KNOWLEDGE OF ATOMIC STRUCTURE, BONDING AND BONDING ENERGY: RESEARCH RESULTS FROM INTERVIEWS AND QUESTIONNAIRE WITH CHEMISTRY AND LIFE SCIENCE STUDENTS

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ABSTRACT

This research depended upon the importance of conceptual understanding in bringing about meaningful learning. Accordingly, this research was designed to assess students' knowledge regarding basic and fundamental concepts in Chemistry: atomic structure, bonding and bonding energy. Therefore, some of year I, II, III Bachelor of Science in Chemistry (BSc (Chem)) and year I life sciences university students were enrolled in this research. According to Novak's theory of meaningful learning, students were taught first before being tested. Therefore, both year II (n=20) and III (n=14) chemistry students were tested in their first semester, while year I (n=61) chemistry and life sciences students were examined at the end of second semester. The results from the interview with students indicated that almost 94% drew electron cloud and Bohr's model as their mental image of atomic structure. Furthermore, they used classical mechanics ideas to explain electron cloud, and probability language to explain Bohr representation. Results from questionnaire indicated that, while a fairly good proportion of BSc (Chem) year II and III students involved in this study showed an appreciable level of scientific literacy, more than 50% of the life sciences students had problems in understanding these concepts. Furthermore, this paper discusses misconceptions as revealed in the interview and questionnaire results. *[African Journal of Chemical Education—AJCE 11(1), January 2021]*

INTRODUCTION

Generally, students seek to connect what they already knew and what they need to know. If a student, because of prior knowledge, misinterprets information (regardless the source), then the understanding becomes flawed, according to Novak's theory of meaningful learning [1-4]. Many studies on students' conceptual understanding of chemistry have indicated that students are not developing a satisfactory conceptual understanding. Many of the researches revealed difficulties students face in connecting basic concepts, principles, representations, and reality.

Prior knowledge plays a vital role in making decisions about behavior of atoms. It was shown that the knowledge students possess about atomic structure is predominantly descriptive and simplified [5]. The group further showed that students had their alternative visions about atomic structure basing on their understanding about Rutherford or Bohr model of the atom rather than the current scientific model of the atoms [5]. The knowledge claims used by students are not often well grounded by relevant associations of concepts. Many studies on students' misconceptions have revealed inconsistencies in knowledge possessed by students. Leading to a conclusion that students' knowledge mostly consists of separate facts, formulas, equations that are poorly organized [5-10]. However, the common factor (conclusion) in most of these studies is that identification of and addressing students' prior knowledge is key for bringing better understanding [5-10].

Most of the studies exploring students' understanding of atom were conducted at secondary schools [11-18]. Furthermore, there are few reports on studies conducted on university level students' understanding of atoms [6-10]. There are scanty reports regarding understanding of university science students on atomic structure, and its application in bonding and bonding energies. Therefore, the research reported herein describes the understanding of some of the year I, II, and III BSc (Chem) and year I life sciences students in the mentioned concepts.

METHODOLOGY

According to Novak's theory of meaningful learning, individual student must possess relevant prior knowledge about the concept before being able to establish substantive connections among concepts [1-4]. Accordingly, year II and III BSc (Chem) students were examined in semester I and year I BSc (Chem) and life sciences students were examined in semester II. That is, students were exposed to the concepts for 2 years and 1 year for year III and II BSc (Chem) respectively, while year I BSc (Chem) and life sciences students were exposed for one semester.

The study involved 95 participants from BSc (Chem) =21, 20 and 14 for year I, II and III respectively, and life sciences year I = 40 at the University of Dar es Salaam (UDSM), in Tanzania. The research involved interview with responders before administering the questionnaire, this aimed at getting the ideas of the atomic structure that student's best identify with, and establish to what extent have the students connected these ideas to bonding and bonding energy.

The interview was in line with Johnstone's explanation that there are three levels at which one understands chemistry. These levels are symbolic which includes equations/diagrams, particulate which includes invisible molecular level and lastly macroscopic consisting of tangible and visible. Therefore, as students gain knowledge, the expectation is that connections in the three described levels will be established. The challenge as revealed through research is that students face difficulty in making connections between the stated levels [19-21]. In line with that, the interview was designed to establish the extent at which students understood the electronic structure of the atom in both the particulate and the symbolic levels. Therefore, in the interview, each responder was asked to draw any representation considered to best fit the mental image of the structure of an atom (symbolic), and describe its essential features (particulate).

The [22] questionnaire was modified following the results from the interview, therefore 11 multiple choice questions targeting at evaluating the mentioned learning categories (1 and 4 below) was formulated and administered to students to evaluate the nature and quality of their understanding in these key concepts (atomic structure, bonding and bond energies).

