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Difficulties faced by Nigerian Senior School Chemistry Students in solving Stoichiometric Problems

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Abstract

The paper investigated the difficulties faced by senior school students' (age 16 – 18) in solving stoichiometric problems. The data were collected from twelve Science, Technology and Technical Education Board (STTEB) schools in Nigeria. A problem solving model that is due to Ashmore, Frazer & Casey (1979) was used. The results revealed that only 1.3 % of the students solved the problems correctly, 59.6 % of the students' scripts analyzed showed that students could not relate the known with the unknown variables. The most common difficulties identified were in relating the known with unknown variables and retrieving information from memory for critical reasoning through the problem. Recommendations for teachers on how to improve students' problem solving strategies are given.

Key words: stoichiometric problems, difficulties faced, problem solving, students' performance, nature of difficulties.

1. Introduction

According to Johnstone (2006) *"Chemistry is a **difficult** subject for students. The difficulties may lie in the capabilities of human learning as well as in the intrinsic nature of the subject."* Chiu (2005) believes that *"Chemistry is a world filled with interesting phenomena, appealing experimental activities, and fruitful knowledge for understanding the natural and manufactured world. However, it is **complex**."* As a result of the difficult and complex nature of chemistry and also the fact that it is one of the most conceptually difficult subjects on the school curriculum, it is of major importance that anyone teaching chemistry is aware of the areas of difficulty in the subject.

The concepts and principles in chemistry range from concrete to abstract. Many students of chemistry find certain concepts difficult to comprehend. The root of many of these difficulties that students have in learning chemistry is traceable to inadequate understanding of the underlying concepts of the atomic model, and how these are used to explain macroscopic properties and laws of chemistry (Ben-Zvi, Eylon and Silberstein, 1988)

Stoichiometry (pronounced "stoy-key-AHM-uh-tree"; Greek *stoicheion,* "element or part," + *metron,* "measure") is the study of the quantitative aspect of chemical formulas and reactions. For example, if what is in a formula or reaction is known, then, stoichiometry tells us how much. It basically involves relating the mass of a substance to the number of chemical entities (atoms, molecules, or formula units); converting the result of the composition analysis into a chemical formula; and applying the quantitative information held within them.

A review of the literature revealed that the mole and reaction stoichiometry concepts pose difficulty to students (Hackling & Garnett, 1985). Besides, it is a task of problem solving for most students of chemistry (Olmsted, 1999; Goering-Boone & Rayner-Canham, 2001). It also involves writing and balancing chemical equations, stoichiometric coefficients, limiting reagents, mole ratios of reactants and products, theoretical yields and percent yields (Perera & Wijeratne, 2006). The major reason why students have problems with these concepts is their abstractness. For solving stoichiometry problems, in addition to demonstrating an understanding of chemical reactions, the student must be able to apply the principles involved in ratio and proportion calculations

In order to actually calculate the quantities of substances consumed or produced in a chemical reaction, it is dependent on first writing a correct and balanced chemical equation for the reaction(s). (Mulford & Robinson, 2002; Tóth & Sebestye´n, 2009) reported that students have difficulties to distinguish or identify the limiting reagent which is a sub-topic of stoichiometry. They are frustrated when a simple proportion of moles are not one by one (Perera & Wijeratne, 2006). Some students might also think that the limiting reagent is a fundamental part of a reaction in preference to a function of the amounts of reagent available for a reaction (Boujaoude and Barakat, 2003).

In a previous study conducted by BouJaoude & Barakat (2000), forty Year 11 students were required to provide explanations when solving eight stoichiometry problems. These students successfully solved traditional problems using algorithmic strategies, but lacked conceptual understanding when solving unfamiliar problems. Similar findings have also been documented with introductory college chemistry students (Chandrasegaran, *et al.*

2011). One reason for the over-reliance on algorithmic procedures suggested by the researchers was lack of understanding of the chemical concepts that was further supported by their inability to solve transfer problems involving situations different from the ones that were used during instruction (BouJaoude & Barakat, 2000; Bodner & Herron, 2002). In Thailand, it was found that some students considered the limiting reagent as the least amount of reactant presented in terms of mass, not mole (Boujaoude & Barakat, 2000). Moreover, some Thai students thought that the limiting reagent was the reactant presented in excess in a reaction (Dahsah & Coll, 2007).

