An Investigation Into Misconceptions Held by Secondary School Chemistry Student
(Study in Stoichiometry and the Mole)

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Abstract: This study investigated misconceptions held by secondary school chemistry students in stoichiometry and the mole. Five objectives and five research questions were formulated. The sample for the study was 152 Form 5 pupils randomly selected from three sample schools in the Shiselweni and Manzini regions of Swaziland. The data used for the study was collected using a diagnostic two tier test on the topic stoichiometry and the mole. data was analyzed using percentages, graphs and means. The findings from the study revealed that students showed misconceptions in balancing equations, writing of ionic and molecular formulas, calculation of mole with respect to the volume ratio and calculation of molar mass and mass of reagents. Students showed no understanding of the limiting and excess reactant concepts. It is recommended that to ensure students understanding of stoichiometry and the mole concepts teachers are encouraged to use teaching methods and strategies that would help students realise their misconceptions and achieve conceptual change.

Keywords: Investigation, Misconceptions, Chemistry, Student & Teachers.

1. Background of the Study

Different scholars use different labels for the students’ constructed scientifically unaccepted views called misconceptions (Ozmen, 2004), alternative conceptions, naive conceptions (Driver and Easley 1978), common-sense reasoning, preconceptions or alternative framework (Kuiper, 1994). Boujaoude and Barakat (2000) view alternative conceptions as including all incorrect descriptions, misinterpretations or inaccurate explanations of scientific concepts created by students during and after the learning process. Schmidt (2007) defines alternative conception as an imperfect or mistaken understanding of concepts by students. Schimidt argues that alternative conceptions can seriously affect students’ learning ability and performance in science.
Alternative conceptions play a larger role in inhibiting learning chemistry concepts than simply leading to inadequate responses to questions. Ayas and Demircioglu (2005) argue that students often make their own understanding on how the natural world exists, prior to formal science education, but these theories are frequently contrary to those accepted by scientists. Takaya (2008) classifies alternative conceptions as students’ conceptual and propositional knowledge or ideas that are inconsistent with those generally accepted by scientists. Yip (1998) classifies misconception into three categories and argues that alternative conceptions in the first category originate from students’ informal ideas shaped from everyday life experiences earlier before formal instruction. Alternative conceptions are said to be highly resistant to change and they can only be modified by instructional approaches that are specially designed to take into account such pre-existing ideas (Yip, 1998).

The second category of incorrect ideas occurs due to the lack of relevant prerequisite concepts, which are necessary for the understanding and construction of new concepts by the student. Ausubel (1968) advocates that educators must make sure that the basic prerequisite concepts are mastered by students before commencement of a new concept or idea. This view suggests that teachers need to assist students to make meaningful linkage between new and existing concepts to promote better understanding and integration of the learned concepts.

The last category of erroneous ideas is related to the fact that teachers may hold incomplete or fragmented understanding of various science concepts, which they may convey to their students through inaccurate teaching or uncritical use of textbooks (Kind, 2004). Muchtar (2012) notes that students bring their prior knowledge into science classrooms, which sometimes relates well to what the teacher did not explain properly. Hence, the concepts students construct fail to correctly explain the scientific phenomena explored during a lesson and thus, deviate from scientific concepts.

Alternative conceptions often have a diversity of sources. According to Ebenezer and Gaskell (2005) the sources include, but not limited to: partial understanding of a concept due to inadequate prerequisite knowledge; negligence on the conditions and assumptions behind a rule; an overgeneralization of principles from inadequate evidence. Alternative conceptions can also result from uncritical acceptance of incorrect information, or wrong deduction due to misleading reasoning. For this reason the researchers conducted this study to investigate the misconceptions held by senior secondary students of the Manzini and Shiselweni region of Swaziland.

Examination Council of Swaziland (ECOS) reports, over a period of five years (2010 – 2015), showed consistent poor performance in the school leaving Swaziland General Certificate of Secondary Education (SGCSE) Physical Science examinations. (Physical Science comprises Physics and Chemistry sections in one syllabus that are taught separately during instruction). This observed poor performance in Physical Science has partially been attributed to students’ misconceptions in some of the scientific concepts, including stoichiometry and the mole. This current study focused on this topic, which appears in the SGCSE Physical Science (6888) Syllabi. The study investigated the alternative conceptions of Form 5 (Grade 12) students who were doing Physical Science in 2015.

