gain one point. Their post-test alternative conceptions were as identified in the MCT post-test and so is not presented in Table 2.

Some of the main misconceptions discovered in both tiers of this study were statements such as**:**

- Ionic bonding is a weak kind of bonding
- Ionic bonding comprises sharing of electrons
- Intermolecular covalent bonding is weak bonding
- If the octet rule is violated compounds or molecules would not be formed
- Metal to non-metal bonding is electrostatic in nature
- Bonding in metals and ionic compounds involve intermolecular bonding
- Bonds in compounds contain the energy for their compounds so when you break a bond you release the potential energy in it
- The energy in the chemical bond sticks the individual molecules or ions together
- Electronegativity is the attraction for a single electron by another electron
- Polar covalent compounds contain charged species
- Polarity is determined by ionic charge
- The charged species in metallic lattices are nuclei rather than ions.
- Over emphasis of process of electron transfer

A summary of the major misconceptions identified in trainees' responses are presented as Table 3. Details of trainees' alternative choices with respect to type of bond are shown in the appendix.

Main misconcepts	Number	Percentage
Overuse/ Misuse of the octet rule	32	32.6
Ionic bonding	44	44.8
Covalent bonding	22	22.9
Attractive force	44	44.8
Bond strength/ energy	42	42.9
Shapes of molecules	42	42.9
Polarity	31	31.6
Metallic bonding	25	25.5
Chemical bond terms	28	28.6

Table 3: Mean percentages of main misconcepts
N= 98

Table 3 shows the distribution of the identified trainees' misconceptions of chemical bonding in a thematic form. The main principles underlying the understanding of chemical bonding are the octet rule for elements in the first two periods, the periodic parameters, the factors necessary for bond formation, polarity, shapes and strength of molecules. Results from this study agreed with earlier research by Butts and Smith (1987), Peterson et al. (1989), Taber (1994, 1997, and 1998) and Tan and Treagust (1999) that TTT unearths better conceptual understanding than the MCT. It made provision to delve into students' deeper understanding on concepts and reduced the incidence of guessing to the barest minimum. This study was also able to use the TTT to elucidate the trainees' deficiencies in their understanding of chemical bonding which had not been expressed in previous studies which employed the MCT only. The outcomes support Tsai and Chou's (2002) as well as Tuysuz's (2009), reiteration that science teachers to better evaluate students' ideas through diagnostic tests. This confirms Treagust's (1995) assertion that the TTT was more effective in determining students' ACs and revealed whether meaningful learning occurred or not at the end of a teaching session. The fact that a student has to think and understand his choice for assigning a reason to an answer also makes the TTT more effective than other tests (Peterson, & Treagust, 1989).
Trainees' loss in scores for the MCT and TTT were computed as MCT – TTT and presented in Table 4. This method was used by Dallal(2013) in a similar study and found to be a useful means of analysing change in students' conceptual growth.

Item	Loss for pre-test (MCT-TTT)	Loss for post-test (MCT – TTT)
1	30	28
2	49	36
3	19	14
4	49	15
5	22	20
6	40	15
7	32	7
8	45	0
9	56	31
10	45	36
11	22	16
12	40	17
13	37	17
14	27	9
15	27	26
16	29	23
17	29	21
18	25	21
19	43	27
20	38	17
Mean changed score	33.20	19.80

Table 4: Comparison of MCT and TTT change scores

Table 4 shows the change in scores for participants' performance in the multiple choice test and the two-tiered test for concepts associated with chemical bonding. A large change in score indicates that participants were able to choose a correct answer in the first tier but failed to justify the choice correctly in the second part to that particular item, which tested for conceptual reasoning and application. Thus if a participant gained 20 points in the MCT but scored 7 points in the TTT, then his change in score was 13, in favour of MCT and a higher poor reasoning of a concept. From Table 3, the changed scores for participants in the post-test are relatively lower than for the pre-test. The implication here is that trainees have gained some conception since the intervention and are choosing better scientific reasons to multiple choices made in their first tier. In other words, the gap between their wrong choices in the first and second tiers is reducing.

8. Discussion

Traditional multiple choice items project students' achievement on tests more than they truly are. They give a flattering impression about understanding when in reality students may be reproducing facts without conceptual understanding. It is easy to make a choice when one has not encountered a chemical concept at all and come out with high scores on a test. In a traditional MCT with the usual four or five options, the chance of guessing the correct answer is 25 or 20% respectively. In a TTT, the probability is only 5 or 4%. The TTT enables a student to have a more focused view or conceptual understanding of a topic in question to perform well.

Here in Ghana, national examinations employ the MCTs so students are able to learn by association to figure out correct options for test items without understanding the reasons behind them. They do not require higher cognitive domains to perform well on such tests. The TTT however, gives a true picture of performance on tests based on conceptual understanding and so is a better test to use when one has to unearth students' true understanding. Students' explanations are important for the teaching of science concepts. Students need to build on already known basic concepts to understand more difficult and complex ones. In a TTT, students get the opportunity to select an answer and its explanation. Teachers are therefore able to learn about reasons for students' misconceptions and then develop corrective measures in their teaching. Duit, Treagust and Mansfield (1996) found in their study, that investigating students' conceptions not only revealed important insights into students' ways of thinking and understanding but also helped teachers to see their own views in new ways. This results in major reconstruction of science knowledge and how it should be presented in classes.