In Nigeria the story is not different as the Chief Examiners' Report on the West African Examination Council; WAEC (2010, 2011) has it that, most of the chemistry candidates displayed inability to accurately write down chemical formulas and to balance chemical equations. The report of students' inability to write a balanced chemical equation had been previously highlighted by Adeyegbe, (1989); Bello, (1990) and Eniayeju, (1990), who reported that stoichiometry posed a threat of difficulty to students because of the formulas, and the numerals involved in solving stoichiometric problems. Beside students' inability to write chemical formulas and to balance chemical equations, (Olmsted, 1999) reported that, poor understanding of stoichiometric principles required for solving stoichiometric problems is another factor that is responsible for students' poor performance in stoichiometry.

From the ongoing discussions, it is obvious that students; difficulties in solving stoichiometric problems is recurrent. Therefore, it is as a result of this that this research work focuses on identifying students difficulties with the help of a problem solving model that is due to Ashmore, Frazer and Casey (1979). The analysis will help us to decide on a more organized framework for teaching purposes.

2. Participants

The target population for this study was all the senior school two chemistry students in Kogi State. The sample for the research consisted of 300 senior school two chemistry students selected from 12 Science Technology, and Technical Education Board (STTEB) Schools in Kogi State. These schools were selected by stratified random sampling i.e. four randomly selected schools from each of the three senatorial districts in Kogi State. An average of 25 students was selected from each of the schools.

The schools were selected based on the following criteria:

(i) a minimum number of five years of experience in entering candidates for public examinations in chemistry;

(ii) students must have been taught the relevant chemistry topics as prerequisite knowledge skills required for solving stoichiometric problems. These prerequisite skills involve: (a) chemical symbols, formulas and equations (b) chemical laws (c) gas laws and, (d) the mole concept;

(iii) the school must have at least an experienced university graduate teaching chemistry at the senior class. Experienced chemistry teachers are those with teaching qualifications, who have taught in the school system for not less than five (5) years.

3. Research instrument

The Problem Solving Test in Stoichiometry (PSTS) that was constructed and administered to the students were past examinations questions of the WAEC Chemistry Paper 1 and Paper 2 from the year 2005 to 2010. These were scrutinized for the questions relating to mole concept and stoichiometry. Items for this test instrument were selected from these papers and some alterations were made in wording, numbers and the structure so as to prevent students from spotting these as past examination paper questions. The test instrument consisted of eight stoichiometric problems of approximately O' level standard where the questions required students to manipulate data and apply the appropriate relationships relating to the content area of study (stoichiometry), and to also gain an insight into individual student problem-solving processes.

The test covered specific areas in stoichiometry which the teachers indicated that they had taught. Areas such as: (i) Empirical and molecular formula; (ii) Chemical formula and percentage composition, (chemical formula from percentage composition and vice versa); (iii) Mass relationship in chemical reactions (mole ratio from balanced chemical equation, mole calculations); (iv) Limiting reagent concepts and percentage yield.

4. Validation of research instrument

To ensure the face and content validity of the instrument, the test items or papers were moderated by two science education experts in the Department of Science Education, University of Ilorin and two experienced senior school chemistry teachers who are WAEC and NECO examiners for their comments and suggestions. The comments by moderators on the language, content and constructs were used to fine-tune the instrument to ensure the validity of the instrument. In addition, the instrument was also be given to 30 students who were not to be part of the test sample so as to verify the clarity of questions, appropriateness of language and to also determine the right duration for the paper such that time would not be a constraint in the measurement.

The reliability of the instrument was determined using the test-retest method of three weeks interval. Scores obtained from the first and second administrations of the instrument were correlated using Pearson-Product Moment Correlation Coefficient Formula to obtain reliability indices for the instrument.

5. Procedure for data collection

The researcher visited the participating schools to obtain permission for the use of the schools from the appropriate authorities. The Problem Solving Test in Stoichiometry (PSTS) was administered in each of the schools during the normal classroom periods by the researcher with the consent and cooperation of the chemistry teachers in these schools.

The PSTS was administered to the respondents who were randomly selected from twelve (12) science-based schools. Respondents were given sufficient time to attempt all the questions and were also instructed at the beginning to write down all their working, including their thinking in the space provided in the booklet. They could seek clarification if they so wished, but only on the instructions.

6. Data analysis technique

After the research was conducted, the attempted solutions and the respondents' scores from the Problem Solving Test in Stoichiometry (PSTS) were obtained. The data were analyzed by locating errors, misconceptions, omissions and difficulties respondents faced (when solving the stoichiometric problems) in the different stages of the conceptual framework of Ashmore, Casey and Frazer (1979) model for solving problems in chemistry that was used.

These stages are:

- Defining the goal of the problem;
- Selecting information from the problem statement;
- Selecting information from memory;
- Reasoning; and
- Error in computation.