1.1 Statement of problem

Researches on students’ understanding of the topic stoichiometry in Chemistry have shown that students have many alternative conceptions related to basic stoichiometric concepts after teaching. Also experiences during classroom instructions showed that most students have challenges in understanding stoichiometry and the mole concepts. Some of the students interviewed by one of the researchers said that the things they were learning were impossible to understand.

Although the term “misconception” simply means an idea or explanation that differs from an accepted scientific concept, some students’ misconceptions can be quite complex. Students come to school with established knowledge about the physical, biological, and social worlds based on their own ideas and explanations that may not be correct or accepted. Some misconceptions may change as students develop their ability to think abstractly, while others persist well into adulthood.

Students’ prior experiences may significantly affect their ability to accept other, more scientifically grounded, explanations of how the world works particularly if the new information does not fit into their established pattern of thinking. Rather, they modify the new information to fit their existing schema. Misconceptions are unknowingly created and reinforced as the student builds
explanations, unravels problems, and files new data based on faulty reasoning. The longer a misconception remains unchallenged, the more likely it is to become deep-rooted and resistant to change. So this study determined the misconceptions held by students on stoichiometry and the mole in ESwatini among rural, semi-urban and urban students and to find out which of area had the most students with misconceptions.

1.3 Objectives of the Study
The objectives of the study were to identify students’ misconceptions:
1. a) Associated with balancing chemical equations.
   b) In the calculation of the number of moles in equations.
   c) In molar mass and mass calculations.
   d) In the writing of ionic and molecular formula.
   e) In the calculation of limiting and excess reactants.
2. Establish which had the highest proportion of students who held misconceptions

1.4 Research Questions
The study was designed to respond to the following research questions:
A: What misconceptions do students have in:
   1. Balancing chemical equations?
   2. The writing of ionic and molecular formulas?
   3. Molar mass and mass calculations?
   4 Calculating the molar mass and mass of reagents in equations?
   5. The calculation of limiting and excess reactants?
B. Which area among rural, semi-urban and urban has the most students with misconceptions?

2. Literature Review
2.1 Theoretical Framework
The work of Jean Piaget, Jerome Bruner, Lev Vigotsky, Joseph Novak, David Ausubel and others have brought remarkable contributions to the educational sector and thus their ideas were used in this regard. This study was based mainly on the constructivist approach and meaningful learning.

2.2 Constructivists Approach to Learning
The constructivist approach to learning is based on the premise that, by reflecting on our own experiences, we construct our personal understanding of the world around us. Thus individuals use their own mental constructs to make sense of their experiences. Taber (2002) viewed learning as a search for meaning. Therefore, the student must actively participate in search for new knowledge and meaning which should be based on the issues that require personal interpretation. However, during the construction of meaning and understanding students can also adopt wrong conceptions hence misconceptions.

The social aspects of learning form a crucial part of the constructivist view of learning. This means that people also learn from other individuals and not in isolation from others. According to Stears and Gopal (2010) learning does not take place in cognitive isolation, but within the context of activities and social interaction informed by the day-to-day contingencies of culture. Social constructivist theorists view knowledge as a socially constructed entity as well as a socially mediated process. Social constructivism acknowledges that the student brings a rich source of prior knowledge to the learning situation (Kasanda, Lubben, Campbell, &Gaoseb, 2003). According to Vygotsky (1978), social interaction plays an essential role in the development of cognition and every human child develops in the context of a culture. Therefore, human cognitive development is affected more-or-less by the culture in which the individual was raised, including family environments and socio-cultural experiences. To a larger extent, this concurs with the ideas of Tekkaya (2002) who stated that some students’ misconceptions emanate from everyday experiences and observations. Tekkaya perceives these preconceived notions as vernacular misconceptions. Vygotsky (1978) asserts that culture seems to make two kinds of contributions to children’s intellectual development. Firstly, children acquire much
of the content of their thinking from culture itself and, secondly, they acquire the processes and means of their thinking from it. In short, according to Vygotsky, culture teaches children both what to think and how to think. In this way, children are very likely to model their behavior on the observed behavior of their parents or role models. Learning is then viewed as dependent on social interaction. Hence, if the people, whom they copy and learn from, hold certain misconceptions on a particular subject, the students are more likely to adopt those unfounded beliefs too. One of the notable aspects of learning that Vygotsky highlighted was that a child learns better with the help of an adult. He did not assign much importance to the stages of development of a child (as Piaget did), but was more interested in the potential for cognitive development. This, he believed, is limited to a certain space which he called the “zone of proximal development” (ZPD). As such, Vygotsky (1978) postulated that the child uses a word or concept label for communication purposes before that child has a fully developed understanding of that word. As a result of the use of the word in communication, the meaning of that word (i.e., the concept) evolves for the child. Hence a wrong utilization of the word results in wrong attainment of concepts. With that regard therefore, the social aspects of learning are significant in this study in view of the fact that some misconceptions originate from everyday language (Tekkaya, 2002)

