

Anthropomorphic notion of atoms, the etiology of pedagogical and epistemological learning proactive interference among Chemistry learners: Implications

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Abstract: This study, based on qualitative design and informed by both the interpretive and participatory paradigms, sought to find out anthropomorphic notion of atoms, the etiology of pedagogical and epistemological learning proactive interference among Chemistry learners. The concept of octet rule has been found to cause proactive interference in the teaching and learning of bonding and chemical structures. A convenient sample of 8 Advanced Level Chemistry teachers, all B. Sc degree holders with a minimum teaching experience of 2 years were involved in focus group discussion together with the researcher trying to identify misconceptions caused by octet rule in Chemistry teaching and learning and the way forward in pedagogics of chemical bonding. Several concepts were highlighted as areas of concern where proactive interference do take place, among others ligand formation in transition metals, hybridization and covalent bonding. Teaching strategies were highlighted as one way to minimize misconception formation at Advanced Level Chemistry learning. Curriculum planners and textbook authors were to revisit their approaches in chemical bonding. The driving force of chemical bonding and chemical reactions must be known as the need for a decrease in free energy of the system or the increase in entropy of the universe. Teachers need to introduce a general notion of bonding based on electrical interactions. Several other teaching strategies were recommended.

Keywords: Misconceptions, Octet, Bonding, Structure, Entropy, Energy, Atom, Chemistry, Learner

1. Introduction and Background

It has been noted with great concern that many learners (68%) of Chemistry argue that Chemistry is a difficult subject [1]. It is argued that the pedagogics of Chemistry is very crucial if learners are to comprehend Chemistry concepts correctly [1,2]. Chemical structure and bonding are some concepts in which learners face challenges [1-5]. These perceived difficulties are part of the context in which learners develop Chemistry concepts in their minds. Being able to recognize and work with student-held ideas and misconceptions is a key component for any Chemistry teacher to be successful. One of the main barriers that learners encounter as they work to understand Chemistry are conceptions which they hold in their minds, the visual images they form in their short term memory and eventually the concepts they encode into their long term memory for further retrieval and usage. Teachers can be

astonished to learn that despite their best efforts, learners do not grasp fundamental ideas covered in class. Even when some of the best learners give the right answers [3], they are often memorized words which are correctly used. Further Chemistry learning, which lacks appropriate understanding of fundamental concepts from the beginning of their studies may have negative implications amongst the learners.

Chemical structure and bonding is one of the key and basic fundamental concepts in Chemistry [6]. Understanding the subject of chemical bonding is crucial for learners' further learning because it underlies most of the advancing subjects in Chemistry. The concepts regarding the topic chemical structure and bonding are essential for the understanding of many concepts and topics in Inorganic Chemistry, Organic Chemistry and Physical

Chemistry. It is therefore necessary for learners to construct the meanings of chemical bonding concepts properly.

