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Full Length Research Paper

Instructional misconceptions of prospective chemistry teachers in chemical bonding

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This paper is a report of an action research which attempts to detect and correct various misconceptions in chemical bonding retained by some pre-service chemistry teachers who were in their third and fourth year in the university. At systematic and elaborate instructional sessions, questioning approach, micro teaching, and structured essay test were employed to detect misconceptions while concept mapping blended with cooperative learning was used to correct the identified misconceptions. 64 pre-service chemistry teachers (which have gone on teaching practice in some Nigerian secondary schools) from a state university participated in the study. Similar chemical concepts were identified by over 90% of the pre-service teachers as topics often being regarded as both difficult to understand by learners and teach by graduate teachers but sources of misconceptions were highlighted in only one major concept among those listed, namely; chemical bonding. The study revealed a high level of varied chemical misconceptions among the pre-service teachers which did not alter significantly through their four years of training. However, during groups' interaction and with the aid of concept maps, some of the misconceptions were removed as they were enabled to apply their knowledge of concepts and their interrelations, as well as formulate appropriate theoretical explanations for the observed changes they viewed.

Key words: Misconceptions, prospective teachers, concept maps, difficult chemical concepts.

INTRODUCTION

Many students hold views and ideas which are not consistent with scientific principles and theories. These varied views may be described as intuitive, informal, misconceived, alternate, preconceived, prior, folk, etc; they may be ideas, concepts, conceptions or framework and so on (Taber, 2002). The different types of misconception are categorized as non-scientific beliefs, vernacular misconceptions, factual misconceptions and conceptual misunderstanding. Students' chemical misconceptions have been noted worldwide since students live and operate within the macroscopic world of matter and do not easily follow shifts between the macroscopic, submicroscopic and symbolic levels (Gabel, 1996; Robinson, 2003).

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Studies have shown that students (including those at the tertiary institutions) learn science with many preconceived ideas (Taber, 1997; Fatokun, 2006; Kind, 2009; Horton, 2001) and bring to instruction concepts, ideas and explanations of scientific phenomena that differ from the views held by scientific community. In many cases, not all these concepts, ideas and explanations are highly significant in terms of impending the intending learning but some of them will (Taber, 2002) because they are not isolated but form conceptual structures, which provide a coherent understanding of specific phenomena. Settlage and Southerland, (2007) also stated that misconception does not exist in isolation from the context in which they appear and students do not just drop their ideas and beliefs just because someone says so or an event disproves what they have come to believe. Three ways in which misconceptions among students differ from generally accepted concepts as pointed out by Lee (1992) are; students have difficulty with the kind of abstract reasoning used by scientists. Secondly, students are interested in unique explanations for a wide variety of phenomena. Thirdly, the everyday language of the society often leads students to have views that are different from those of the scientists. Consequently, they tend to build themselves alternative conceptions and non scientific mental models (Ben-Zvi et al., 1986; Taber and Coll, 2002).

Wickman (2006) viewed teaching/learning process as the act of giving meaning to events experienced by making them continuous with prior experience. The teaching of chemistry has traditionally been based on the objectivist view of knowledge; a largely teacher-centered approach where the students learn through rote learning and assessed through ability to regurgitate facts. Students are trained to answer examination questions with little or no emphasis on a constructivist approach (Coll and Taylor, 2001). Conceptual misunderstanding arises when students are taught in a way that does not provoke them to confront paradoxes and conflicts resulting from their preconceived and non -scientific beliefs (Chamber and Andre, 1997).

Teachers often serve as sources of erroneous ideas based on their prior poor base knowledge (misconceptions) and the instructional strategies adopted in the classroom. Most in-service chemistry teachers possess inadequate understanding of some fundamental chemical principles. Some chemistry teachers are unaware and or uninterested in some of the common misconceptions conveyed by students (Fatokun, 2006) while some over-simplify basic concepts in order to facilitate understanding which eventually leads to misconception.

There are many examples of ‘misrepresentations’ of chemical ideas in secondary text books most teachers use for instruction. These are often introduced as analogies to explain certain concepts. In the process, students are often led to develop wrong impressions. For example, electron density surfaces are represented by spherical, dumb-bell shape, and clover-leaf shape orbital. Many students believe that electrons really occupy such shapes. Such misrepresentations are ‘necessary mis-conceptions’ without which students may find it difficult to understand and discuss orbital overlap in chemical bonding. A dilemma often created is either to teach the ‘correct’ chemistry and make students more confused or to introduce wrong concepts to them for the sake of passing examinations. One of the professional capabilities of a teacher is to find ways of making complex ideas seem accessible, but this must be balanced by the need to present material in a way that is scientifically valid, and provides a suitable platform for future learning.

