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Analysis of Students' Error in Learning of Mole Concept among Selected Senior Secondary School Chemistry Students in Zaria, Nigeria

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Abstract: *The purpose of the study was to determine the students' error in learning mole concept A total of 120 Senior Secondary 2 chemistry students randomly selected from two private schools in Zaria with a mean age of 17 constituted the sample size for the study. The Chemistry achievement tests (CAT) and Mole concept diagnostic test (MDT) were used as the instruments for the study . Diagnostic interview and semi-structured questionnaire were also used to identify at which level students' errors occur in solving problems and the perception of students towards mole concept was that success can be achieved in problem solving with a good grasp of the subject and an above average mathematical ability. The type of error analyzed were based on the modified Newman Error Hierarchy Model that includes reading type error, comprehension, transformation, process skill, and encoding error. Data was analyzed using mean, percentage, frequency, Duncan's (Multiple-Range) and Wilcoxon test at P< 0.05. The study found out among others that the error most students make involving transformation and process skill in solving problems in mole concept was significant (P<0.05) .There was no error found in reading. The number of students who made encoding error and carelessness was small. The students' error in solving problems in mole concept was due to their weaknesses in stoichiometry and basic arithmetical operations. The need for an appropriate and friendly pedagogical approach in the learning of mole concept was proposed and recommendations were made based on findings.*

Keywords: *Mole concept, Chemistry, Comprehension error, Transformation error, Process skill error*

I. Introduction

The 'mole' concept was introduced by Ostwald, at the beginning of the 20th century, with a meaning of weight (mass), in a context of skepticism towards Dalton's atomic hypothesis[1] . Historically, the 'mole' concept was introduced before the quantity 'amount of substance' for which it is the unit. This, together with the evolution undergone by its meaning, accounts for the controversy and abstractness in these concepts [2, 3,4].

The subject of mole concept is pervasive in all aspect of quantitative chemistry at the senior secondary school level. It is a topic in chemistry that calculates the quantity of a product that can be obtained from a reaction by assuming that the reaction is the only one involved and that the entire product is collected [5] . I t is an area that very few students like and succeed at, and which most students hate and struggle with because of their phobia for mathematics [1, 6, 7]

It is therefore not surprising that students who do not fully understand the mole concept experience difficulties in understanding other subsequent topics that has to do with stoichiometry as problems solving and the calculations in stoichiometry revolves around the mole concept [8]. Be that as it may, the subject of problem solving involving mole concept has become so fundamental that effort has been geared by teachers and science educators in ensuring that students understand this seemingly abstract concept. Many studies concerned with mathematical application of this chemical concept has found that that students have misconceptions and make errors. These errors in solving problems involving mole concepts often occur directly or inadvertently ranging from written to oral and even computation [9, 10,11]. These situations from study has been shown to grow out of learning complexities [12,13,14]. Of late, a few researchers have mentioned students' misconceptions, errors, and related these to, learning complexities about mole concept [7,15,16,17]. In a study conducted by Larson [18) revealed that five areas were prominent in the general failure of students to construct meaningful understandings of the mole concept and these included:

- inconsistency between the instructional approaches of the textbook and teacher,
- confusing mole concept vocabulary,
- students' mathematical anxiety and proportional reasoning ability,
- learners' cognitive levels, and
- Lack of practice in problem solving.

A few researchers studied more specific issues in mole concept such as students understanding of stoichiometry [16]. In another study, Gabel and Sherwood [19]] used four forms of an analog test to determine skills and concepts necessary for solving mole concept problems. They concluded that the lack of understanding of basic mathematical principles is a "real impediment to solving mole problems correctly using reasoning methods and should be considered by chemistry teachers when presenting students with problems to solve". Taha [5] studied the influence of students' concept of mole and mathematical ability on stoichiometry and found that students' understanding of the concept of mole and their problem representation ability are significant predictors, but noted that mathematical ability is not a significant factor in determining students' success in solving the problems. Ahiakwo [7] studied senior secondary school students' performance in quantitative chemistry and found among others that students perform poorly in chemical calculation.

The mastery of the fundamentals of mole concept from simple stoichiometry is an essential step in concept development. When basic concepts are not learnt at early stage, the learning process of an advanced stage becomes more difficult. This occurs because the learning process in chemistry is categorized as hierarchical learning processes which are broadly interrelated [20]. During the process of teaching and learning mole concept, students will face many obstacles because problem solving in mole concept is a skill that is very complex. More often than not, students may know how to answer the question stated, but are careless in computation.