Anthropomorphic notion of atoms refers to the completion or filling in of atomic shells using the octet rule. The octet rule (originally proposed by American chemist Irving Langmuir in 1921) states that atoms of low (<20) atomic number tend to combine in such a way that they each have eight electrons in their valence shell, giving them the same electronic configuration as a noble gas. The rule applies mainly to the main group elements. In junior high school Chemistry teaching, it is purported that all atoms react in order to attain an octet stable gaseous configuration state also known as the ionic state. Metals react by loss of electrons to become cations and non-metals react by gaining of electrons to become anions. For instance, Sodium atom [Na] reacts by donating its only one outer shell electron [Na-e] to attain a stable octet configuration / ionic state [Na⁺]; whose electron configuration is [2,8]. Likewise a Chlorine atom Cl; [2,8,7] reacts by gaining an electron in its outer most shell to attain a stable gas structure of Argon, [2,8,8], with a full octet outer shell. Therefore the electronic configuration of a new chloride ion becomes stable with a formation of Cl⁻; [2,8,8]. The octet rule (anthropomorphic notion) gives a lot of trouble to Advanced Level (high school) students (Boo, 1998). The octet rule seem not to apply when we attempt to explain several concepts in high school Chemistry. For instance helium, there is no 1p level. There is only 1s² according to quantum theory. In this element, the octet rule does not apply but the duet rule does. The atoms before (H) and after helium (Li) follow the duet rule and hence violates the octet rule. For transition metals, the octet rule doesn't apply, but the dodecet (18 electron) rule applies. The dodecet rule is unannounced or is not often referred to. Authors do not refer to this rule. High school chemistry learners find difficulties in comprehending the s, p, d, f configurations because of the 'silent' dodecet rule e.g the permanganate ion (MnO₄⁻). The octet rule confuses learners e.g phosphorus pentachloride (PCl₅) and Sulphur hexafluoride SF₆ do not obey octet rule. Five and six covalent bonds are formed respectively with the participation of d orbitals, in violation of octet rule. The majority of transition metal complexes violate the octet rule. The former knowledge of octet rule (very popular in junior classes of high school Chemistry) causes proactive interference of latter concepts in higher Chemistry learning. (Proactive interference is when information learned previously interferes with information being currently learned. Learners forget or fail to understand what they are currently learning or what they have just learned, as a result of what they already knew before. The original knowledge or what was known before is causing one not to understand what is being learned now). The previous memory is befuddling my present memory. The octet rule befuddles the learning of higher concepts in Chemistry. The octet rule cannot be used to explain why bonding pairs of electrons do not repel each other despite the same charge. The same octet rule fails to explain how

moving electrons can stay between two nuclei of atoms. The same octet rule cannot explain the reaction of transition elements because they do not always necessarily react to assume the gaseous noble octet state. [8] suggests that having learned to think about atomic structure in terms of electron shells may impede learning about orbitals. Learning the details of shapes and designations of atomic orbital then acts as an impediment to thinking about molecular orbital and shapes. Learners confuse molecular orbits with atomic orbital suggesting that bonding electrons in bonds, in molecules, in orbital they designated as s or p or confusing sets of hybridized molecular orbital e.g. sp³ hybrids with molecular orbital. Consequently, learners cannot understand strengths of covalent bonding correctly. They just think that atoms share their valence to get an octet.

The etiology or causes of these several misconceptions are mainly based on the octet rule, hence this will further inhibit or interfere with formation of new concepts in bonding and chemical structure in Chemistry. Octet rule appears to be a stumbling block to the learning of Chemistry. Inasmuch it is helpful in lower classes of high school, the concept is a stumbling block to higher level learning. The pedagogics (art and science of teaching) then becomes critical [1].

Teachers must be able to teach to avoid both retroactive and proactive inhibition or interference. It is against this background that I set to study the concept of (anthropomorphic in atoms) as a major cause (etiology) of blockade / inhibition or interference of correct concept formation during chemistry pedagogy (teaching). Possible solutions are to be identified and discussed in order to enhance correct concept formation during the teaching and learning of chemical structure and bonding in Chemistry.

2. Research Question

The study was guided by the following main research question. how can we apply octet rule during pedagogy to minimize proactive interference during learning of chemistry at high school.

3. Methodology

3.1. Research Method and Design

My study is located in the qualitative design which is intended to explain social phenomena 'from inside' in a number of different ways," [9] p. xi. One of the common ways argued by [9] is the ability to analyse experiences of individuals or groups. The experiences of selected teachers during their teaching Advanced Level Chemistry was sought.

This study was grounded and informed by both the interpretive and participatory paradigms or worldviews. In this paradigm, my participants who were teachers in high schools were interviewed. I relied as much as possible on the participants' view of the situation," [10], p. 20. Their interpretation of the pedagogics of chemical bonding was

obtained with reference to application of octet rule [11].

3.2. Participants

Research participants were eight (8) teachers conveniently selected from five (5) high schools within Gweru urban district of Zimbabwe. They were selected on the basis that they had graduated from a University with a Bachelor's degree with Chemistry as one of their majors. They had taught Chemistry at Advanced Level (A 'Level) for more than 2 years. All were males except one lady who was a Bio-Chemist. Age range was (25- 42 years).