Overall, the interview and questionnaire were designed to measure student's knowledge and understanding of the mentioned concepts. Therefore, learning categories that were under testing included:

1) Atomic structure (measured from the drawings from each student, and questionnaire);
2) Representation of an atom (measured by quality of illustration given by each student);
3) Knowledge of atomic models (measured by the description concerning the illustration given by each student);
4) Connection of the atomic structure to bond formation/breaking and their associated energy changes (measured through questionnaire).

Description of sample and their respective curriculum

This research was conducted primarily on undergraduate students at UDSM, therefore, some of year I to III Bachelor of Science in chemistry (BSc (Chem)) and year I life sciences students were involved in the research. Table 1 indicates basic statistics of the students involved in this study.

Table 1: Basic statistics of the students involved in the study

Degree program	**Year of study**	**Semester**	**No. of students**	**Gender**
BSc (Chem)	I	II	21	5 females/16 males
BSc (Chem)	II	I	20	4 females/ 16 males
BSc (Chem)	III	I	14	3 females/11 males
Life sciences	I	II	40	73 females/ 127 males

As their core courses, BSc (Chem) students involved in this research, study the fundamentals of physical chemistry including kinetics, thermodynamics, quantum chemistry, and spectroscopy. However, with students enrolled in life sciences programs, general chemistry is taught in second semester of year I, covering concepts such as atomic structure, chemical bonding, and nuclear energy and its effects on matter. Each of these courses are taught by different instructors, and upon their consent, students in these programs were involved in this study. Table 2 summarizes the courses related to the concepts offered to BSc (Chem) year I – III and life sciences year I.

Table 2: Courses related to atomic structure, bonding and bonding energy

Program	Course	Core/Optional
Life sciences Year I	Atomic structure and chemical bonding. Nuclear radiation and its effects on matter.	Core
BSc (Chem) (Year I)	Introduction to electronic structure and spectroscopy Basic Analytical and Physical Chemistry	Core
BSc (Chem) (Year II)	Chemical thermodynamics Chemical kinetics and electrochemistry	Core Core
BSc (Chem) (Year III)	Organic spectroscopy	Core

Purpose

The research topic evaluated in these investigations was the knowledge of students in atomic structure, bonding and bonding energies. As explained by [23], individual that is "well informed, cultured, literate individual" must know these topics after being taught for two years in advanced level secondary schools, instructors at the university level expect that students already have some ideas concerning the topics. Therefore, the researcher's goals were to find answers to the following research questions:

(1) What were the learning outcomes of the courses dealing with atomic structure, bonding and bonding energies?

(2) What misconceptions were apparent?

To answer these questions, interview with students and questionnaire were designed and carried out/administered to BSc (Chem) year I, II and III, and year I life sciences students.

Data collection and analysis

The interviews with responders were conducted in English, and after they were taught the subject. All students who participated in this study, signed consent forms, and the interview lasted for about an hour. Questions were asked where the descriptions given were not clear, therefore, important notes were taken by the researcher when explanations were given. Papers with drawings and interpretations, and the notes taken were collected for further analysis. Results from interviews were analyzed by comparing the information gathered from students amongst themselves (constant comparative analysis [24-25]). Therefore, each student's representation and interpretations were compared to one another, allowing analyses for their similarities and contradictions. Lastly, all student's representations and interpretations were compared to the literatures. The results reported herein, refer students by their 'fake names'.

The questionnaire was administered to BSc (Chem) I, II and III years of study, and year I life sciences students, and their responses were thoroughly analyzed quantitatively and qualitatively. Therefore, most common misconceptions about the topics were identified, and the results presented herein are in number/percentage of students.

RESULTS AND DISCUSSION

Results from interviews with students

A total of 95 undergraduate students doing BSc (Chem) and life sciences courses were involved in this research. Therefore, in the interview, each student was asked to draw any representation considered to be the mental image of the structure of an atom (symbolic), and describe its essential features (particulate). Students' most drawn diagrams that suitably represented their mental image of atoms were put into three categories as shown in Figures 1, 3 and 5.

As it is observed in Fig. 2, 58% of the students indicated diagrams in category A (shown in Fig. 1) as the ones that best fit their mental image. Major features indicated by these students included nucleus, the reason being '*it is an important feature, it is a reference point of an atom, it holds the atom together, it determines the identity of an atom/element'*. This diagram agrees with the quantum model of the atom.