According to Stears, Malcom and Kowlas (2003), constructivist approaches to learning support services and programs designed to build on students’ understanding, concerns and prior knowledge. These scholars state that socio-cultural knowledge arises not only from children’s ethnic backgrounds but also from socio-economic conditions, their environment as well as their personal circumstances in life. These circumstances may influence the perceptions and knowledge of the students such that they feel isolated and harbor many misconceptions, as they cannot make the link between school science and their socio-cultural knowledge.

On the other hand, constructivists like Jerome Bruner in his theory of discovery learning states that students participate in making many of the decisions about what, how, and when something is to be learned and even play a major role in making such decisions (Bruner, 1990). Instead of being presented the content by the teacher, it is expected that the students explore exemplars in order to discover the principles or concepts that are to be learned, as posited by (Snelbecker, 1974,) in Bruner (1990).

Bruner’s theory of discovery learning encompasses two key features, which are analytical thinking and intuition. Intuition relates to a gut feeling that leads to a solution to a problem without getting proof (Bruner, 1990). It should be noted that when students use discovery processes make inferences and speculations about scientific phenomena, they may also develop misconceptions. This is in view of the fact that the meaning is idiosyncratic in nature or unique to that individual. Most constructivists acknowledge that learning is affected by the context, beliefs and attitudes of the students, thus, this forms the basis of the current study to investigate the types of misconceptions formed by the students based on their beliefs.

Furthermore, it is generally accepted that students do not enter the classroom as a “blank slate”. They come to school with already formed ideas on many topics, including how they view and interpret the world around them. Sometimes these views may be rather strange, even elaborate regardless of their content. In fact, some researchers have found that individuals whose ideas conflict with new information might disregard the new information and hold on to their existing beliefs, and may even end up defending those prior beliefs. This simply emphasizes the significance of investigating students’ misconceptions especially in chemistry to attenuate the problem and ensure quality education.

2.3 Meaningful Learning

Ausubel (1968) in his theory of meaningful learning suggests that learning can occur if the new information is basically meaningful and the student can link it to relevant knowledge that he/she has already acquired. The student makes a conscious effort to relate new knowledge to the pre-existing knowledge. The theory also argue that meaningful learning builds one’s cognitive structure by assimilating new concepts into the one’s existing conceptual structure. Many recent studies support the idea that students do not come into the classroom with a blank mind. Children often have their own explanation of natural phenomena they encounter in their everyday life (Novak and Nussbaurri 1981).
Ausubel (1968) also talks of rote learning as opposed to meaningful learning. Here, the student does not make any conscious effort to relate new meaningful learning to the old knowledge, neither does he/she relate or make a conscious effort to identify key elements in the new knowledge to link with pre-existing knowledge to make meaningful learning. Instead, the student simply acquires robust knowledge by taking it as is, without relating it to anything he/she knows. This mere memorization of facts and concepts might result in accumulation of unfounded beliefs and, thus, misconceptions. Ausubel (1968) suggests that students ought to embark on progressive differentiation of concepts such that there would be an integrative reconciliation of prior knowledge and new concepts, which justifies the choice of this theory as the framework for this study.

2.4 Empirical Studies

Misconceptions held by students in the field of science education have become a focal point for many researchers in recent years. The latest studies have revealed that students have difficulties in understanding many scientific concepts, and these concepts create considerable obstacles to learning in later years of study (Ozay and Oztas, 2003).

Boujande and Barakat, (2000) conducted a study to find out whether German students have alternative conceptions or misconceptions on stoichiometry and the mole. They prepared a stoichiometry test and carried out unstructured interviews with 16 – 17 year old students on misunderstandings about molar quantities, limiting reagents, conservation of matter, molar gas volume at room temperature and pressure (r.t.p) and coefficients in chemical equations. They found that students have difficulties in linking these ideas before numerical ideas are presented. Also, when trying to solve stoichiometric problems, they use incorrect formats or strategies in trying to solve those problems.