3.3. Data Gathering Tools

The data generating instruments used included focus group discussion as a face-to-face verbal interchange, in which I attempted to elicit information from my participants as a group [12]. Participants were asked to tell their chemistry teaching stories in a variety of ways with reference to use or application of the octet rule especially in Inorganic Chemistry and Organic Chemistry. I opened the discussion with conversing issues pertaining to the octet rule. Participants narrated their experiences with regards to teaching chemical bonds. Their objectives, methods, challenges, in general were sought as they used the octet rule. Misconceptions held by learners were elaborated by participants. How to teach to stamp out or avoid such misconceptions when applying octet rule were highlighted.

The focus group sessions took place in Gweru gardens on a Saturday afternoon for about 2 hours. Focus group discussion centered on the research question saying; how can we apply octet rule during pedagogy to minimize proactive interference during learning of Chemistry in high school.

In order to avoid dominance by a few individuals during the discussion, I provided a platform for all individuals to participate without feeling intimidated or inferior by giving each participant the room to make contributions, pertaining to his / her teaching experience. During the discussion session, the participants took the lead while I listened and gave necessary guidance.

Responses from the focus group were transcribed, coded in order to organize the data and analyzed for common themes. This narrative data were analyzed using themes and descriptions of context. Qualitative analysis and presentation of research data was done in form of descriptions of observed phenomenon.

Triangulation is a validity procedure where I searched for convergence among multiple and different sources of information to form themes or categories in a study [13]. As a validity procedure, triangulation is a systematic process of sorting through the data to find common themes or categories by eliminating overlapping areas. Further validity of the study hinged on the assurance that the teachers had the same understanding of octet rule as the researcher had.

3.4. Ethical Considerations

Participants in the study gave their consent in writing before commencement of the study after the purpose of the study and what would be expected of them had been explained. Since their selection was purposive, they were assured that they were free to withdraw at any stage without any negative consequences. Pseudonyms were assigned to participants to maintain and guarantee anonymity and confidentiality.

4. Results and Discussion

During discussion, participants agreed that Ordinary Level learners think that covalent bonds are the weakest because of the application of octet rule. This is because covalent bonding involves the sharing of electrons whilst ionic bonding involves transfer of electrons and form two ions of opposite charges which attract each other. Participants argued that learners assume that all covalent bonds are weak. Learners believed that covalent bonds are weaker [17] than ionic bonds because learners had the notion that covalent substances have low melting points. [14] argues that the description of covalent bond gives a lot of trouble to high school learners. Some studies indicated that learners have misconceptions and learning difficulties concerning atomic structure, chemical bonding and matter [14].

Many learners do not distinguish between the properties of a substance and the properties assigned to a single, isolated atom [14]. From discussions with the participants, it was observed that learners believed that the "particles" of a substance, called atoms or molecules, are very small portions of the 'continuous' substance. Any misconceptions that learners harbor about the fundamental concepts of atoms and molecules will impede further learning [15].

From the octet rule, stable molecules can usually be drawn as overlapping atomic structures so that each atom has noble gas structure if electrons in the overlapping region are counted to both atoms. Although this pattern can be explained in terms of higher level chemical models such as molecular orbital, it is normally introduced at a high school level before such concepts are available [14]. Thus, this description of covalent bond strength gives a lot of troubles to high school learners. The octet rule does not explain why bonding pairs of electrons do not repel each other despite the same charge and how moving electrons can stay between two nuclei of atoms. Consequently, learners cannot understand strengths of covalent bonding correctly. They just think that atoms share their valence electron to get an octet. [16] highlighted that learners would commonly identify and distinguish which electron in a covalent bond belonged to each of the bonded atoms [1]. From the discussion, participants argued that learners also consider the sharing of electrons as the 'force' holding the atoms in a molecule together instead of electrostatic attraction between the shared electrons and the nuclei involved. This finding is corroborated by [17] who found