Fig. 1: Category A drawings

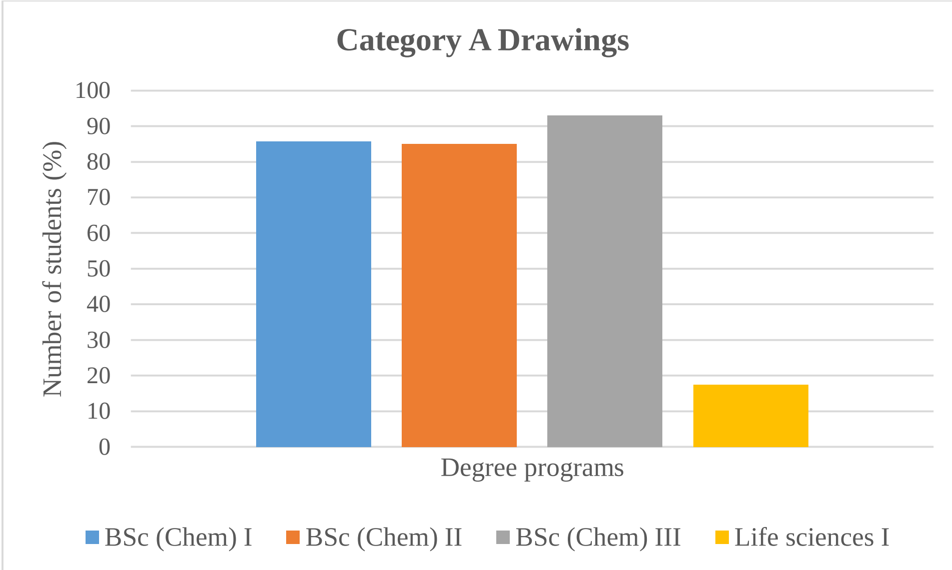

Fig. 2: Number of students (%) that indicated category A diagrams

Students interpreted the first and second drawings indicated in category A (Fig. 1) as consisting of a region (darker) which many said that it is the most probable 'area' or 'region' to find electrons. Fewer students indicated this area to represent different energy levels, others compared it with the attraction of electrons to the nucleus, and how likely it is to find electrons in that given area. Specifically, Indigo indicated that the darker area is shells and the lighter showed 'lower possibility' of finding electrons, *"…like hydrogen has one electron, and it will be closer to the nucleus because it must fill that shell first"* (Indigo, year II BSc (Chem)).

It is interesting to note that first and second diagrams in category A are in fact similar, by showing electron probability. Also having very few students draw the second diagram in the series does not correlate with the fact that it has been ubiquitously used in chemistry textbooks. Most students that indicated this diagram as their mental image of atom, understood that the dots represented "*places to find electrons, locations of electrons over time*". Few interpreted as *multiple particles, or what makes the inside of an atom (protons, neutrons and electrons).*

The third diagram was indicated by an appreciable number of students, and the description being '*the diagram indicates the equal possibility of finding electrons anywhere in the region outside the nucleus*' (Yellow, year III BSc (Chem)).

On the other hand, an appreciable number of students (36.8%) indicated category B diagrams (Fig. 3) as the ones that best represents their mental image of an atom, as indicated in Fig. 4.

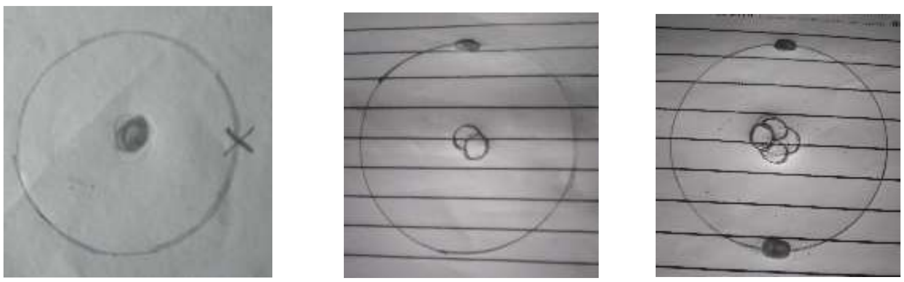

Fig. 3: Category B drawings

Students that indicated these diagrams as the ones that best fits their mental image of atom, explained that the well elaborated nucleus is the one that captured their minds. However, additional comments such as '*it is easy to count and see the electrons'*, and '*it is familiar*' (seen in text books and in high school) were given in these drawings. These diagrams agree with classical model of the atom. These findings are not very different from the ones previously reported by [7, 11-12, 16-18, 26-27] who indicated that students would prefer to draw a representation that resembles Bohr's model.

Some students thought that *the ring represented the path for the movement of electrons, and manner at which electrons move around the nucleus*, and others thought of it as an '*orbit*' of electrons. The diagram represented Bohr's model, it is interesting to note that one of students said "*electrons move randomly, and therefore they could be anywhere, and not rotating around the nucleus, but I find it hard to understand,… it's easy to understand that they go round the* *nucleus…*" (Red, year I life sciences). Another student went further by saying "*electrons move so fast that one can't tell its speed and location at the same time, …one can neither know how it moves nor the direction*…. (referring to category B)" (White, year I BSc (Chem)). It is interesting to note that students misinterpreted Heisenberg uncertainty principle thus leading to the idea that electrons must be moving randomly. It is observed that, some students knew something about the quantum model but mixed with classical theories. These results coincide with the reports by [28-30], who indicated that students used terms from quantum theory to explain Bohr's model.