An earlier study by Cerveliati, Montuschi and Perugini (1982) investigated secondary school students’ misconception on stoichiometry and the mole in Italy. They gave students written tests and found that students possessed several alternative conceptions in the topic. One of their major finding was that the students saw the mole as just a value. For instance; 1 mole, 2 moles, 3 moles etc. They also found that the students did not recognize that a mole is equivalent to Avogadro’s number, which is 6.02 × 10^{23}. Another finding was that students could not distinguish between empirical formula and molecular formula. Students for instance, when asked to give the empirical formula for Benzene, they gave the molecular formula C_{6}H_{6}, instead of CH, which is the correct empirical formula.

In addition, they found that students have misconceptions in balancing equations. Students tended to change the subscript when trying to balance a given chemical equation, more especially in the case of molecular formula of coefficients equal to one. The correct concept in the balancing of equation is that only the coefficients, which are whole numbers, are altered. Another misconception they found was that students gave the units for molar mass with respect to the number of elements of the molecule or compound, e.g. they gave molar mass for water (H_{2}O) as 18g/2mol. Furthermore students chose the reactant with the lowest number of moles in an equation as the limiting reactant.

Bentley, Fleury, & Garson (2007) conducted a study to explore the understanding of stoichiometry and related concepts of Thai science students in Grade 10 and 11. Student’s conceptions and misconceptions were investigated through the use of a questionnaire, which consisted of sixteen multiple choice items. For answers chosen, students had to provide a reason for their choices. They found that only half of the student’s surveyed held scientifically accepted conception and the others held misconceptions. Some of the main misconceptions held by Thai the students were; one mole of all substances has a volume of 22.4L at r.t.p, another misconception is that a solution that contains greater mass of solute has got the higher molar concentration and also that the limiting reagent is the reagent for which the lowest mass of reactant is present.

Barker (2000) investigated London students’ misconceptions in stoichiometry and the mole. She reported that the responses of two hundred 16-17 year olds to a question about the reaction between iron (Fe) and sulfur (S) differ, some were correct and some were incorrect. In the question, they were told that 56g of iron reacts with 32g sulfur to give 88g iron sulfide and were asked to predict what would be produced when 112g iron and 80g sulfur react. It is reported that about 50% gave the correct answer, that 176g iron sulfide would be produced with some sulfur remaining. The most common
incorrect response, given by 32% of the students, was to add the two figures generating 192g. These students had not realized the need to apply reacting mass reasoning. At the end of their two year course of study, about 72% gave the correct answer, while about 16% still gave 192g. Also BouJaoude and Barakat (2000) report that about 40% of their sample of forty 16-17 year olds calculated molar mass by dividing or multiplying the totals of atomic masses by the coefficient shown in the chemical equation.

Horton (2007) also conducted a study on misconceptions in chemistry (stoichiometry) with California high school students. He found that students have many alternative conceptions in stoichiometry and the mole. These misconceptions related to confusion on whether a mole is a number or a quantity. The use of ratio and proportional reasoning needed for molar mass problem; overestimating the size of atoms - saying that atoms can be seen with a microscope and that water molecules can be seen with an optical microscope.

In Ithaca Schmidt (1987) investigated misconception and learning difficulties in stoichiometry among secondary school students. He used a multiple choice test item for this investigation and found that students had misconceptions in stoichiometry and the mole. He pointed out that students represented misconceptions when calculating the mass percentage of an element in a compound, equated the percentage of mass to simple ratio or percentage of atoms. Also, he found that some students did not recognize the particles concept in chemical formula. They assumed that the chemical formula represents the mass ratio of individual elements instead of the ratio of molar masses of the elements.

Meor, Ambrose and Ling (2003) conducted a case study on eighteen students of Chemical Education Degree; they reviewed student achievement on mole concept and the concept of matter and its influence on problem solving ability in stoichiometric problems. The results showed that out of the 18 students, only 22% of them comprehend chemistry concepts, of which 6% understood the concept of atoms, 6% showed understanding of the concept of molecules, and 11% understood ions concept. For the mole concept and its relationship to the equation, the achievement of conceptual understanding of the respondents was very poor.

Shongwe (2011) investigated students understanding of concepts in stoichiometry. She investigated students in four schools, one in each of the regions of Swaziland. She used pencil and paper test. She found that students understanding of the mole are very poor and also that students used incorrect problem solving methods when solving quantities such as the mole, mass, concentration etc. This current study will look at misconceptions in Stoichiometry, in the context of ESwatini.