that some of her learners held the misconception that a covalent bond is a pair of shared electrons. This misconception probably arises out of exposure to statements often found in textbooks such as the covalent bond is the pair of shared electrons in a covalent molecule. Some learners held the misconception that an ionic bond is electrostatic in nature but not the covalent bond. It seems that these learners were unaware that all chemical bonds (including metallic bonds, van der Waals bonds and hydrogen bonds) are electrostatic in nature. This misconception may have arisen because in discussing ionic bonding, textbooks tend to mention that ions are formed as a result of electron transfer between metallic atom and the non-metallic atom and are held by an electrostatic attraction between these positively charged and negatively charged ions. At the same time, in discussing covalent bonding these textbooks either make no mention of what constitutes the covalent bond or they merely mention that the pair of shared electrons is the covalent bond.

According to [17], learners believe that covalent bonds are weaker than ionic bonds because learners had the notion that covalent substances generally have lower melting points and boiling points compared to ionic substances. This appears to be linked to the inadequate textbook treatment on the concepts of bonding and properties of covalent and ionic substances. In many textbooks, the discussion on bonding often does not include the explanation that ionic bonding results in the formation of a giant ionic lattice structure whereas covalent bonding usually results in the formation of simple or discrete molecular structures. The notion that melting (or boiling) a covalent substance with simple molecular structures does not involve breaking the covalent bond within the molecule but only involves breaking the relatively weaker bonds between molecules is often not pointed out in textbooks.

Participants also raised another misconception about atomic orbital as a result of octet rule. Learners perceive each orbital as a box [18] as in box diagrams or orbital filling diagrams used for electron configuration of multi-electron atoms. Learners define an orbital as a box that can be full or empty but filled by electrons [18]. This misconception may result from the presentation of the orbital filling diagrams used for electron configurations in Chemistry textbooks [18,19]. The octet 'rule' is simple for the learners to visualize and use [20]. The octet 'rule' is often presented as an obligatory condition for proper bonding. Thus, learners often adopt the anthropomorphic notion of atoms, wanting to possess octets or full outer shells and consider that chemical reactions occur in order to allow atoms to achieve this natural desire. This causes some learners to have difficulties in accepting anything that is not clearly explicable in 'octet' terms, for example, hydrogen bonds or even covalent bonds or transition metal bonds not leading to 'octets'[21]. [2] suggests that the octet rule can also be considered as another important obstacle in perceiving the hybridization topic, just as it has been found to be when studying chemical bonding. He stated that learners use the octet rule as a basis for explaining chemical

reactions and chemical bonding rather than using it as a guide to identify stable species and molecular shapes. [8] also suggests that the octet rule is a cause of a widespread epistemological learning block among Chemistry learners. Reference [8] reported that when learners were first taught about orbitals, some seemed to take this term as a synonym for shells, and for orbits: so all three terms tended to be used interchangeably. He stated that learners confused molecular orbitals with atomic orbitals: suggesting that bonding electrons in bonds in molecules were in orbitals they designated as s, or p, or confusing sets of rehybridized molecular orbitals (e.g. sp^3 hybrids) with molecular orbitals. Participants agreed that at Ordinary Level, the formation of ionic bonding is described with the need of atoms for the octet. According to [22] learners explain that metal atom gives its valence electrons to the nonmetal atom to make their outer shell full. Thus, two ions with opposite charges attracted each other and became 'a pair of ions', and the pair of ions was represented by a formula unit [14].

From this perspective, sodium chloride solid is molecular in nature. So, in the lattice where a sodium ion is surrounded by six chloride ions, learners tend to think of one bonding as a strong covalent bond but other five bonds weak intermolecular bonding. This is because only one electron can be transferred from a sodium atom to one chlorine atom resulting in the formation of one bond. [20] p.565 give the example of the 'full octet outer shell' heuristic approach of most learners as of little help when it comes to explain and discuss bond polarity, hydrogen bonding, van der Waal's forces and many other important bonding phenomenon.