The fact that the two categories of drawings (A and B) were drawn by many (94.8%) as their mental images of an atom implied that students have preference for quantum and Bohr models. These results coincide with the ones reported earlier by [26] who indicated that students strongly preferred both quantum-like models and the Bohr model, and often mixing features of the two very different models.

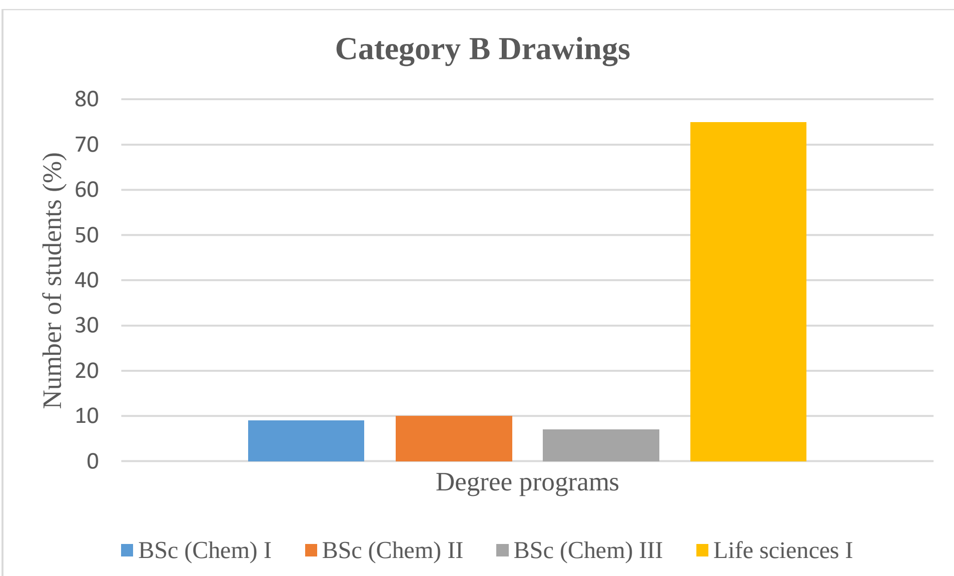

Fig. 4: number of students (%) that indicated category B diagrams

Diagram in category C (Fig. 5) was indicated by 3% of the students as indicated in Fig. 6.

