UNDERGRADUATE CHEMISTRY TEACHER TRAINEES' UNDERSTANDING OF CHEMICAL PHENOMENA

[1]Ruby Hanson, [2]Twumasi Ankrah Kwarteng & [3]Victor Antwi

[1&2]Department of Chemistry Education, University of Education, Winneba
[3]Department of Physics Education, University of Education, Winneba

ABSTRACT

Knowledge about periodic trends enables students to understand and explain chemical phenomena which they encounter in everyday life and in formal settings such as in chemical activities in school laboratories. The case of first year undergraduate students' understanding of chemical phenomena was assessed through an interpretive study. The study revealed that almost half of Ghanaian students at the entry point of tertiary teacher education had several alternative conceptions about periodicity in general and chemical phenomena in particular. The highest alternative conception was found to be on the electronegativities within a group of atoms and how they changed as well as how they affected polarity.

Keywords: Diagnostic test, Electron affinity, electronegativity, ionisation energy, periodic trend.

INTRODUCTION

Most students perceive the study of chemistry to be difficult for many reasons such as specialised vocabulary and its seemingly abstract nature. According to Wandersee, Mintzes and Novak (2005) in spite of chemistry teachers' best efforts in teaching chemistry, learners do not easily grasp the fundamental ideas covered in class. Although some smart students give apparent correct answers to questions in class, they only use correctly memorised words and naïve explanations. When they are questioned further on their conceptual underpinnings they reveal lack of in-depth conceptual understanding and subsequently encounter problems in understanding additional new or higher knowledge.

Explaining conceptions on the periodic trends of elements, ions and molecules is difficult for most chemistry students. Periodic trends are specific patterns that recur in the periodic table which illustrate different aspects of a certain element, including its size and electronic properties. Major periodic trends include electronegativity, ionisation energy, electron affinity, atomic radius, melting point, and metallic character. Periodic trends, arising from the arrangement of the periodic table, provide chemists with an invaluable tool to quickly predict an element's properties. These trends exist because of the similar atomic structure of elements within their respective groups, families or periods, due to the recurring trends among elements (Aldridge & Down, 2001). Knowing and understanding the periodic properties of elements will enable students to:

1. Predict atomic size, ion formation and radial distribution in neutral atoms and ions
2. Measure and compare ionization energies
3. Compare electron affinities and electronegativities
4. Predict redox potentials
5. Compare the character of metals with other elements
6. Predict chemical reactivities based on periodic trends
7. Determine greater cell potential during reactions

There are several ways through which children develop conceptions and misconceptions. While they develop authentic or scientific concepts upon the recognition of patterns, alternative concepts are formed based upon ineffective teaching methods, uncoordinated teaching activities, folklores, everyday words which have different connotations in science and vernacular interpretations of some science terms. According to Gooding and Metz (2011), the brain files new data by making connections to existing information. If this new information does not fit the learner's established pattern of thinking, it is refashioned to fit their existing pattern. This is when misconceptions are unknowingly created and reinforced- the learner builds explanations, unravels problems, and files new data based on faulty reasoning. The resulting misconceptions often stem from everyday observations, religious or mythical teachings, and science teachings that do not adequately challenge students' misconceptions. All these, and vernacular misconceptions could be compounded by linkages to other misunderstandings or inaccuracies which could generate a vicious cycle of misconceptions that could run through levels of learning and from generation to generation. There are multiple contexts through which young children encounter information that promotes misconceptions. It is therefore possible for children to have multiple explanations for a given phenomenon, depending on the context in which it occurs. This has sometimes been called 'paraconceptions' because they are sometimes plausible (Coll & Taylor, 2010). All these various alternative conceptions could be classified as

1. preconceived notions,
2. non-scientific beliefs,
3. conceptual misunderstandings,
4. vernacular misconceptions, and
5. factual misconceptions.

A misconception is more than having an incorrectly memorised fact. As indicated earlier, a misconception could originate from an inaccurate mental structure that underlines one's ideas of a group of related concepts. Taber (2006) investigated students' misconceptions on ionic bonding and established that students have difficulties understanding ionic bonding. He suggested a conceptual approach to teaching ionic bonding. Conceptual change is important for understanding the growth of scientific knowledge, the development of children's thinking, and education of students in the field of science and even mathematics (Thagard, 2004; Quinn, 2006). Conceptual change can also promote students' interest, curiosity and understanding. Thagard referred to conceptual change as "branch jumping" and "tree switching". He stated that conceptual change is the creation and alteration of mental representations that correspond to words. It is an important part in learning science through mental processes that create and alter mental representations for the best. Sevgi, Nurdane, Yezdan, Ayla and Oktay (2009) also reminiscence about how conceptual change, through the constructivist approach could enable students to build personal construction of concepts.
Horton (2007) has noted that alternative conceptions (misconceptions) concerning a number of topics are yet to be found or evaluated, regardless the many current efforts which have begun. These new or unexhausted areas for study include the periodic table of elements, geometry, polarity of molecules, the third law of thermodynamics and some topics in organic chemistry. However, this study will be limited to some areas of inorganic chemistry. Students' conceptual understanding before and after formal instruction have become a major concern among researchers in science education. This is because it influences how students build on or learn new scientific knowledge.