The conceptual framework that is used in this study is based on the modified Newman Error Hierarchical Model. The model of error investigation proposed by Newman [21] has proved to be a reliable model for mathematics and science teachers. The framework has six types of errors: reading error, comprehension, transformation, process skill, encoding error and carelessness. The Newman Error Hierarchical Model is suitable to be used in identifying students' error in mathematically related disciplines. This model has the hierarchy that classifies types of error based on the problem solving level done by students. According to Clements and Ellerton [22], Newman used the word "hierarchy" because she reasoned that failure at any level of the sequence prevents students from obtaining satisfactory solutions. Fang [17] pointed out, that in the process of problem solving the nature of obstacle that hinder students from arriving at correct answers has to do with problems in linguistics fluency and conceptual understanding that correspond with level of simple reading and understanding meaning of problems, and those involving mathematical processing that consists of transformation, process skills, and encoding answers. This classification implies that the students have to interpret the meaning of the question before they proceed to mathematical processing to obtain appropriate answer. It is in the light of the above that the study set out to analyze students' error in learning of mole concept among senior secondary school students.

II. Purpose Of The Study

The main purpose of the study was to analyze students' error in learning of mole concept which focused on the manipulation of quantitative problems using appropriate formulae and stoichiometric reasoning Specifically, the study sought to:

1. Determine the extent to which individual students commit error in the learning of mole concept.
2. Find out the possible categorization of these errors in the learning of mole concept.

III. Research Question

Three research questions were posed for this study:

i. To what extent will individual students' error influence the learning of mole concept?
ii. What are the possible categorizations of these errors in the learning of mole concept?
iii. What are the student's answers that help us explore the students' thinking and reflection about learning of mole concept?

IV. Hypotheses

The following null hypotheses were tested at $P < 0.05$

H_o There is no significant difference in the type of error committed by students in solving problems involving mole concept.

H_A There is no significant difference in the perception of students in solving problems involving mole concept

V. Methodology

The population for the study consists of all senior secondary schools in Zaria, Nigeria. Zaria and its environ is made up of over twenty senior secondary schools with a population of over seven thousand (7000) students. The government funded schools unlike the privately own ones are non-coeducational. Apart from having qualified teachers, the students offer chemistry as a major subject. The private schools were therefore considered appropriate for the study and it is from this population that the study sample was drawn.

5.1 Sample

The study was conducted using 120 senior secondary (SS2) students randomly drawn from two non-governments funded (private) secondary schools in Zaria metropolis in Nigeria. The mean age of the students was 17 years.

5.2 Instrumentation

The study used a set of mole concept diagnostic test (MDT) questions designed by the investigator to identify type of error committed by students. Prior to the commencement of the study, the questions which were obtained from texts[20] and past examination papers were subjected to face and Pearson's product moment content validated test respectively. The reliability coefficient as computed from Pearson's product moment correlation for mole concept diagnostic test (MDT) was r= 0.89. The value suggest that the test questions were reliable and as such would test what it was designed for. In addition, content and face validity of the instrument was carried by the investigator who is a specialist in chemistry and other specialists in cognate field compared to the overall objective of the curriculum.

Prior to the investigation, the respondents were subject to general chemistry achievement test. The primary objective of the CAT items was to categorize the students into high achievers (A) for those that scored 65% and above and achievers (B) for those that scored 50-64%. This is shown in Table 1.

5.3 Data analysis

Data was analyzed using mean, percentages, Duncan's (multiple-range) and Wilcoxon sign-rank test at P values of < 0.05 using Statistical Package for Social Sciences (version 13.0) software (SPSS, Chicago, IL). For results of Likert scale-based questionnaires [23], significant deviations of student responses to questions from the neutral score of 3 were analyzed using a Wilcoxon one-sample sign rank..

The investigator also interviewed the respondent based on the modified procedure of Newman Error Hierarchical Model [21] from the outcome of the written test. The questions for the respondent included:

i) Can you read the problem? (Reading level)
ii) What does the question ask you to do? (Comprehension level)
iii) What do you use to solve the question? (Transformation level)
iv) Can you show me the working steps that you have used in order to find the answer? (Process Skills)
v) Tell me what is your answer? (Encoding)

VI. Results

Table 1: Distribution of Students According to Different Achievement Levels

Profile	High Achievers (A)	Achievers (B)	Total	Percentage(%)
Male	32	30	62	51.7
Female	31	27	58	48.3
Total	63	57	120	100

Table 2: Number of Items (MDT)* according to Skills

Solving method	**Item number**	**Number of Items**
Mole concept by formula	**1-7**	**7**
Mole concept by relating stoichiometric equation	**1-7**	**7**