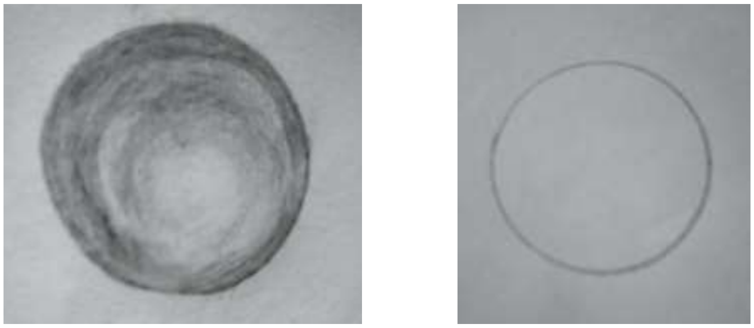

Fig. 5: Category C drawings

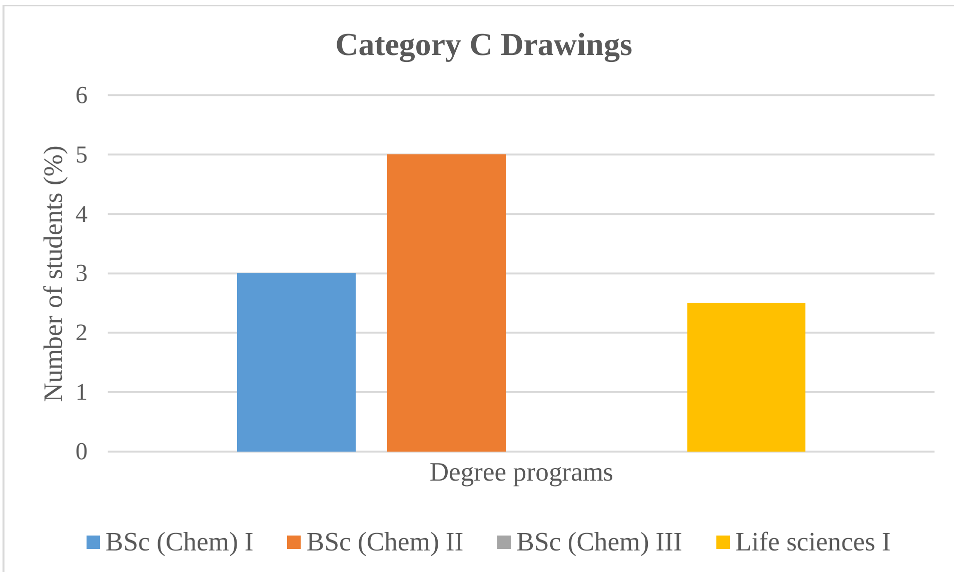

Fig. 6: number of students (%) that indicated category C diagrams

Many students interpreted their diagrams (in category C) as nucleus of the atom, one said '*nucleus is everything.'* (Pink, year I life sciences), *'it is the one holding the atom together*' (Green, year I life sciences), and another said '*it determines the identity of an atom/element'* (Blue, year I BSc (Chem)), these concurred with [12] results that students compared 'ball model' to the nucleus of the atom. Others said the spherical nature shows *the equal probability of finding electrons anywhere in atom* (Grey and Brown (BSc (Chem)) year I and II respectively). This argument indicated that although the idea of probability was to help students develop an accurate mental image of atom, students failed to understand that the main idea in the diagram they proposed was to show the overall spherical nature of atom.

Overall, it is observed that students couldn't distinguish features of diagrams they drew to represent their mental image of atom. Therefore, concur with the previously reported observation that students face difficulties in differentiating the atomic models, sub-microscopic level and actual atoms [31-32].

Results from questionnaire

All the 95 participants were involved in this session of the research, therefore filled the questionnaire, there was no time limit, but the session lasted for about 20 minutes to half an hour. The questionnaires were collected and thoroughly analyzed, the results are hereunder discussed. Table 3 represents the number of students with correct responses in each question.

Table 3: Number of students with correct responses in each question

Question	Students with correct responses					
	BSc (Chem)-I	BSc (Chem)-II	BSc (Chem)-III	Life Sciences	Total	%
1	4	5	5	10	24	25.3
2	4	6	7	11	28	29.5
3	5	4	6	10	25	26.3
4	5	8	7	18	38	40
5	8	9	8	20	45	47.4
6	5	8	8	12	33	34.7
7	9	10	8	14	41	43.1
8	9	9	8	12	38	40
9	8	10	6	15	39	41.0
10	7	5	6	13	31	32.6
11	5	8	8	10	31	32.6

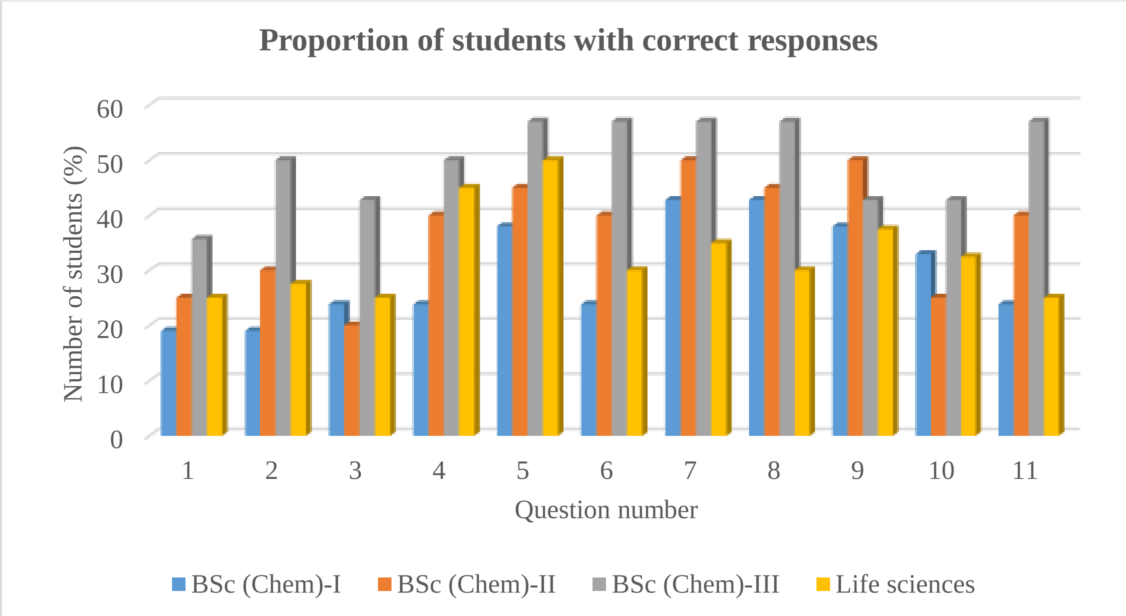

Fig. 7: Proportion of students with correct responses in each question

Generally, the proportion of students with correct responses as observed in table 3 and figure 7 has been very low, where less than 50% students exhibited scientific literacy in the concepts investigated. However, superior scientific literacy in the concepts was demonstrated by year III BSc (Chem) students, while, a comparable literacy has been shown by year I BSc (Chem) and Life sciences responders.