The development of science (chemistry) education both at the secondary school and tertiary levels in Nigeria lie solely on the quality of science (chemistry) teachers. A teacher should be both familiar with common misconceptions and anticipate where and when learning is likely to distort teaching and he is well equipped to avoid some of the common learning difficulties in the subject. Hence, the efficiency of pre-service chemistry teachers is significant in overcoming the so called “pedagogical learning impediment” because they are being trained to teach effectively by applying the findings of research in chemical misconceptions for improved learning process but unfortunately most of them retain numerous misconceptions themselves and lack the ability to detect such (Nakiboglu, 2003; Tan and Taber, 2009; Haidar, 1997).

Chemistry teachers’ pedagogical content knowledge (PCK) plays a critical role in helping students to overcome their misconceptions. Studies (Adodo, 2014; Al-Rawi, 2013; Benjamin, 2004; Osokoya, 2013) have equally shown that there is direct correlation between teacher’s efficiency and learners’ performance. Focusing on the development of teachers PCK within the constructivist epistemological framework must be stressed but effective development and utilization of pedagogy requires a better and more detailed understanding of conceptual change. In other words, for teachers to teach constructively, they themselves also must learn constructively (Yager, 2000).

A constructivist teaching approach involving new ideas and open discussions will certainly help in identifying and correcting most misconceptions. However, this is hardly practiced in any Nigerian typical classroom because students have not been brought up to ‘inquire’ or argue their views but rather to accept whatever they are taught with much emphasis on keeping within the frame-work of the syllabus and the consciousness of covering its voluminous content within a stipulated period before examination.

Chemical bonding has been cited as one of the most difficult chemistry concepts (Gabel, 1996; Robinson, 2003; Okebukola, 2005) for many secondary school and college students to comprehend. Bonding is a central concept in chemistry teaching, and therefore a thorough understanding of it is essential for understanding almost every other topic in chemistry such as carbon compounds, proteins, polymers, acids and bases and chemical energy (Hurst, 2002). The concepts associated with chemical bonding and structures, such as covalent bonds, molecules, ions, giant lattices, and hydrogen bonds are abstract and in order to understand these concepts, students must be familiar with mathematical and physical concepts that are associated with the bonding concept such as orbital, electro negativity and polarity.

The traditional teaching of the bonding concept often provides students with several nonscientific conceptual frameworks such as the "octet rule" and the dichotomous way of classifying chemical bonds (Hurst, 2002; Taber and Watts, 2000). Tan and Treagust (1999) investigated on Singaporean students' misconception on chemical bonding and found out that most of the students had some misconceptions about the formation of bonding between atoms, lattice structure of compounds, inter-molecular and intramolecular forces. Taber (1997) carried out a study on British students' understanding of ionic bonding and discovered that high percentage of the student had misconception about the lattice structure of sodium chloride and how ionic bonding was formed. The basic steps to help students come out of their misconceptions are; identify the misconception, provide a forum for students to confront their misconceptions and help them reconstruct and internalize their knowledge based on scientific models.

Concept maps (Johnstone and Otis, 2006) are useful tools to assess the instructive process in order to ensure better learning in chemistry and it also contribute to the development of the intellectual skills. The elaboration of concept maps by the students as a previous step to the instruction have helped to visualize the initial conceptual structure of students, detect possible misconceptions and according to that, design the teaching–learning process in order to obtain the desired conceptual change (Fatokun, 2012). Fatokun and Eniayeju (2014a) investigated the effect of Concept Mapping- Guided Discovery Integrated Teaching Approach (CMGDITA) on chemistry students' achievement and retention and observed that students achieved more and had higher retention when exposed to treatment. Concept maps also had influence on students' learning style and aided their proper understanding of electrochemistry (Fatokun and Eniayeju, 2014b).

Motivation for the study

Two major concerns which informed this study were; firstly, there are many graduates or in-service chemistry teachers which hold a lot of misconceptions as reflected by what they were taught when at the secondary schools. Consequently, the learning outcomes as evidenced most often by their students' poor performance in internal and external examinations do attest to this. Also the concurrent model (curriculum) of teacher education practiced in Nigeria which involve a four year degree programme both in science and education do not give room for adequate development of the prospective teachers' PCK as they are overloaded with knowledge from many education based courses and some chemistry courses taught separately without appropriate provision for effective application of such knowledge in teaching at the secondary school level. The acquired pedagogical and content knowledge by most chemistry teachers seem isolated and faulty in the implementation of the curriculum.