Aim and design of the study

The aim of this study was to use interpretive studies to identify alternative conceptions that students hold in explaining chemical phenomenon related to periodic trends and suggest methods to curb the menace. Participants in this study were twenty six 26 undergraduate first year chemistry students. The researchers administered an adopted open-ended diagnostic test (Taber, 2002) dubbed Chemical Phenomena Diagnostic Test (CPDT, Appendix A) to identify the students' understanding of concepts so that erroneous ones could be addressed accordingly.

Data collection and analysis

Data was obtained from the scored CPDT to find out the students' alternative concepts for onward correction. Their responses, which were marked out of a total of 40 marks, were analysed and categorised as conceptual (CC), partial conceptual (PC) and alternative conceptual (AC) understanding. If an answer was scientifically explained with the associated scientific terms, it was classified as 'conceptually correct'. If it was partly correct, it was classified as 'partial conception'. If however, there was no scientific connotation to the answer or it was not attempted at all, then it was deemed to be wrong or an 'alternative concept'.

RESULTS

A distribution of the students' general performance on the CPDT is presented as Table 1.

Table 1: Marks distribution of students' performance on the CPDT as percentages

Marks	Number of students	Percentage
0 – 19	13	50
20 –29	9	34.6
30 – 40	4	15.4

From the Table 1 thirteen (13) students representing 50% of the student showed misconceptions, nine (9) students representing 34.6% demonstrated partial conception and four (4) students representing 15.4% demonstrated conceptual understanding by explaining the various chemical phenomena related to periodic trends-using correct scientific terms, linkages and analysis.

An analysis of the students' responses with respect to their conceptual understanding or otherwise is presented in Table 2.

Table 2: Students' understanding of chemical phenomena in percentages

Concept	AC	PC	CC
Bond strength and temperature	46.2	34.6	19.2
Strength of hydrogen bond	53.8	38.5	7.7
The effect of nuclear charge on size	38.5	33.7	27.8
Electronegativity within groups	57.7	30.8	11.5
Strengths of bases within groups	38.5	50.6	10.9
Factors that affect lattice energy	32.1	47.1	20.8
Heat of hydration	42.3	30.8	26.9
Concept of electronegativity	54.0	42.3	3.7

Table 2 shows polled responses of students' overall performance and understanding.

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Findings

1. About 45.39% of students had virtually no idea about the trends in the periodic table of elements.
2. About 38.55% of students had partial misconception as terms were wrongly used and interpreted.
3. Periodic trends were memorised without understanding. This is evident in the total number of students (83.94%), who demonstrated poor conception of the periodic trends.
4. Periodic parameters were applied wrongly; and in most cases not at all
5. There was an over reliance on the octet rule, which often times was implied but not applied.
6. Incorrect relation between charge densities and metallic bond.
7. Inability to relate cationic size to lattice energy
8. Inability to relate melting or boiling point to lattice energy.
9. Inability to relate electronegativity to polarity and subsequently to base strength
10. Inability to link the relationship between ionic size hydration energy
11. Poor knowledge about hydrogen bonding
    Periodic anomalies were difficult to explain

DISCUSSION

Periodic trend is one of the chemistry topics taught at the senior high schools as well as at the university level. A pre-assessment test conducted on some level 100 chemistry major students at the University of Education (UEW) by the researchers on periodic trends revealed that they had alternative concepts about many chemical phenomena. Their answers indicated lack of deeper understanding on the chemical and physical properties of elements. It appeared as if the 'nature of matter' was not well understood by majority of the students (83.94%) at the secondary school level. For example, a student wrote on his CPDT paper that $MgCl_2$ had larger lattice energy than $CaCl_2$ because; magnesium was metallic while calcium was chalky and brittle as reasons for the stated observation in item6. The student concerned associated solid or metallic calcium with calcium carbonate or lime stone. Almost half of the students could not explain why magnesium chloride ($MgCl_2$) has larger lattice energy than calcium chloride ($CaCl_2$). Students often acknowledge the trends in the periodic table of elements as an increase or decrease of parameters across the period and down a group but fail to explain the underlying concepts. Bunce (2009) intimated that students enter chemistry classes with many insecurities and fears about their ability to be successful in chemistry. Sometimes they are afraid to engage in laboratory activities which facilitate conceptual understanding because they are afraid of explosions from chemical reactions and their attendant injury or death (Acquah & Hanson, 2013). Thus, these fears often result in students choosing memorisation rather than understanding science through personal experiences (practical activities) as a way to succeed and earn acceptable grades. The lack of conceptual understanding inhibits students from performing to the best of their abilities. It also limits their capabilities in the acquisition of manipulative, process and concept skills.