Descriptive statistics such as the frequency count, mean, and standard deviation were used to analyze the data obtained from the administration of the tests. The hypothesis was put to test using t-test statistical tool.

The study on the difficulties faced by senior school chemistry students' in solving stoichiometric problems was undertaken to answer three research questions and one research hypothesis. Twelve intact classes were used from twelve selected schools randomly selected Science, Technology and Technical Education Board (STTEB) Schools in Kogi State.

7. Summary of the major findings

1. Generally, students found problem solving difficult, only 31(1.3%) of the respondents were able to solve the questions correctly.
2. Selecting relevant information from memory and relating the known to unknown data was another major source of difficulty as 59.7% of the total number of scripts analyzed.
3. Many students did not reach the reasoning stage (Ref. Table 7 and 8), because students do not seem to have adequately developed proportional reasoning, but they follow the algorithms learnt, using mathematical operations in solving the stoichiometric problems. They do not think chemically about the obtained results in the problem solving process. 526 (21.9%) scripts or solutions had difficulties reasoning, probably because of careless omissions and lack of critical and logical reasoning.
4. About 8.8% of the attempted solutions had errors in computation.
5. More females (28.7%) than males (25.3%) students had difficulty defining the problem goal. Consequently, more females tend to start without finishing. More females (7.3%) than males (5.3%) had difficulty in selecting appropriate information from the questions, and also more females (23.3%) than males (20.7%) students had difficulty in reasoning. However, a greater percentage of males' (2.0%) than females' (0.7%) solutions were correct.

8. Discussion

8.1 Difficulties in defining the problem goal

In this stage of the model, the problem solver is expected to know what is required in the question before starting to solve it. It involves writing down in a systematic presentation all the given data together with the unknown data. In this study, difficulties of respondents were as a result of misuse of this stage which involves:

1. Failure to identify and write down all the necessary data, including the unknown;
2. Lack of clarity on what to find out i.e. the problem goal;
3. Starting off by rushing into calculations involving data that seemed familiar, as evident in their scripts, at the expense of the problem goal.

In most cases, the scripts showed that only data or pieces of information that seemed familiar to respondents, and thus, could easily be manipulated were written down and worked on. In other words, they started with the data and tried to progress from there. Consequently, these salient but sometimes redundant pieces of information appeared to capture their attention and drew them away from the problem goal.

Question 1 is a good example among others, where respondents' difficulty in defining the problem goal was evident. "20 g of copper(ii) oxide was warmed with 0.050 mole of tetraoxosulphate (vi) acid. Calculate

the mass of copper(ii) oxide that was in excess. The equation for the reaction is $CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(g)$."

The respondents' task was to use the information given to determine the amount (in mass) of CuO in excess.

Analysis of the answer scripts (Ref. Table 7, question 1) revealed the reason for the difficulty. For instance, about 22 % of the respondents were not able to define the problem goal before starting to solve the question. They failed to recognize what was required in the question. Some 20% started with, writing down the mass of copper(ii) oxide as 20 g; without indicating whether it was the mass involved in the reaction or the mass used without any clue as to where they were going. If the respondents had defined the goal of the problem by asking; what mass is to be found out, they would have been able to answer the question correctly.

Question 5, was stated as: "What volume of Hydrogen collected over water at 25 ^{0}C and 755 mmHg pressure can be obtained from 6.0 g of magnesium and an excess of tetraoxosulphate(vi) acid ? (Mg = 24, standard temperature = 0 ^{0}C, standard pressure = 760 mmHg; vapour pressure of water at 25^{0}C = 23.8 mmHg; 1 mole of gas occupies 22.4 dm^3 at s.t.p)."

The task involved first writing a balanced chemical equation of reaction, then use the equation to find the volume of hydrogen 6.0 g of Mg will produce, and thereafter, show how to use the results to find the volume of hydrogen collected over water at a room temperature of 25 ^{0}C and 755 mmHg pressure.

The unsuccessful respondents (22.6 %) ran into difficulties because they did not first isolate the known and unknown data and therefore, could not write down a balanced equation for the reaction. Instead, they started off by writing down the General Gas equation, $P1V1/T1 = P2V2/T2$. The difficulties would have been reduced if the respondents had written down a balanced equation for the reaction, then determine the volume of hydrogen gas 6.0 g of Magnesium would produced.

Respondents' inability to write a balanced equation and their tendencies to apply learnt algorithm was responsible for most students going the wrong direction.

8.2 Difficulties in selecting information from memory

In this phase of the model, what is important is whether the respondents could access the subject matter or not. If the problem is one that is unfamiliar from experience, then, the students must try to recall from memory some key relations involving the known and the unknown data. To be able to do this, the problem solver should have the mastery of the content area and must have an idea of what the relations look like.