Specifically, this study sought to identify some misconceptions in chemical bonding, their sources and the level of awareness of pre-service chemistry teachers about them. Effect of correcting such misconceptions using concept mapping and cooperative learning was also determined.

Research questions

Four main questions were raised in this study;

1. What are the common misconceptions held by prospective chemistry teachers in chemical bonding?
2. What are the sources of those identified misconception?
3. What is the level of awareness of prospective teachers on such misconceptions?
4. Is there any difference in the prospective teachers' conceptual knowledge after exposure to an interactive session and concept mapping?

METHODOLOGY

Research design

The study adopted an exploratory case study design (action research) which span for two concurrent academic years in a Nigerian University to detect and correct misconceptions among prospective chemistry teachers.

Sample

All the sixty four pre-service 300 and 400 level chemistry education students in an academic session (already in the third and fourth year of their professional training) from a university in the north-central of Nigeria participated in the study. These participants were familiar with the secondary school chemistry curriculum and have had the experience of teaching and being supervised for six weeks during their teaching practice exercise at different secondary schools within the study area.

Instruments

The instrument used for the study was chemistry objective and essay test named Chemical Bonding Comprehension Test (CBCT) written in English language. It was developed by the investigator and validated by experts (chemistry educators). The first section of the instrument was made up of 25 multiple choice objective test items which were drawn from past UTME and SSCE questions on chemical bonding. These test items selected were distributed among the six intellectual levels of Bloom's taxonomy (original version) in the cognitive domain and was used to assess the initial knowledge of the prospective chemistry teacher on the selected topic.

The second section of the instrument was made up of 30 essay questions on chemical bonding obtained from review of previous related studies. This was to detect any misconception and its probable source as the research subjects were expected to give detail explanation to justify their stated answers to each of the questions. The reliability of CBCT showed satisfactory internal consistency (Cronbach $\alpha = 0.75$).

Experimental procedure

During organized instructional sessions which lasted for three consecutive weeks (3hours per week), prospective chemistry teachers' misconceptions were detected and demystified. The phases of the (research) experiment was in the sequence stated below:

Week One: Prospective chemistry teachers were first asked to enumerate difficult concepts/ topics from the current senior secondary school chemistry syllabus. Many topics/concepts were listed but majority of the participants (over 90%) indicated that chemical bonding is one of the most difficult concepts both to teach and learn because of its abstract nature and complexity. A pre- test (both objective and essay) was then administered to establish and compare pre-service teachers' misconceptions with the already identified ones from literature. Six participants were then randomly selected from the entire sample to prepare and teach specific aspects of chemical bonding e.g ionic, covalent, metallic, hydrogen e.t.c. All the other participants were instructed to study the selected topic as well and come up with their questions during the lesson.

Week Two: Each of the six pre-service teachers was required to give a 20 minutes micro-teaching on an aspect of chemical bonding. The other participating teachers were required to play the role of students; having no prior knowledge of the subject and asking questions for clarifications from time to time. They also tried to figure out the type of misconceptions that could have developed directly or indirectly from the lessons. Misconceptions imparted by the teachers or preconceived beliefs by students, were identified after each lesson. There was an interesting (argumentative) and interactive period after all the lessons and the researcher equally engaged the participants with questions on the treated topics within the last one hour of the session to further discover more misconceptions, their sources and the participants' level of awareness. Afterwards, each participant was assigned into different groups through picking of numbers from one to four. The researcher classified all the participants that picked number one into group one and those that picked number two into group two and the rest in that order. Some of the identified misconceptions were distributed to each of the four groups. Each group was expected to provide the appropriate conception with clear explanation and justifiable evidences.

Week Three: Each group made her presentation to the class after brainstorming, some concepts were presented through concept maps and others were explained through verbal expression. The researcher later made necessary comments, corrections and clarifications for general acceptability.

RESULTS

Table 1 shows the list of some of the essay questions in chemical bonding the pre-service chemistry teachers were asked, the misconceptions generated from their responses and the percentages of those holding such misconceptions.