A closer look at the number of responders with correct responses in questions 1, 2 and 3 in the administered questionnaire as shown in Table 3 and Figure 1, indicates that <30% of the responders in year I and II BSc (Chem) and life sciences showed the required scientific literacy. The comparison of results between the four groups indicated that year I BSc (Chem) and life sciences responders have shown lower scientific literacy with respect to other groups. This is probably because both year I BSc (Chem) and life sciences students are in their first year of study, and were taught for one semester, therefore, have lesser exposure to the concepts than year II and

III BSc (Chem) groups. A comparable scientific literacy was demonstrated by both year I BSc (Chem) and life sciences groups in questions 9, 10 and 11, indicating the same level of conceptual understanding concerning energy changes during bond breaking and formation.

Generally, it can be concluded that life sciences and BSc (Chem) year I students have lower conceptual understanding concerning these concepts, this might be due to the fact that both groups have been exposed to these concepts for one semester, and also life sciences' curricula covers general chemistry, that is only basic ideas about bonding and energy concepts are covered. BSc (Chem) year III have shown superior conceptual understanding throughout all questions, this might be due to longer exposure to the concepts knowledge.

Analysis of students' responses in each question

The section below will summarize the analysis of responses for each distracter in each question. Irrespective of their degree programs, responses of the responders are summarized in Fig. 8. Analysis of selected distracters by responders in their respective degree programs are presented in in Table 4.

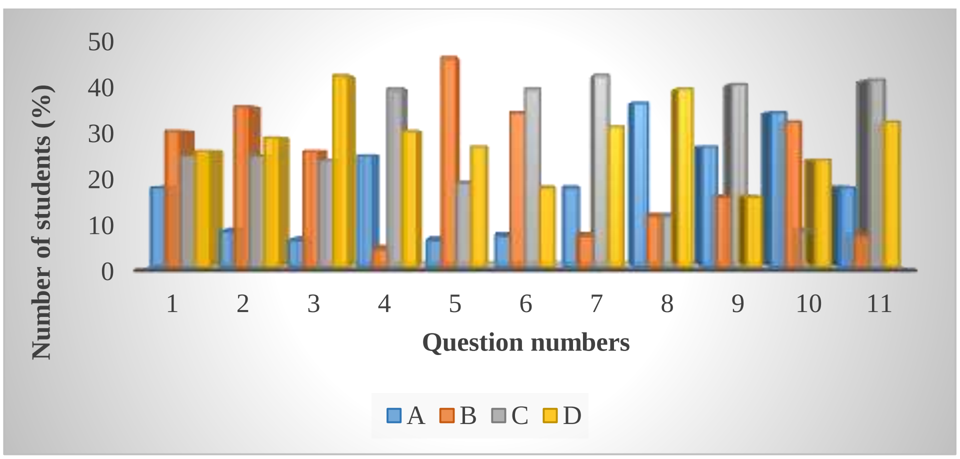

Fig. 8: Proportion of responses for each distracter in each question

Table 4: Analysis of selected distracters by responders in their respective degree programs

Question	Distracters	BSc (Chem)-I	BSc (Chem)-II	BSc (Chem) -III	Life sciences
1	A	5	6	3	3
	B	6	6	3	14
	C	4	5	5	10
	D	6	3	3	13
2	A	1	3	2	2
	B	9	9	4	13
	C	7	2	1	14
	D	4	6	7	11
3	A	1	0	1	4
	B	5	4	6	10
	C	7	6	2	8
	D	8	10	5	18
4	A	5	4	3	12
	B	2	0	0	2
	C	5	8	7	18
	D	9	8	4	8
5	A	1	2	1	2
	B	8	9	8	20
	C	5	4	2	7
	D	9	5	3	11
6	A	3	1	0	3
	B	5	8	8	12
	C	9	10	4	15
	D	4	1	2	10
7	A	4	2	1	10
	B	3	1	0	3
	C	9	10	8	14
	D	5	7	5	13
8	A	9	9	4	13
	B	1	2	1	7
	C	2	0	1	8
	D	9	9	8	12
9	A	3	4	4	15
	B	2	1	3	9
	C	8	10	6	15
	D	8	5	1	1
10	A	7	9	3	14
	B	7	5	6	13
	C	2	1	1	4
	D	5	5	4	9
11	A	2	2	1	12
	B	0	1	1	5
	C	14	9	4	13
	D	5	8	8	10

Question 1

Which of the following best fits your mental image of an atom?

