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MATHEMATICAL PROBLEM-SOLVING SKILL AND CONCEPTUAL UNDERSTANDING AS CORRELATES OF SENIOR SECONDARY SCHOOL STUDENTS' ACHIEVEMENT IN STOICHIOMETRIC ASPECT OF CHEMISTRY

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Mathematical Problem-Solving Skill and Conceptual Understanding as Correlates of Senior Secondary School Students' Achievement in Stoichiometric Aspect of Chemistry

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Abstract

The study investigated mathematical problem-solving skill and conceptual understanding as correlates of students' achievement in stoichiometry content of senior secondary school chemistry. The study adopted the non-experimental correlational research design. The sample for the study consisted of 264 senior secondary school year two (SSS II) chemistry students from randomly selected ten senior secondary schools within Amuwo Odofin Local Government Area of Lagos State. The valid and reliable research instruments used for data collection were Mathematical problem-solving skill test (MPST α=0.62), Conceptual Understanding Test (CUT α=0.66) and Stoichiometry Achievement Test (SAT α=0.75) to collect information from the participants. The data collected were analysed using descriptive statistics of mean and standard deviation and inferential statistics of multiple regression analysis. The study revealed the following findings: There were significant positive correlations between conceptual understanding, mathematical problem-solving skill, and achievement in stoichiometry. Conceptual understanding and mathematical problem-solving skill jointly contributed 69.5% to the variability in students' achievement in stoichiometry. Also, conceptual understanding pooled the largest share in students' achievement in stoichiometry. Hence, students' achievement in stoichiometry could be predicted by their mathematical problem-solving skill and conceptual understanding. Based on the study's results, it is recommended among others that previous students' performance in mathematics should be used as prognostic assessment of students in chemistry class at the beginning of a term or a session.

Introduction

Chemistry is one of the most challenging subjects in the secondary school science sequence (Uce, 2009). One of the important goals of chemistry education is the acquisition of problem-solving skill, which is also a very cogent goal in mathematics education. Mathematical problem-solving skills has been found to be important in the study of science subjects particularly Chemistry because of its role in the development of scientific and technological processes (Kankia, 2010; Olalekan and Jerome, 2006).

In the chemistry curriculum, one of the important concepts' students must master is the concept of stoichiometry and it is also considered the most complicated concept to learn (Hand, Yang, & Brusvoort, 2007). According to Brown, LeMay, & Bursten (2013), stoichiometry is the study of quantitative aspects of the mass-mole number relationship, chemical formulas, and reactions. It involves the mole concept and the balancing of chemical equations (Zumdahl, 2002). Stoichiometry is a mathematical oriented chemistry concept that is used to determine how much product will be produced or formed from a given quantity of reactants (Zumdahl, 2002). Reactants are substances that are chemically combined to form a new product or products (e.g., sodium hydroxide and hydrochloric acid are combined to produce sodium chloride and water). Stoichiometry is the foundation of chemistry, so if students cannot comprehend it, then, it will be difficult to understand chemistry generally (Paideya, 2010). Stoichiometry also requires a series of skills, organized conceptual knowledge of chemistry, and knowledge of mathematics.

Stoichiometry is fundamental to all aspects of Chemistry, it involves problem solving where students are required to calculate the masses of reactants consumed and products formed with the aid of a balanced chemical equation, given the mass of a reactant or product in a chemical reaction (Okanlawon, 2010). The advantages of problem solving may be implemented at any point in time if the environment enables the learners to express their own understanding of the problem. These include determining whether the information given is sufficient or there is need to solve sub-goals, using their prior knowledge. In stoichiometry, the advantage of problem solving is that it supports and elucidates concepts (Selvaratnam & Canagarama, 2008). This begins in secondary school when stoichiometry is introduced to learners. At this level, learners can either be motivated or discouraged to learn this concept, by either developing a positive or negative attitude towards learning to solve stoichiometry problems.

Solving stoichiometry problems is important because it is one of the factors that determine learners' achievement in chemical equilibrium, acids and bases problems at secondary school, and analytical chemistry at tertiary education (Toth & Sebestyen, 2009). However, acquisition of mathematical problem-solving skills in stoichiometry is affected by the way the topic was taught, the worked examples learners encountered, prior knowledge, and metacognition of the learners.
Some very important assessments have shown that there is a considerable gap between students' ability to solve algorithmic questions (symbolic or numerical) that can be answered by applying a set of procedure to generate a response (Bowen & Bunce, 1997) and their comprehension of chemical concepts (Deming & Ehlert, 2008)

Many students solve chemistry problems using algorithmic strategies and do not understand the chemical concepts behind their algorithmic manipulations; they have less trouble with the algorithmic part of the problem than they do with the conceptual part (Cracolice et al., 2008). Identifying this concern is problematic because teachers may accept a correct numerical answer without examining students' conceptual understanding dealing with the related concepts (Dahsah & Coll, 2008). If this occurs, then students who produce the correct numerical answer may be presumed to understand the underlying concepts (Sawrey, 1990). Teachers find it easier to teach algorithms and formulas, neglecting the conceptual knowledge, and this does not help students to build in-depth understanding of concepts (Antwi, 2013). Therefore, students' conceptual understanding goes beyond their algorithmic understanding