Knowledge about terms such as electronegativity, electron affinity, ionisation energy, nuclear charge, core charge, charge density, charge separation and lattice energy as well as how each parameter bears on the other, are important in understanding chemical phenomena. Adequate understanding of these factors enable one to understand why some atoms are small in size while others are bigger or specifically, why elements to the left of the periodic table have bigger sizes while those to the right decrease in size as one moves along a period from left to right. In this study, it was realised that a few students could apply the general periodic trends but found it difficult to explain why lithium, for example, should have a higher melting point than sodium.

They reasoned that lithium was smaller in size (generally sizes increases down a group) and had less matter and so had to have a lower melting point as compared to sodium which had a bigger size and mass, thus, requiring more heat energy to break down. Issues of charge densities of elements and how they influenced metallic bonding as well as melting point was difficult for students to rationalise. This indicated poor understanding or application of periodic trends. They could not explain logically that more energy was required in breaking down the metal lattice in lithium since the delocalized electrons were strongly attracted to the highly charged metal core.

Again, in item 2, the students presumed that since 'hydrogen' was common to both oxygen and sulphur, there should have been no difference in bond strength. If there had to be a difference, then bond strength should have been higher in H_2S as Sulphur was down the group. The issue of electronegativity strengths and how they varied down a group was lost on the students. They made unintelligible attributions to the correct observation given in the question. Responses to item 3 also proved interesting. Here, both atoms had two inner shell electrons but nitrogen had a greater nuclear charge (+7) as compared to carbon (+6). Nitrogen had a higher core charge (+5) than carbon (+4). The closer the outer electrons, the smaller the size and so nitrogen was indeed smaller. Students stated that nitrogen was a gas and so could be smaller as carbon was a solid with a fixed state so could be higher.

In items 4, 5 and 6, the octet explanation was most prevalent. Chlorine was more electronegative and so tried to attain the octet better than bromine which was less electronegative. Their core charges were not applied at all. In item 5, students were expected to explain the observations based on electronegativity and polarity, while in item 6, cationic sizes, with respect to the periods where the group 2 species were originating from were necessary parameters to consider. The chloride was common to both cations. They also failed to relate how electronegativity influences types and strength of bonds. Similar ideas were required in discussing the observations made in items 7 and 8. Some students get confused when comparing atomic sizes of elements of which one is a metal and the other either a liquid or a gas. It was observed in a similar diagnostic study that some students ignored their knowledge about the general periodic trend and used their naïve interpretation that particles of liquids spread out more than solids. Thus nitrogen atoms could be bigger than sodium atoms because the particles of nitrogen are wider apart.

A thorough analysis of students' response intimated that they had knowledge of the periodic parameters but had perhaps learned them by rote- without understanding. The researchers noted that making students review what they knew and giving evidence to support their explanations was an important step in the concept formation process. The simple diagnostic test uncovered as many as 12 major findings about basic periodic chemistry, which otherwise would have been carried over into higher levels of learning to hamper further acquisition of scientific knowledge. The concept of electronegativity appeared to be least understood by students as shown by their responses to items 4 and 8 (57.7 and 54.0%) respectively. This was followed by the concept of hydrogen bonding (53.8%). The most understood concept was on how nuclear charge affected the size of a particle (atom). The least understood concept was again the concept of electronegativity (3.7%) as shown in Table 2. Observations

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in Table 2, confirm those made in Table 1, where 13 (50%) of students scored between 0 and 19 marks.

CONCLUSION

The study showed that creating a platform for students to test their conceptual frameworks through a diagnostic means is a laudable practice for conceptual change as proposed by Keeley, Eberle and Farrin (2007). In this study, 12 major misconceptions were identified, most of which appeared to be classroom-based misconceptions. This is because students had knowledge about the periodic parameters from their study of science in high school but could not apply them effectively. It is recommended that teachers assess and re-assess the validity of their students' understanding of concepts, while providing ample opportunity for practice.

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Appendix A

EXPLAINING CHEMICAL PHENOMENON 1

Explaining chemical phenomena (1) Chemists use their models and theories to try and explain phenomena about chemical systems. Suggest an explanation for each of the following (you may find it useful to refer to a periodic table):

1. Lithium has a higher melting temperature (454 K) than sodium (371 K).

2. There is stronger bonding, called hydrogen bonding, between molecules of water (H_2O) than between molecules of hydrogen sulfide (H_2S).

3. The nitrogen atom is smaller than the carbon atom (ie it has a smaller covalent radius – 0.074 nm compared to 0.077 nm).

4. Chlorine is more electronegative than bromine.

5. Ammonia (NH_3) is a stronger base than phosphine (PH_3).

6. Magnesium chloride has a larger lattice energy (2489 $kJmol^{-1}$) than calcium chloride (2197 $kJmol^{-1}$).

7. More energy is released when sodium ions are hydrated (390 $kJmol^{-1}$) than when potassium ions are hydrated (305 $kJmol^{-1}$).

8. Nitrogen is less electronegative than oxygen.