The results of this study showed that the TTT could help teachers to increase students' knowledge level and minimize their ACs. Analysis of their work sheets showed that they could not distinguish between some basic terms such as bond and bonding. For example, 45% of the trainees could not distinguish that bonds are attractive forces which hold atoms, ions or molecules together but bonding is a process. Another 47% of participants thought that sodium chloride and magnesium chloride exist as molecules while sugar and iodine exist as ionic compounds. The trainees drew the transfer of an electron from sodium atom and magnesium to chlorine atom to form a positive sodium ion, positive magnesium ion and negative chloride ions. They explained that sodium and chloride ions are attracted by electrostatic forces. They saw sodium chloride as a discrete unit. The idea of $NaCl$ or $MgCl_2$ as an ionic lattice is not as easily acceptable to students much later when the structure of solids is taught (Taber, 1994).

In all 25 participants (about 26 %) said that the bond between metals and non-metals was covalent bonding. A few said that the bonding was metallic and almost ionic since metals were stronger and possessed the stronger attractive force if metals and non-metals were to bond. This group of trainees' conceptions about metals and non-metals were being likened to the physical nature of (matter /solids) metals such as iron and non-metals such as plastics. Those who explained the bonding as being covalent had an alternative conception also. They explained that the non-metals completed their octets. There was no idea of sharing, to suggest covalence yet they distinguished covalence here merely by virtue of completion of an octet. Taber (1997) and Tan and Treagust (1999) suggest that teaching of covalent bonding before ionic bonding could result in the learner tending to perceive ion pairs as molecules and interpreting electrovalence as a determinant of the number of bonds a species forms. Thus it is suggested that ionic bonding be taught before covalent bonding so that the idea of covalence or sharing and the octet do not pervade other associations which would be learnt later. Robinson (1998) found that students use the octet rule as a basis for explaining chemical reactions and bonding instead of using it as a guide to identifying stable species. The octet concept was mostly overused and even misused. It was even used in explaining the bonding in the PCl_5 molecule. It was observed that trainees would have to be taught, using perhaps models, besides the multimedia and pictorial representations to show how other bonds could be formed on other principles besides the octet. If appropriate interventions are put in when alternative concepts are discovered, remediation could be achieved.

9. Conclusion

An important outcome of this study was the development of a 2-tier diagnostic instrument which was able to unearth chemistry teacher-trainees' alternative concepts. These alternative concepts were corrected through multimedia and pictorial representations of trainees. The importance of the TTT has been confirmed by the positive outcome of the study and gains made by trainees in their analysis of concepts on chemical bonding. It was observed after the treatment period in this study, that trainees demonstrated more scientific reasoning when asked similar questions that had been asked them before the intervention. The gap between unscientific and scientific reasoning on the topic *Chemical bonding* closed up by 13.40 units, which is quite substantial. This means that when' alternative concepts are identified and addressed; the prepositions and linkages of chemistry concepts as well as their applications in varying situations would be clearly understood. This would eliminate ACs in chemical bonding. Ionic bonds must be clarified within the context of a three dimensional ionic lattice. In addition, simple terms and analogies which are not likely to confuse students must be used to explain terminologies and concepts. This paper also suggests corrective measures for the identified misconceptions.

10. Recommendation

Teachers should be more receptive and willing to try and develop alternative teaching strategies if they find that their own methods are inadequate in solving their students' difficulties. In this case, the quality of teaching and learning would be raised as teachers would research to be able to teach with emphasis on conceptual understanding and not on mere acquisition of facts by rote or finding out students' attitudes and perceptions. Teachers must incorporate students' misconceptions into their teaching process and teach them how to apply concepts in varying situations to overcome their alternative concepts. Further research could be done on students' understanding of metallic bonds.

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Appendix

1. Identified alternative conceptions on Ionic bonding

- An ionic charge determines the polarity of a bond.
- Ionic bonding is a linkage between a metal atom with a non-metal
- Ionic compounds consist of ‘discrete molecules’ and ‘covalent bonds’.
- The coordination number is determined by the charge of ions.
- Ionic bonding is when an element shares electrons chemically
- Ionic bonds have higher melting and boiling points than all covalent bonds.
- Elements lose electrons in covalent bonds but share electrons in ionic bonds.
- When two non-metals share electrons, ionic bonding occurs
- Bonds in ‘ionic molecules’ are stronger than intermolecular forces

2. Alternative conceptions on covalent bonding

- Covalent bonding is when an element loses an electron to be stable
- Atoms share electrons because they want to form stable compounds through the octet
- The number of covalent bonds formed by a non-metal atom equals its valence electrons
- The strength of covalent bonds and intermolecular forces are similar
- Strong internal forces exist in a covalent network solid
- Heat causes the breaking down of covalent bonds within water molecules
- Equal sharing of electron pairs occurs in all covalent bonds
- The shape of a covalent molecule is due to its valence electrons

3. Alternative conceptions on chemical bonding terminologies and principles

- When chemical substances react then bonds are formed
- Bonds stick atoms together
- Atoms are held together because they share electrons; so sharing electrons is like a force
- Atoms lose or gain electrons because they want to achieve the stable octet of electrons
- Polarity of a bond is dependent on number of valence electrons in each atom

4. Alternative conceptions on metallic bonding

- Metallic bonds are strong bonds but not quite like ionic bonds. They can be twisted
- The bonding in metals and ionic compounds involves intermolecular bonding
- Solid iodine shines like a metal because molecular iodine contains some ions.
- Charged species in metallic lattices can result in ionic bonding.