*** Appendix 1**

Table 3: Error in solving problem in mole concept by use of stoichiometric quantity

Frequency of Error

Item	Reading	Comprehension	Transformation	Process Skill	Encoding	Carelessness
1	0	12	41	49	11	7
2	0	13	42	51	8	6
3	0	11	45	47	10	7
4	0	14	36	53	11	6
5	0	15	44	49	6	6
6	0	12	45	50	8	5
7	0	12	40	51	11	6
Total	0	89**	303*	301*	65**	43**

** Student error significant at $P < 0.05$ with Duncan's(Multiple-Range) test.
* Student error not significant at $P < 0.05$

Table 4: Error in solving problem in mole concept by use of formula

Frequency of Error

Item	Reading	Comprehension	Transformation	Process Skill	Encoding	Carelessness
1	0	10	35	53	12	10
2	0	11	38	54	9	8
3	0	10	36	58	10	6
4	0	11	31	61	11	6
5	0	12	33	55	12	8
6	0	12	37	53	12	6
7	0	11	40	51	10	8
Total	0	77*	250**	303**	76*	52

** Student error significant at $P < 0.05$ with **Duncan's (Multiple-Range) test**.

* Student error not significant at $P < 0.05$

Table 5: Students' perception rating of mole concept*

Item	Agree %	Neutral %	Disagree %	Total
Interesting but extremely challenging	75	15	10	100
Very important topic in chemistry	70	24	6	100
Could very difficult due to it Abstractness	65	21	14	100
Has a lot of misconception	70	15	15	100
Teacher makes it more simpler	69	14	15	100
Success in solving problem is due to:				
-translating worded problem to equation	80	12	8	100
- writing appropriate balanced chemical equation	80	10	10	100
- determination of correct mole ratio	72	18	10	100
Mole concept understanding help me to Solve problems easily	85	8	7	100
Mathematical ability help in problem solving	70	20	10	100

N= 120 . Ratings were scored on a 5-point likert scale, where 5= strongly agree, 4= agree, 3= neutral, 2= disagree and 1 = strongly disagree.

*Significant deviations of student responses to questions from the neutral score of *3* were analyzed using a one-sample **Wilcoxon sign-rank test** P value of <0.05 were considered to be of statistical significance.

VII. Discussion

The most frequent errors made by student in solving problems in mole concept include comprehension error, transformation error and process skill error [Tables 3 and 4.]. Most comprehension errors occur when students do not understand how to approach a given problem from the concept. Students' often misunderstand the demand of the question .This may be due to the lack of emphasis by teachers in teaching the simplification of concepts as they appear. It may also be due to rote learning on the part of the learner. Ibrahim [24] noted that errors committed by students in learning mole concept may be useful for the teacher in evaluating his teaching so as to be able to correct the students as appropriate. Fang [17] in identifying some essential knowledge for teaching and learning the mole concept, opens up the whole question of the need to recognize the distinctive goals of the science classroom in comparison with the scientific laboratory. Therefore, teachers must ensure that the teaching of quantitatively based concepts must be balanced with the arithmetic skills.

The error type in transformation occurred during computation process especially during multiplication. This takes place due to computation problem especially among achievers. Most students make error at the process skill level especially in the manipulation of mole concept using formula. For example in item 3 the students were required to find the number of moles of carbon (IV) oxide and the volume evolved at s.t.p from the thermal decomposition of $CaCO_3$ it was found most students who got the item by the use of stoichiometric reasoning method could not replicate same answer using the formula as a result of inappropriate placing and manipulation. The findings of the study support the research of Ahiakwo [7] and Jonassen [25] who noted in their separate studies that most average students face difficulty in performing chemical calculations.

The error in process skill seems more pronounced in the use of formula than the reasoning method. This error may be due to the fact that students failed to understand and describe what is required by the questions. Most students found it difficult to perform the operation especially when numerical values are involved. This results in failure to solve the problems. Results of this study concurred with the findings of Polancos [6] in which problematic students failed to translate chemical problems into mathematical form and also having problem in understanding the special terms in mole concept. This failure may be caused by lack of emphasis by teachers on understanding the language of mole concept and the skills needed by the students. Ibrahim[24] puts the buck of students' error in mole concept at the teachers table and noted that when mole concept is taught via teacher-active method with constant memorizing of the ready knowledge and repeating them will make the students learn mole concept effectively. For example, emphasis on balanced chemical equation is critical and highly fundamental in manipulating quantitative problems in chemistry. Thus, a thorough grasp or mastery of stoichiometry will go a long way in preparing the students for a logical and systematic learning of mole concept. This in the author's view is probably why the students write the answers that are at variance with concepts and methods learnt in class. Proponents of mole concept have advocated the use of friendly pedagogical approach in a manner that will link theory with practice [5,17,26] .