3. Methodology
The current study employed a cross-sectional experimental design. The sample for the study was 152 Form 5 pupils randomly selected from three sample schools in the Shiselweni and Manzini regions of Swaziland. The data used for the study was collected using a diagnostic two tier test on the topic stoichiometry and the mole. Students were expected to calculate the correct answer and then give a justification for their answer as to why they were confident that the answer was the correct one. The test consisted of questions that were taken from the internet, chemistry textbooks, and from past examination papers for SGCSE Physical Science (6888). The test has a test–retest reliability value of 0.78. The test was administered in a formal classroom setting by the researchers with the cooperation of the subject teachers from the three schools. A concept-evaluation scheme developed by Muchtar (2012)) was used to analyze the data. Students’ responses were classified into four different categories. These categories are shown in Table 3.1 below together with their descriptions.
Table 1 Concept Evaluation Scheme

<table>
<thead>
<tr>
<th>Categories responses representing level of understanding</th>
<th>Criteria for scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientifically correct (SC)</td>
<td>Scientifically complete responses and correct explanations</td>
</tr>
<tr>
<td>Partial correct (PC)</td>
<td>Scientifically correct responses but incomplete explanations</td>
</tr>
<tr>
<td>Specific misconception (SM)</td>
<td>Completely scientifically unacceptable responses or explanations</td>
</tr>
<tr>
<td>No understanding (NU)</td>
<td>Students who do not make any response; make irrelevant or unclear response; rewrite the question or no explanations, left answer space blank</td>
</tr>
</tbody>
</table>

Data obtained from students’ responses after marking the test scripts was categorized according to the concept evaluation scheme presented in Table 1. Grouping the students’ responses into categories helped in identifying the alternative conceptions held by the students. Responses for all questions were tallied and the tally marks were used to obtain the frequency of responses under each category (SC, PC, SM and NU). These frequencies were then converted to percentages for ease of interpretation. The category that showed the highest frequency or percentage indicated the students’ most dominant level of understanding. This information was presented on bar graphs with the aid of the Microsoft excel programmer.

Results

Research question A1: What misconceptions do students have in balancing chemical equation?

Table 2: Analysis of students understanding on balancing equation.

<table>
<thead>
<tr>
<th>School</th>
<th>No understanding</th>
<th>Specific misconception</th>
<th>Partial concept</th>
<th>Scientific concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>25</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>17</td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td>Average</td>
<td>17.3</td>
<td>21.3</td>
<td>26.7</td>
<td>34.7</td>
</tr>
</tbody>
</table>

Students’ responses key

NU – no understanding  SM – specific misconception  PC - partially correct  SC – scientifically correct

Schools

School A – rural school, School B - semi-urban school, School C – urban school

Evident from the data in Table 2 is that the majority of students had some understanding of the concept of balancing chemical equations. It can be deduced that less than half of the respondents showed no understanding or specific misconceptions. It was observed that 22% showed misconceptions balancing chemical equation in School A, 15% in School B and 27% in School C. The misconceptions that were identified include the following; students write the charges of the monatomic anions in terms of the group number e.g. O$^{6-}$ and F$^{7-}$ hence the formula of magnesium Oxide becomes Mg$6_2$O$_2$. Some changed the subscripts to balance chemical equations, gave a chemical equation instead of a formula, also, they wrote the formula of a sulfate ion as SO$3_-^-$, failed to differentiate between ion and formula as they gave the ions instead of a formula, balanced equations with bigger values instead of using the lowest values as possible when balancing equations, inserted coefficients in between the atoms of a molecule as a way to balance the equations.
Fig 1 is a graphical presentation of the results shown in Table 2 above. Results from Table 2 and Fig. 1 show that students have varied misconceptions in the concept of balancing equations.

Research question A2: What misconceptions do students have in writing of molecular and ionic formula

Table 3 Analysis of students’ understanding of the concept of writing ionic and molecular equation.

<table>
<thead>
<tr>
<th>School</th>
<th>Categories of responses, frequency and percentage of students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No understanding</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
</tr>
<tr>
<td>Average%</td>
<td>15.3</td>
</tr>
</tbody>
</table>

Data from Table 3 shows that the proportion of respondents showing specific misconceptions was highest, with an average of 38.3% for the three the schools. It can be seen from the table that 35% of respondents of School A, 41% respondents of School B and 39% respondents of School C showed misconception in the writing of ionic and molecular formulae. The following misconceptions were identified: students write the formula of a carbonate anion is CO\(_3^-\); students write the formula of compounds in terms of ions, they also think that charges of the ions should be swapped to form the formula of a compound. Some calculated the molecular mass of water as 18g/2mole, some are giving an ammonium ion as an anion (negative ion), yet some treated ammonia and the ammonium ion synonymously, and for the symbol for potassium was P instead of K. Students demonstrated unfamiliarity with the specific nature of chemical nomenclature.
Fig. 2 Students’ level understanding on writing molecular and ionic formulas of compounds.