Difficulties students faced at this stage were:

1. Knowledge incorrectly recalled and applied;
2. They did not the subject matter too well;
3. They wrote down data arbitrarily and applying learnt algorithms.

8.3 Difficulties in reasoning

Comparatively, few students (1.83%) reached this stage of the model, which involved the execution of correct mathematical operations or deductive reasoning. This was because they did not go beyond the preceding stages. However, sources of errors were mainly careless omission of units and improper logical reasoning.

8.4 Evaluation

There was no definitive way to determine whether or not respondents tried to check their answers against this estimate. But, from the analysis of scripts, respondents did not always evaluate their answers to confirm if the answers were correct.

9. Conclusion

Researchers' reports have gathered evidences in a variety of topics which support the view that both university and secondary school students have difficulties in solving stoichiometric problems, because they lack understanding of the basic concepts relating to stoichiometric calculations. Perera and Wijeratne (2006) found that many students could do stereotype numerical problems based on calculating the concentration and the amount of solute in solution, did so without any idea about the unit conversions involved in the calculation.

Based on the result of this study, majority of the students did not display a clear understanding of basic concepts such as numbers of mole, relative molecular mass, molar mass, molar volume and limiting reagents–most probably because these formulas were memorized rather than understood. Despite not having a clear understanding of these concepts, comparatively few students (1.3%) were still able to solve routine problems involving the calculation of these quantities.

Furthermore, a considerable percentage of students appeared not to even attempt some of the questions. Many of the students who were able to solve the routine problems showed a lack of ability to solve problems involving similar concepts that requires a different approach, thus showing a significant lack of problem solving skills.

10. Recommendations

On the basis of these research findings, the following recommendations need to be practised and implemented as soon as possible.

- Students should be given enough opportunities to practice problem solving with real problems. Asking students merely, to substitute numbers or quantities into equations is problem solving at the lowest level, thus units designed for group work will be a useful resource to offer enjoyable experiences of problem solving. Apart from problem solving, chemistry is revised and students enjoy the experience.
- Students must be familiar with the basics of chemical equations as well as being able to recall easily the information in order to be able solve real problems. The retrieval of information will be facilitated by the storage of chunks of related idea in the memory.
- The aspect of stages of the problem solving model used, which need to be emphasized in teaching and exercising are: (i) clarification and definition of the problem goal, (ii) retrieval of information or required knowledge from memory which will show how the unknown variables are related to the known variables in the problem statement.
- The use of efficient skills and strategies like: thinking aloud, reflective thinking, noting down systematically all the known and unknown variables in a problem will help to organize and clarify students' ideas and reduces the likelihood of careless errors and omissions. Students should work in pairs to solve problems. One partner describes how he would solve the problem, while the other partner listens. The listener contributes to the process by asking questions for the purpose of clarification. But, if a student prefers to work alone, then sub-vocalize or writing down thoughts should be employed to solve a problem.
- Chemistry teachers should help develop students' confidence in problem solving. One way to do this, is by providing students with tasks (in both practical and theoretical contexts) which are neither too novel and therefore beyond their knowledge and skills, nor too familiar, and therefore routine, but tasks which are 'real' problems, and yet, the knowledge and reasoning required will be within their competent repertoire (Onwu and Moneme, 1986).
- Curriculum planners, authors and teachers should seek to redefine the curriculum in terms of content and context; such that will emphasis the required conceptual understanding of chemical concepts and the development of problem solving skills in students. In addition, it will require more research on the complex relationship between students' approaches to learning and problem solving in chemistry because of the possible close association between content and learning approaches.

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Research question 1

To what extent were students able to solve the stoichiometric problems correctly?

Table 1: Comparison of male and female students' average abilities to answer the questions correctly.

Questions	**Total no of students involved**	**No of male students**	**% of male students**	**No of female students**	**% of female students**
Ability to answer Question 1 correctly	6	4	2.7	2	1.3
Ability to answer Question 2 correctly	4	3	2	1	0.7
Ability to answer Question 3 correctly	5	3	2	2	1.3
Ability to answer Question 4 correctly	4	3	2	1	0.7
Ability to answer Question 5 correctly	4	3	2	1	0.7
Ability to answer Question 6 correctly	4	3	2	1	0.7
Ability to answer Question 7 correctly	4	3	2	1	0.7
Ability to answer Question 8 correctly	4	3	2	1	0.7
Total Question	4	3	2	1	0.7

Table 1 shows that male students were more frequently able to answer the questions correctly than the female students.