Of the 120 students that were anonymously surveyed at the end of the study. Most students reported that the mole concept is interesting but could be extremely challenging. Responses to each statement were scored from *1* to *5* and are shown in Table 5. The Wilcoxon test showed that the difficulty and abstractness of mole concept caused more positive response and scores on each of the questions relative to the neutral response value ($P < 0.05$), indicating that the topic is full of abstractness . The majority of students (85%) were of the opinion that a good grasp of the concept with good mathematical ability will go a long way in solving problems in mole concept. Already in Nigeria, the National Teachers' Institute (NTI) is in the vanguard of training and re-training of in-service teachers. This is however, a step in the right direction and effort by other bodies should gear towards this cause with particular emphasis on these seemingly abstract areas of the science curriculum.

The writer is of the view that refresher courses be organized by learned societies such as the Science Teachers' Association of Nigeria (STAN) and examination bodies like the National Examination Council (NECO) with a view to harmonizing the teacher method and the textbook approach as well as the use of multiple pedagogic skills for students to adopt the method that is convenient for them. This is because when learners are comfortable with a particular problem solving skill, the attendant difficulty faced is likely to be reduced and error minimized accordingly. A finding of this study is consistent with previous report [10, 14]. However, other investigators have suggested the use of algorithmic skills but observed that emphasis on algorithmic skills without explanation on the concept or principle are among the factors that causes difficulties in mathematical manipulations and by extension poor achievement in mole concept [11, 18, 20, 27, 28] .

VIII. Conclusion And Recommendations

The results of this study revealed that most error committed by students irrespective of the method used are transformation and process skills errors. It further shows that generally, students irrespective of different cognitive ability are generally susceptible to error in solving problems in mole concept. Therefore, the question of an appropriate student friendly pedagogical approach that will enhance performance in mole concept is very much open to further investigation.

In view of the findings above, it is therefore recommended that:

1. Teachers as facilitator of the teaching–learning process should encourage the learners to concentrate on one point at a time and proceed stepwise in a logical manner to reduce attendant difficulty faced in mole concept.
2. Teacher should make mole concept lessons exciting by encouraging group work with frequent activity-based demonstrations so as to demystify the difficulty encountered in problems involving mole concept.
3. Learners should be given enough opportunities to do regular problem exercises as this will go a long way in assisting them and increasing their reasoning skills.
4. This study should be repeated with other similar quantitative based concepts so as to compare findings.

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Appendix 1

Mole concept Diagnostic Test (MDT) used in the study

1. Determine the number of moles present in:

a) 3.2 g of CH_3OH; b) 224 cm^3 of SO_2 (in stp) , c) 3.01 x 10^{22} molecules of NaCl

2. N_2 reacts with H_2 according to the reaction: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$.

Calculate the number of moles of N_2 and H_2 that must react for 5 moles NH_3 to be formed.

3. Calcium trioxocarbonate (IV) undergoes thermal decomposition to produce quicklime and carbon(IV) oxide.

i. Write the equation for the reaction.

ii. Calculate the number of moles of $CaCO_3$ required to produce 2.8 g of quicklime.

iii. Also determine the volume of CO_2 produced at s.t.p from (ii) above.

4. a) How many grams of magnesium oxide would be produced by reacting completely 4.0 g of magnesium with oxygen?
b) How many moles of magnesium oxide is formed from (a) above.

5. How many moles of potassium hydroxide (KOH) would be present in 250 cm^3 of a KOH solution of concentration 0.4 $moldm^{-3}$?

6. What volume of 0.5 $moldm^{-3}$ solution could be made using 13.25 g of sodium trioxocarbonate (IV), Na_2CO_3?

7. 20 cm^3 of a solution of NaOH is exactly neutralised by 25 cm^3 of a solution of HCl of concentration 0.5 $moldm^{-3}$.
a. Write the equation for the reaction.
b. What is the mole ratio?
c. Calculate the concentration of the NaOH solution in $moldm^{-3}$.
[Where necessary take: H= 1.0,C = 12.0, N= 14.0 , O = 16.0 , Na = 23.0, Mg = 24, S = 32.0 , Cl= 35.5, K= 39.0, Ca= 40.0, Avogadro's number, $N_A = 6.02 \times 10^{23}$ mol^{-1}, Gramme-molar- volume, GMV = 22.4 dm^3].

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