Data shows that 13% School A respondents, 16% School B respondents and 17% School C respondents showed no understanding in writing of chemical formulas of compounds. It can also be deduced that School B showed the highest percentage of respondents with specific misconceptions followed by School C and School A is last. Data from Fig 2 shows that 35% of School A respondents, 41% of School B respondents and 39% of School C respondents showed misconceptions in the writing of ionic and molecular formula. Also it can be deduced from Fig 2 that School B showed a higher percentage of respondents reflecting partial understanding on the concept of writing formula of compounds, followed

**Research question A3:** What misconceptions do students have in the moles to volume ratio calculations?

Table 4 Analysis of students understanding of the concept related to calculation of the mole and volume.

<table>
<thead>
<tr>
<th>Categories of responses, frequency and percentage of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schools</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

From Table 4 it can be seen that School B showed the highest percentage (15%) of respondents demonstrating specific misconceptions in calculation of mole and volume, with School A being second with 6% and School C is last with 5%. This study identified misconceptions of students that included coefficients when calculating moles in equation. Under this concept there was only one alternative conception identified. Most students who showed no understanding of the concepts of mole and volume calculations were in the category of no understanding (NU). Students mostly showed scientifically incorrect responses. Worth noting is that just over half of the respondents had some understanding or good understanding of the concept.
Based on Fig. 3 it can be deduced that School C showed the highest percentage (36%) of respondents with no understanding, followed by School A (32%) while School B showed the lowest percentage (28%) of respondents with no understanding in calculating moles and volume. It can also be deduced from Fig. 3 that School B showed the highest percentage of respondents with misconceptions while School A is the second and School C is at last in terms of students with misconceptions in calculating moles and volume. Data revealed that 6% of the respondents of School A, 15% of the respondents of School B and 5% of School C respondents showed misconceptions in calculating moles and volume. Fig. 3 also shows that School C showed the highest percentage (41%) of respondents with partial understanding of the concept of calculating moles and volume, followed by School B (32%) and then School A as the third (20%). Based on Fig. 3 it can also be further deduced that School A respondents had the highest percentage (32%) of respondents with scientifically correct understanding of the concept on calculating moles and volume, followed by School B (25%) and then last is School C (18%).

**Research question A4:** What misconceptions do students have in molar mass and mass calculations?

<table>
<thead>
<tr>
<th>Categories of responses, frequency and percentage of students</th>
<th>No understanding</th>
<th>Specific misconception</th>
<th>Partial concept</th>
<th>Scientific concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schools</td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>A</td>
<td>15</td>
<td>48</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>22</td>
<td>35</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>24</td>
<td>41</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Average %</td>
<td>41.3</td>
<td>7.3</td>
<td>33.3</td>
<td>18.0</td>
</tr>
</tbody>
</table>

From the data in Table 5 it is evident that almost half (an average of 48.6%) of the respondents either had no understanding or showed specific misconceptions regarding molar mass and mass calculations. The data in Table 5 shows that School A showed the highest percentage of respondents with misconceptions, while School B and C showed equal percentage of students showing specific
misconception in calculation of molar mass and mass. Data shows that 10% of the respondents of School A, 6% of the respondents of School B and 6% of the respondents of School C showed misconceptions in calculating molar mass and mass. The misconception identified in this study is that students calculated the molar mass and concluded that it is the mass of that compound. Students confused the mass of a reagent and its molar mass. It can be deduced that few misconceptions were identified as there were the few (7.3%-average) students who showed specific misconceptions of this concept.

Figure 4 below shows the graphical representation of the data in Table 5 to provide a visualization of the students’ understanding of molar mass and mass calculations among the three schools.

**Fig. 4 Students’ level of understanding on calculating mass molar and mass**

Fig. 4 shows that School A presented the highest percentage (48%) of respondents with no understanding in calculating molar mass and volume, followed by School C (41%) and School B (35%) showed the lowest percentage of respondents with no understanding. Fig 4 also shows that School A had a higher percentage of respondents with misconceptions while School B and School C had equal percentage (6%) respondents with specific misconception in calculating molar mass and mass.