Participants argued that their learners regard intermolecular bonding not as a type of chemical bonding because it does not help atoms achieve full octet shells. Some learners believe that it is absent even in polar molecular substances such as water [23]. Also when learning about hydrogen bonding, some learners just assumed this is nothing more than covalent bonding involving hydrogen. A proper bond is considered as one that only allowed an atom to obtain a full shell or octet of electrons. This means it is either covalent or ionic [14]. Some learners thought that intermolecular bonding is stronger than intramolecular bonding and that intermolecular forces were influenced by gravity [23].

Participants argued that in order to prevent learners from having misconceptions as a result of the 'octet rule' which is correct but limited in scope, teachers are called upon to assist learners to be aware of the pitfalls of the rule. At high school, teachers must work hard and research on all possible limitations of the octet rule and expose them to high school chemistry learners. Learners must be conscious of their misconceptions, which must be confronted and interrogated. Teachers must interrogate macroscopic chemistry as well as microscopic chemistry with the view of attempting to demonstrate to the learners that dwelling on octet rule alone, this may not explain some concepts hence the rule is limited. Reactions of complex transition elements cannot be explained by octet rule. Reaction of

hydrogen and fluorine gases can't be explained by octet rule because each of the two molecules of hydrogen and fluorine do already have full shells but they go on to react to form hydrogen fluoride. Such learning of removing misconceptions is a process. It is not a single operation. Chemists with proper and correct conceptions must come out of high school rather than to have chemists in industry with weird/(mis)conceptions.

From the discussion with participants, it was observed that there is a need to shift away from octet framework towards understanding of chemical bonding in terms of electrostatic forces [1]. The notion that chemical bonding has to do with minimizing energy and can be described in terms of molecular orbital has been found to be critical [1-2]. Text book authors, teachers and curriculum planners should consider making a number of changes in the area of chemical bonding. The driving force of chemical bonding and chemical reactions must be known as the need for a decrease in free energy of the system or the increase in entropy of the universe [14,1]. Teachers need to introduce a general notion of bonding based on electrical interactions,[1] before exploring specific bond types in detail. Metallic bonding, ionic bonding will be easier to conceptualize at high school. Bond strengths can now be introduced logically with a relationship between charges and radii of particles involved. Therefore the teaching strategies which allow learners to make correct scientific connections among concepts should be employed.

Teachers can plan and teach in such a manner that learners should remedy their misconceptions. Curriculum planners, text book authors should make use of learners misconceptions revealed in such studies in order to design learning environments in which effective concept teaching is performed. The general notion of bonding based on orbital theory will be introduced. High school learners will need to know that when atoms 'overlap' their atomic orbitals form molecular orbitals that consist of chemical bonding. The octet rule will be of less significance. Octet rule is important but it will depend on how teachers articulate the concept to minimize or avoid proactive interference in the mind of the learner. Prior knowledge of octet rule, if not well managed by teachers and textbook authors, it will act as a stumbling block to the acquisition of new concepts which are to be acquired in high school chemistry.

5. Conclusions and Implications

The octet rule is used to explain many basic concepts in chemistry. Although it has some shortfalls in explaining some higher concepts, it may not necessarily be discarded. Teachers, textbook authors and curriculum planners have a role to play in adapting to meet the needs of chemistry learners. Teachers must emphasize the transition from macroscopic chemistry to microscopic chemistry. In their teaching, they should use models such as concrete models, analogical models, theoretical models and simulations to

make concepts clearer when teaching chemical bonding. Teaching strategies based on concept mapping, conceptual change of texts and computer aided instruction should be designed to minimize or prevent misconceptions. Teaching should also be centred on the driving force of bonding and chemical reactions which is the need to decrease free energy of any system or to increase their entropy, the octet rule can then be by passed even at lower classes of high school chemistry teaching.

More vigorous research on possible ways of preventing misconceptions using octet rule and possible solutions cannot be overemphasized.

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