16 out of 64 participants held misconception on how atoms are held together during formation of chemical bonds. 7 of them could not properly define an ionic compound and 10 of them also could not sufficiently explain what covalent bond is, 20 of the pre-service teachers lack proper understanding of how a molecule of sodium chloride is represented while more than half of the participants (36) were unable to explain what happens when NaCl is dissolved in water. 27 and 29 of the pre-service teachers held misconceptions on why aqueous HCl conduct electricity and how water molecule is formed respectively. 31 and 35 of them also misconstrued why graphite conduct electricity and what metallic bonding is respectively.

Table 2 shows the rating of the three main (identified) sources of pre-service teacher's misconceptions in chemical bonding.

The level of awareness of their retention of such misconceptions was also indicated in percentages. It is evident from the table that most of the pre-service teachers had conceptual misconceptions in five out of the eight stated misconceptions and majority had factual misconception on the location of electron pair in the covalent bond.

Many of them as reflected by the highest rating, had vernacular misconception in explaining the concept of electronegativity.

From the table, it is clear that majority of the pre-service teachers were not aware of holding different erroneous views and ideas until when they were confronted with the truth except in confusing the definition of ionic bonding with covalent bonding where 60.9% of them were conscious of. From estimation, about 68.8% of the pre-service teachers were not aware of their misconception on polar and non- polar covalent bonding and molecules while 90.4% of them were not aware that their views about electron pair location in a covalent bond were incorrect.

Table 3 shows five misconceptions out of some major ones identified and held by the pre-service teachers in chemicals bonding. These misconceptions listed were corrected through group presentation after thorough deliberation within the group or through peer tutoring. A representative from each group discussed each concept assigned and clarified misunderstanding by stating the appropriate idea on each concept through adequate explanation as seen on the table.

Concept mapping was used to explain the difference between covalent and ionic bonding and the properties of metals and non -metals that enable them engage in either of the bonding type.

Table 1. List of some identified misconceptions in chemical bonding by Pre- service chemistry teachers.

Questions	Misconceptions	Responses number (%)
How are atoms held together in the formation of chemical bonds?	Atoms are attracted to one another and then form either ionic or covalent bonds.	16 (25)
What is an electrovalent compound?	An electrovalent compound has atoms held together with one atom giving an electron to another.	7 (10.9)
What is a covalent compound?	A covalent compound is one where each atom contributes one electron each to form a covalent bond.	10 (15.6)
How do you represent a molecule of sodium chloride?	A molecule of sodium chloride is represented by NaCl where a sodium atom donates one electron to a chlorine atom.	20 (31.2)
What happens when NaCl is dissolved in water?	Na^+Cl^- bonds are not broken when dissolved in water; only inter-molecular bonds are broken. This explains why we can recover NaCl when water is removed.	36 (56.2)
How would you represent a covalent bond?	Electrons forming the covalent bond are identifiable and are equally shared between the two bonding atoms.	26 (40.6)
Why does aqueous HCl conduct electricity?	HCl is an ionic compound because it conducts electricity in water.	27 (42.2)
How is water molecules formed?	Non polar covalent bonding and hydrogen bonding since water contain hydrogen atoms and other atoms	29 (45.5)
Why does graphite conduct electricity	Each carbon atom in graphite only bond to three carbon atoms, graphite conduct electricity because of the free carbon atoms which are not bonded to any carbon atoms and are free to move.	31 (48.4)
What do you know about metallic bonding?	Metallic bond is the bond between metals. The presence of metallic bonds raises the boiling point of a substance	35 (54.7)

Table 2. Rating of the sources of some identified pre-service teachers' misconceptions and their level of awareness.

Misconception in chemical bonding	Sources of preconceived ideas (Rating: 3=highest and 1= least)			Level of awareness (%)	
	Factual misconception	Conceptual misunderstanding	Vernacular misconception	Quite aware	Not aware
Confusing ionic and covalent bond together	1	3	2	60.9	39.1
Confusing the concept of polar and non- polar covalent bonding with each other and 'polar and non- polar covalent bonding' with 'polar and non- polar covalent molecules'	1	3	2	31.2	68.8
Confusing chemical bonds and intermolecular forces, thinking as if intermolecular forces were chemical bonds or as if they were some types of covalent bond	1	3	2	23.8	76.2
Hydrogen bond misunderstood as a chemical bonding and as if it was formed within all molecules inkling a hydrogen atom	1	2	3	30	70
Not considering electronegativity concept and electronegativities of atoms	1	2	3	17.6	82.4
The electron pair is centrally located in a covalent bond	3	2	1	0.6	90.4
Breaking bonds releases energy	1	3	2	29.4	70.6
Ionic bonding is always stronger than covalent bonding	1	3	2	10.3	89.7

Table 3. Effect of Cooperative Learning and Concept Mapping (CLCM) on some identified pre-service teachers' misconceptions.