It can also be deduced from the Fig. 4 that School C showed the highest percentage of respondents that showed partial understanding on the concept of calculating molar mass and mass, it was followed by School B and School A was last. Data shows that 29% of the respondents of School A, 35% of the respondents of School B and 36% of School C respondents showed partial understanding on calculating molar mass and mass.

Based on Fig. 4 it can also be deduced that School B showed the highest percentage of respondents with scientifically correct understanding on the concept on calculating molar mass and mass than the other two schools, it was followed by School C and then School A was at last. Data show that 13% of the respondents of School A, 24% of the respondents of School B and 17% of School C respondents presented scientifically correct understanding on calculating molar mass and mass. This group of students comprised an average of 51.3% (33.3%+18.0%).

**Research question A5:** What misconceptions do students have in calculating limiting and excess reactants?

Table 6 below is summarises the frequency and percentages of respondents in category of responses regarding students’ understanding of the concepts of limiting and excess reactants.
Table 6 Analysis of students understanding of the concept related to calculation of limiting and excess reactant.

<table>
<thead>
<tr>
<th>Schools</th>
<th>No understanding</th>
<th>Specific misconception</th>
<th>Partial concept</th>
<th>Scientific concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>27</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>61</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>56</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>93.3</td>
<td>3.3</td>
<td>3.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

From Table 6 it evident that on average 96.6% of the respondents from the three schools had challenges with concept relating to calculating limiting and excess reactants, while only 3.3% had partial understanding. Of interest to note from the data in Table 6 is that none of respondents in the study demonstrated scientifically correct understanding.

Data from Table 6 indicates that School A showed the highest percentage 6% of respondents with specific misconceptions regarding calculating limiting reactants, while School B and School C showed equal percentage of 2% of students with misconceptions. There were very few misconceptions identified considering that only 3.3% of respondents showed specific misconception of the concept. The misconception identified from this concept was that students just used the mole ratio to calculate the mass of the other substance instead of calculating the actual mass used in the reaction.

Figure 5 below summarises graphically the level of students’ understanding of the concept of calculating limiting and excess reactants.

Based on Fig 5 it can be deduced that the concept of calculating limiting reactants is problematic for all the respondents in the study, shown by the very high percentages. School C and School B showed equal percentage (96%) of respondents with no understanding in the concepts while School A showed the lowest, but still high, percentage (88%) of respondents.
It can also be deduced from Fig 5 that School A showed a higher percentage of respondents with misconceptions while School B and School C had equal percentage of respondents with specific misconceptions in calculation of limiting and excess reactants. Based on the presentation on Fig 5 it can also be inferred that School A had the highest percentage of respondents with partial understanding on the concept of calculating limiting and excess reactants, while School B and School C showed equal percentages.

Research question B: Which area among rural, semi-urban and urban has the most students with misconceptions?

From the finding presented above, it is evident that students’ levels of understanding of the different concepts varied among the schools. For some concepts one school had more students with misconceptions than the others, but less students in another misconception. To establish the school with the highest number of students with misconceptions overall, a summary comparing the number and proportions of students in each category representing levels of understanding of students in the three schools is shown in Table 7 below.

Table 7 A comparison of student distribution among the four response categories and schools

<table>
<thead>
<tr>
<th>Schools</th>
<th>Category of responses, frequency and percentage of students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No understanding</td>
</tr>
<tr>
<td></td>
<td>No of responses</td>
</tr>
<tr>
<td>A (Rural N=31)</td>
<td>59</td>
</tr>
<tr>
<td>B (Semi-urban N=63)</td>
<td>127</td>
</tr>
<tr>
<td>C (Urban N=58)</td>
<td>119</td>
</tr>
</tbody>
</table>

(%) was calculated from the total number of responses in each category in all schools and the total number of respondents)

Regarding the area with the highest number of students with misconceptions, the data shows that School B, a semi-urban school presented the highest percentage of students with no understanding of stoichiometry and mole concepts (16.7%), next was School B, an urban school, with 15.8% of the students demonstrating no understanding and School C, a rural school that had 7.8% of the students. The same order can be observed in the data shown in Table 7 where again School B had the highest proportion of students showing specific misconceptions, followed by school C with 6.1% and then School A with 3.6%.

Of interest to note from the data in Table 7 is that the variation in proportion of students with accepted scientific concepts is small (significance not established). It can be inferred from the data in Table 7 that School B presented more students with partial understanding (11.4%) followed by School C with 9.6% and last was School A with 3.7%. On the other hand, School B and School C presented the same proportion of students with scientific concepts, each with 6.8%, while School A presented 5.4%.