Research question 2

What difficulties do students encountered when solving stoichiometric problems using Ashmore, Frazer and Casey's Model?

Table 2(a): Comparison of students' difficulties in the different stages of the Model for the Problem Solving Test in Stoichiometry**.**

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S/N	Stages of problem-solving	Question 1		Question 2		Question 3		Question 4		Question 5		Question 6		Question 7		Question 8	
		No. of students	%	No. of students	%	No. of students	%	No. of students	%	No. of students	%	No. of students	%	No. of students	%	No. of students	%
1.	Difficulties in defining the problem	66	22.0	71	23.7	69	23.0	83	27.7	68	22.6	88	29.3	99	33	102	34.0
2.	Difficulties in selecting information from data	19	6.3	11	3.7	15	5.0	22	7.3	28	9.3	12	4.0	17	5.6	25	8.3
3.	Difficulties in selecting information from memory	104	34.7	89	29.7	119	39.7	120	40.0	118	39.3	112	37.3	97	32.3	77	25.7
4.	Difficulties in reasoning	88	29.3	70	23.3	60	20.0	56	18.7	64	21.3	50	16.7	57	19.0	81	27.0
5.	Errors in computation	17	5.7	55	18.3	32	10.6	15	5.0	20	6.6	34	11.4	28	9.2	11	3.7
6.	Correct solution (no error)	6	2.0	4	1.3	5	1.7	4	1.3	4	1.3	4	1.3	4	1.3	4	1.3
	Total	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100

Table 2a reveals that only 1.3 % of the students solved the problems correctly, 59.6 % of the students' scripts analyzed showed that students could not relate the known with the unknown variables. The aspect of stages of the problem solving model used that posed challenges to students are: (i) clarification and definition of the problem goal, (ii) retrieval of information or required knowledge from memory which should show how the unknown variables are related to the known variables in the problem statement.

Table 2(b): Comparison of male and female students' difficulties in the different stages of the Model for the Problem Solving Test in Stoichiometry (combined).

S/N	Stages of problem-solving	Males (N = 150)		Females (N = 150)		Total No. of students	Percentage (%)
		No. Involved	%	No. Involved	%		
1.	Difficulty in defining the problem goal	38	25.3	43	28.7	81	27.0
2.	Difficulty in selecting information from data	8	5.3	11	7.3	19	6.3
3.	Difficulty in selecting information from memory	58	38.7	46	30.7	104	34.7
4.	Difficulty in reasoning	31	8.0	35	23.3	66	22.0

5.	Errors in computation	12	2.0	14	9.3	26	8.7
6.	Correct solutions (no error)	3	2.0	1	0.7	4	1.3
	Total	150	100	150	100	300	100

Table 2(b) shows the combined results for female students that had more problem solving difficulties in the different stages of the model than their male counterparts in Problem Solving Test in Stoichiometry (PSTS)

Research question 3

Do male students encounter difficulties more than their female counterparts?

Table 3: Comparison of the nature of difficulties male and female students faced in Problem Solving Test in Stoichiometry.

Nature of difficulties	Total no of students involved	No of male students	% of male students	No of female students	% of female students
1. Inability to write formulas of compounds correctly	259	128	85.3	131	87.3
2. Misunderstanding of the concept of combining power	256	124	82.7	132	88.0
3. Molar mass taken as relative molecular mass	253	125	83.3	128	85.3
4. Misunderstanding of mole concept	222	106	70.7	116	77.3
5. Wrong use of units	221	104	69.3	117	78.0
6. Wrong use of coefficients and subscripts	268	133	88.7	135	90.0
7. Misunderstanding of relationships between molar mass and volume	270	133	88.7	137	91.3
8. Wrong application of gas law	226	108	72.0	118	78.7

Table 3 shows that female students were more frequently involved in the various difficulties than the male students.

Research Hypothesis 1

There is no significant difference in the performance male and female students in the problem solving test in stoichiometry.

Table 4: Performance of male and female students' in the problem solving test in stoichiometry.

Gender	N	Mean	Standard Deviation	d. f.	Calculated t-value	Critical t-value
Male	150	13.81	14.136			
Female	150	9.99	9.214	298	2.773	1.96

Table 4 shows that the calculated t-value of 2.773 is greater than the critical t-value of 1.96 at a 0.05 level of significance with 298 degrees of freedom. Thus, the null hypothesis was rejected. The inference, therefore, is that there was a statistically significant difference in the performance of male and female students' in the problem solving test in stoichiometry. The average score (mean) for male students was 13.81 and 9.99 for females. This suggests that male students performed better than female students in the test.