S/N	Misconceptions	Effect of CLCM on some identified pre-service teachers' misconceptions
1	Confusing ionic and covalent bond formed between atoms together	Students were able to understand the properties of non- metals and metals that enable them to engage in either ionic or covalent bonding.
2	Confusing polar and non -polar covalent bonding with each other.	Bond polarity makes sense in terms of difference of electronegativity.
3	Confusing chemical bonds and intermolecular forces.	Interactions within a mononuclear species are chemical bonds and intermolecular interaction can be regarded as chemical bonds also.
4	Inability to imagine how bonding is formed at submicroscopic level.	Explanation on the transition from the macroscopic properties of a matter or event to the sub-microscopic properties of those matter
5	Not understanding how bonds are formed between metal atoms.	Avoid using anthropomorphic language, but rather explain bonding in terms of forces, and emphasize the nature of bonds as electron interactions

DISCUSSION

Tables 1 and 2 give a summary of week one and week two activities while Table 3 was generated after week three exercise. From Table 1, it was ascertained that many of the prospective chemistry teachers lack the basic knowledge and understanding of the concept studied (chemical bonding). This result confirms the earlier reports of existing literature on students' misconception in chemical bonding. Only few (approximately 11% and 16%) had problem with proper definition of ionic bond and covalent bond respectively. There is a clear indication that most of them, though assumed to have the understanding and capability to define covalent and ionic bonding often engage in rote memory because of their inability to further explain the underlying principles of these types of bonds properly. It was also evident from the results (rating) on the sources of some identified pre-service teachers' misconceptions in chemical bonding in Table 2 that many of the participants have conceptual misunderstanding in most of the basic concepts, others were plagued with vernacular misconceptions while few had factual misconceptions of the content knowledge. This finding is in line with Tan and Treagust, (1999) studies on evaluating students' understanding of chemical bonding using two-tier multiple choice diagnostic instru-ment where most of the secondary students investigated had conceptual misunderstanding.

Apparently from Table 2, it was noted that majority of the pre-service chemistry teachers were not conscious of their misconceptions because their level of awareness was very low, except for the first item, that is, their confusion as regards the definition of ionic bond and covalent bond but this is elementary. And this can also be logically discerned since one involves sharing of electrons and the other transfer (gain or loss) of electrons. The outcome of this study is consistent with Hurst (2002) and Taber and Watts, (2000) which reported that the traditional teaching of the bonding concept often provides students with several nonscientific conceptual frame-works. This also supports the findings of Nakiboglu, (2003) and Tan and Taber (2009) which revealed that most of the intending teachers retain numerous misconceptions themselves and lack the ability to detect them unless they are faced with vivid conceptual proofs.

Table 3 shows the effect of Cooperative Learning and Concept Mapping (CLCM) on demystifying most of the identified misconceptions (though only few of them were listed on the table) and this agrees with earlier assertion by Fatokun (2012) and Johnstone and Otis (2006) that concept maps are useful tools to detect misconceptions and assess instructive process in order to ensure better learning in chemistry.

This record is also in consonant with Yager (2000)'s views that teachers must learn constructively in order to teach constructively.

Conclusion and Implication

Effort should be made to constantly assess the PCK of prospective teachers on specific and seemingly difficult chemical concepts/topics. This is because an assumption that prospective chemistry teachers have acquired and are equipped to transmit required chemical knowledge to their intended subject (students) may be a gross oversight.

This study revealed the effect of constructive interactions and collaborative efforts in detecting and correcting unknown errors or unnoticed misconceptions. Though this study is still progressive, there was a remarkable conceptual change and improvement in the knowledge base of the prospective chemistry teachers as their misconceptions were detected and dissolved. This was evident by their ability to clearly understand the concepts in 'bonding' and the basic connections within them.

Revealing students misconceptions and erroneous connections among the concepts is a major contribution of this study to both chemistry teachers and curriculum developers as teachers become aware of how to plan their teaching in such a manner that students could easily remedy their misconceptions and have scientific ideas about phenomena.

Conflict of Interests

The author has not declared any conflicts of interest.

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