A. The atom has a proton which is found inside the very small nucleus. The electron appears and disappears randomly in a cloud that surrounds the nucleus.

B. The atom is circular with a small center and lots of empty space - just like a marble in the middle of a football field. The proton is inside the nucleus and the electron is a smaller particle that is orbiting around the nucleus.

C. **The atom is a fuzzy sphere in which the electron can be found anywhere outside the very small nucleus which is in the middle. The nucleus consists of one proton.**

D. The atom consists of a very small central core, which is the proton. The electron can be found in an orbital and moves around the core in a spherical path.

Question 3

Why do two atoms form a molecule?

A. An atom has a low atomic number and mass. Thus, two atoms need to be together to increase these properties.

B. **As two atoms approach each other, the electron from each atom starts to be attracted to the nucleus of the other atom producing a molecule.**

C. An atom is electropositive and wants to get rid of its valence electron to reach its most stable state. Therefore, it will give up its valence electron to another atom so that they both can reach their most stable state.

D. Both atoms might have a spot to accommodate another electron. Therefore, the two atoms share electrons and form a very strong covalent bond.

Questions 1 and 3 addresses misconceptions observed in the interview, such as an orbital is a shell in which electrons are placed; orbitals are electrons' trajectories arranged around the atomic nucleus where electrons rotate; an orbital is an energy level of the electron; the use of Solar System Model or a simple nucleus-electron shell model to explain the structure of atom; electrons rotate around the nucleus like the planets around the sun; and orbitals are equivalent to orbits or shells. The same misconceptions were reported by [29, 33- 34]. As it can be observed in question

1, >55% of responders selected distracters B and D, thinking of atomic structure as a solar system in which electrons like planets orbit around the nucleus in a circular manner. In question 3, a significant number of responders do not have a clue that there are no fixed positions for electrons, but they can be found anywhere outside the nucleus.

Question 2

What really happens when a bond is formed between two atoms?

A. The electrons of the two atoms are attracted to each other because electrons like to be paired up, thus holding the two atoms together.

B. A single bond is formed by the electrons making a solid connection between the two hydrogen atoms, like a stick joining the two atoms together.

C. As the electron of one atom approaches the nucleus of the other, energy is transferred from the electron to the nucleus which forms the bond.

D. **As the atoms move closer together, there is an attraction between each electron and the nucleus of each atom making the two atoms stick together.**

Large proportion selected distracter B as best answer. What happens when two atoms are brought together? A BOND is formed, what is student's mental image of a bond? ~37% think that it is a solid connection visualized as a stick joining the two atoms.

Question 4

What happens when two monoatomic atoms form a diatomic molecule?

A. When two monoatomic atoms reach a distance that is most stable, a bond is formed which requires energy. The electron from each monoatomic atom is attracted to the nucleus of the other atom.

B. There is sufficient energy between the two monoatomic atoms to be bonded together. If there were not enough energy then the two monoatomic atoms would not be able to form a diatomic molecule

C. **When a bond between two monoatomic atoms is formed the potential energy of the system decreases, making the system more stable.**

D. The diatomic molecule is more stable since it contains a lot more energy than a free-roaming monoatomic atom.

Distracter A was chosen by 25% of the responders, although it is true that electron from each hydrogen atom is attracted to the nucleus of the other atom, it is not true that there are most stable distance during bonding. Here a misconception of a bond like a stick between two atoms; and a solid connection between two atoms is observed.

Question 5

What happens if you try to push the atoms in a diatomic molecule closer to each other?

A. The electrons get closer to each other resulting in a greater attraction between them. Because of this increased attraction, the two atoms are held together even more strongly.

B. **The potential energy of the system drastically increases as the electrons and nuclei of the two atoms repel each other.**

C. The potential energy of the system increases to form bond energy which causes the two atoms to be more strongly held together.

D. Initially, potential energy is required to push the two atoms closer to each other; however, after being brought very close together the potential energy of the system is released to the surroundings.

Although it is true that once un-bonded atoms are bought closer, electrons from each atom are attracted to the nucleus of the other, neither 'electrons are attracted to each other', nor 'attraction of electrons forms a bond between two atoms' are true, therefore, >50% of responders had difficulty with these concepts.

Question 6

Consider the following reaction, which statement describes the energy changes?

$$CCl_3F(g) \longrightarrow C(g) + 3Cl(g) + F(g)$$

A. The energy of the products must equal the energy of the reactants because energy can neither be created nor destroyed.

B. **Energy is needed by the system to break the four bonds.**

C. The potential energy stored in the reactant molecule is released when the reactant is converted into atomic gases.

D. Since heat energy is added to the CCl_3F, the compound boils and the bonds to break.

Although distracter A "Since energy can neither be created nor destroyed, the energy of the products must be equal the energy of the reactants" is not necessarily wrong, but it is not appropriate for the question. Therefore, a significant number of responders (40%), did not opt for it, but instead they had the generalization that energy is released when breaking bonds.