Figure 6 below illustrates the comparison of the proportion of students in each category of response and school. This shows how the students from the three schools were distributed in the response categories.
Evident from Fig 6 is that on the overall, School B had a higher percentage of students in the no understanding, specific misconception and partial conception while School A had the lowest percentages of students in all categories. School B and C had the same proportion of students in the scientific conception category.

4. Discussion of the findings

Based on the findings of the study it was observed that senior secondary students do possess misconceptions in stoichiometry and the mole. However, to a very small extent (less than 10% on average) some of the students showed scientifically correct understanding and partial understanding in some aspect of the concepts. Also most students in the three schools showed no understanding of stoichiometry and the mole concepts and calculating excess and limiting reactants.

The fact that students bear some misconceptions in the mole concepts has been demonstrated by other studies that were done in and out of the country. For example, Shongwe (2011) investigated students understanding on stoichiometry and the mole in Swaziland and found that students have less understanding on concepts of the mole and showed less understanding of the concepts of limiting and excess reactants. Cerveliati, Montuschi and Perugini (1982) found that students have misconceptions in the balancing of chemical equations. Students tend to change subscripts when balancing chemical equations, more especially when the molecular formula of a reagent in an equation has a coefficient equal to one.

The findings of this study are also consistent with findings of a study conducted by Meor, Ambrose and Ling (2003). They investigated misconceptions and student understanding on stoichiometry and the mole. The results showed that less than 25% of the students demonstrated comprehension of chemistry concepts, of which 6% understood the concept of atoms, 6% were showed understanding of the concept of molecules, and 11% understood ions concept. For the mole concept and its relationship to chemical equations, the achievement of conceptual understanding of the respondents was very poor. In this study a very small percentage (less than 10%) of students showed understanding of stoichiometry and the mole concepts.

5. Conclusion

Based on the research findings above the following conclusions were drawn.

a. Senior secondary school students have misconceptions in writing molecular and ionic formula and balancing chemical equations. They change subscripts to balance chemical equations and give a chemical equation instead of a formula without differentiating the ion, molecule and atom. They also insert coefficient in between the atoms of a molecule when balancing equations.
b. Senior secondary students have the misconception that the formula of a carbonate anion is CO₃⁻, write the formula of compounds in terms of ions, in order for a to form they to explain the formation of a compound in terms of swapping of charges. Some calculated molecular mass of water 18g/2mole, some considered an ammonium ion as an anion. Furthermore, some students were unable tell the difference between ammonia and ammonium, while for some the symbol for potassium was P instead of K.

- Senior Secondary school students have the misconception of including coefficients when calculating moles in equation rather than ignoring them.
- Senior secondary school students have the misconception on the concept of molar mass and mass that students calculate molar mass and conclude that is the mass of that compound instead of calculating the mass from the molar mass.
- The misconception in calculating excess and limiting reactants found was that students just used the mole ratio to calculate the mass of the other substance instead of calculating the actual mass used in the reaction.
- The semi-urban area had a high proportion of students who demonstrated misconceptions while the rural area had a lower proportion of students.

6. Recommendations

Based on the conclusions the following recommendations were made:

a. Teachers should familiarize themselves of these misconceptions and make practical efforts at ensuring that the misconceptions are addressed, for example by giving students more exercises in these areas both as homework and class activities.

b. Teachers should ensure that prerequisite concepts, such chemical bonding are in place and used as reference when teaching students how to write formulas of molecules, ions and compounds, and to differentiate from atoms. The use of models in teaching of formula of compounds is encouraged.

c. In the issue of moles and volume ratios, teachers should spend time to assisting students to understand these concepts.

d. Even under the concepts of molar mass and mass calculations, molar mass calculations involve many formulas. So, teachers should make sure that they teach these calculations so that the students can identify the differences in the formula used for calculating molar mass and mass of reactants.

e. Most students did not show understanding on the concept of limiting and excess reactants, which might suggest that the teachers themselves have problems understanding this concept. It is recommended that regional education administrators should host workshops in their regions to help teachers on how they can teach the concept of limiting and excess reactants.

7. References


Boujaoude S. and Barakat H., (2000), Secondary school students’ difficulties with stoichiometry, School Science Review, 81, No. 296, 91


Kind V. (2004). Beyond Appearances: Students’ misconceptions about basic chemical ideas. 2nd Edition, School of Education, Durham University, UK.


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