Question 7

Consider the reaction below, which of the statements describes the energy changes?

$$Na(g) + Cl(g) \longrightarrow NaCl(g)$$

A. The reaction requires energy to combine the atoms to form NaCl.
B. The energy of the system will increase when bond formation occurs.
C. **The reaction produces energy when the atoms bond to form NaCl.**
D. The energy is absorbed from the system to create the bonds in the product.

It is observed that distracters A and D indicated that energy is absorbed during the reaction were chosen by a significant number of responders (about 50%), however, the fact that the reaction involved no bond breaking indicates that energy is not required.

Question 8

Which of the following statements best fits the energy changes involved in this chemical reaction?

$$CH_4(g) + H_2O(g) \longrightarrow 3H_2(g) + CO(g)$$

A. When breaking the bonds in the reactants, energy is released which will be used to make the bonds in the products.
B. Energy is released from the system because more bonds are broken than are formed.
C. Energy is neither created nor destroyed when the reaction occurs. It is only transferred from the reactants to the products.
D. **Energy must be added to the system break the bonds in the reactants and is released from the system when bonds are formed in the products.**

Question 9

During bond breaking, which of the following statements describes the energy changes involved?

A. When bonds are broken, the energy stored in them is released to the surroundings as heat.
B. When a bond is broken, depending on the energy difference between the reactants and products, energy is either released or absorbed.
C. **Energy is needed to break bonds, this is because when atoms bond to each other they are more stable than the separate atoms.**
D. Energy is required to break bonds because bonded atoms have more potential energy than separated atoms.

Question 8 and 9 are in fact similar, they are targeted to elicit misconceptions like "during bond formation, energy may be absorbed/released depending on the atoms involved in the reaction; since energy is conserved, there are no change in energy during reaction; and energy is required to form bonds and therefore stored in the bonds". As it is observed, 60% of the responders fell into the mentioned misconceptions.

Question 10

Statements below describes energy changes when chemical bonds are formed, which one best describes the process?

A. When bonds are formed depending on the type of atoms that are present in the bond, energy may be absorbed or released.

B. **Energy is released, when chemical bonds are formed and the system becomes more stable.**

C. Energy can be neither be created nor destroyed, therefore no overall energy changes.

D. Energy is required to form bonds in the products of a reaction. That energy is stored in the bonds.

The shown data indicates that ~60% of responders had no clue that a stable system is the one with lower energy.

Question 11

During bond formation and breaking, which of the following statements describes the energy changes of the process?

A. During bond breaking, energy is released as heat while energy is required to keep bonds in place.

B. Broken bonds release energy to the surroundings for an exothermic reaction.

C. Since energy can neither be created nor destroyed, the energy that is required to break bonds is equal in magnitude to the energy released when bonds are formed.

D. **When bonds are broken energy must be absorbed by the system, but when bonds are formed energy is released.**

As it is observed, >60% selected distracters A-C, indicating that they had no clue that during bond breaking, energy must be absorbed by the system, but when bonds are formed energy is released.

CONCLUSIONS

In this study, some of year I, II, and III BSc (Chem) and year I life sciences students were involved. The study explored their understanding on atomic structure, bonding and energy as interrelated concepts in chemistry by interview and questionnaire. The results from the interview with students indicated that almost 94% drew electron cloud and Bohr's model as their mental image of atomic structure. Furthermore, they used classical mechanics ideas to explain electron cloud, and probability language to explain Bohr representation. Moreover, it is indicated that as students are continually exposed to the concepts concerning the stated topics, their literacy level increases, this is shown by BSc (Chem) year III students in both interview and questionnaire.

However, the life sciences and BSc (Chem) year I students involved in this study showed comparable literacy, this might be because both groups were exposed to these concepts for one semester only. Overall, as indicated in questionnaire results, it can be concluded that more than 50% of those involved in this study could not show an expected scientific literacy level related to these concepts. This study indicates that students' understanding of atomic structure affects their understanding of bonding and energy.

LIMITATIONS AND RECOMMENDATIONS

This research has got limitations such as

1. With small number of students involved in this research, determination of inter group differences could not be detected, thus, a study with larger sample is proposed.
2. Although the research tool was able to indicate the extent of some misconceptions, a study involving students from different universities in Tanzania to develop inventory questions is proposed. This is because the tools used in this study might have left some misconceptions that need to be addressed.

The author recommends a thorough research to be done to explore atomic structure, bonding and energy conceptual understanding of students in advanced level secondary schools in the country. Since universities enroll students after completing and passing this level of education, the proposed research will reflect the common misconceptions in this level of education that might have been carried to university level.

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