For instance, it is very important that students comprehend the particulate nature of matter, in its own nature of chemistry before they can comprehend other concepts about the structure of matter and will be able to solve new or uncommon problems (Nakhleh, 1992; Krajcik, 1991) otherwise, they will have to resort to rote learning of definitions, formulae, and processes (Stefani & Tsaparlis, 2008). Nurrenbern and Pickering (1987) stated that students do not struggle to understand chemical equations on a molecular level. Krajcik (1991) and Gültepe (2004) found that students solve algorithmic chemical problems using formulas as if doing a puzzle and they express them in a comfortable way. However, in light of the interviews in Gültepe's (2004) study, students cannot explain the physical and chemical phenomena (e.g., dissolution, metallic corrosion, and carbon dioxide formation) and cannot clearly describe the interactions taking place at the molecular level. Gültepe (2004) linked these findings to students' not comprehending the concepts at the molecular level and not reconciling the relations between concepts and agreed with the view of Niaz (1995a) that students with strong conceptual knowledge are better at algorithmic problem solving. According to (2015) sound conceptual understanding is therefore necessary for solving stoichiometric problems more scientifically.
Mathematical Problem-solving skills in chemistry requires understanding of the language in which the problem is stated, interpretation of what is sought, an understanding of chemistry concepts involved in the problem and ability to perform mathematical operations that are inherent in the problem (Gabel, 1994). In solving chemical problems effectively, students are required to identify, define and carryout executive operations using logic and creative thinking. In the process, students arrive at a deep understanding of the topic area and construct new knowledge and understanding on which they can make decisions. Acquisition of mathematical problem-solving capability is an important component of chemistry because of its practical value in solving individual and societal problems (Bandhana & Darshana, 2012).

The goal of good chemical education is to build up an equally strong conceptual and algorithmic understanding and then to reinforce their interdependence. Johnstone and Kellett (1980) believed that developing conceptual understanding (knowledge) influenced the students' achievement in solving problems, and that being fluent and flexible in recalling relevant information would increase the chance of being successful in solving problems. Conceptual understanding, then, is believed to be the most important factor in problem solving (Bédard & Chi, 1992). Experts' achievement in the recognition of patterns and interpreting different aspects of problems that can lead to successful solutions can also be accounted for by their better conceptual understanding of subject matter (Phelps, 1996). Conceptual understanding in stoichiometry has been shown to be important in student achievement (Gauchon & Meheut, 2007; BouJaoude & Barakat, 2003). Recent studies also show that failure in the understanding of chemical concepts such as the mole concept (i.e., chemicals react in fixed mole ratios as defined by a chemical equation) and chemical reactions results in misunderstandings in chemistry (Dori & Hameiri, 2003).

This does not mean, however, that conceptual understanding guarantees correct solutions. It has been observed that a few students have difficulty formulating algorithms for problems even though they have conceptual understanding of the subject (Nakhleh & Mitchell, 1993). Likewise, students who can solve problems algorithmically do not necessarily have a conceptual understanding of the problem (Nurrenbern & Pickering, 1987).

According to Gabel & Bunce, (1994) developing a good conceptual understanding of stoichiometry is closely associated with the belief that matter is made of particles not visible to the unaided eye, that changes observed at the macroscopic level can be explained in microscopic terms, and that these concepts can be represented by symbols. Williamson, Huffman, and Peck (2004) have suggested that understanding the particle model will provide the learner with many benefits, such as a better comprehension of chemical concepts and more effective problem-solving skills (Harrison & Treagust, 2002; Tuncer, 2003; Valanides, 2000). Lacking conceptual understanding of the particulate nature of matter could cause difficulties in learning subsequent chemistry topics and encourage dependence on previously memorized techniques. Studies indicate that the stoichiometric relationship between atoms, molecules, and reactants and products are not recognized well (Dori & Hameiri, 2003).

Mathematical Problem-solving skill is one such capability which is a process of overcoming difficulties that appear to interfere with the attainment of a goal in secondary school chemistry.

And secondary school chemistry curriculum contains essentially chemical stoichiometry as the major mathematical aspect and students learn stoichiometry basically with algorithm (Hanson & Oppong, 2014). A few studies have drawn attention to inadequate mathematical skills of secondary school students in Nigeria. It is generally believed that mathematics is not being properly taught in schools. This view is because secondary school students perform poorly in mathematics examination (Kankia, 2010; Kajuru' and Kauru', 2010; Kajuru' and Popoola, 2010). The evidence from these studies seems to suggest that mathematics classrooms may not be providing students with adequate mathematics skills to enhance their performance in mathematics-based subjects in school. The poor achievement indicates that students have learning difficulties in acquiring the basic thought-processes, conceptual understanding, and mathematical problem-solving skills. Also, previous reports (Offia and Njelita, 2010; Madichie and Isreal, 2010; Doka, 2010; Mari, 2008; Offia and Samuel, 2008; Ibole, 2007) found that students had poor performances in chemical stoichiometry and that it was a difficult topic for students. However, this identifies secondary school students' inadequacy of using the relevant mathematical concepts, principles, and skills to solve chemical stoichiometry problems.

Considering the above, it becomes necessary to investigate the extent to which the mathematical problem solving, and conceptual understanding skills could influence secondary school students' understanding of stoichiometry aspect of chemistry.

Statement of the Problem

Since our society is becoming increasingly more technical, problem-solving capability is also increasingly becoming a highly valuable skill. The capability to solve stoichiometric problems is of high relevance in chemistry research and practice, medical fields and in industry. Students should therefore not be constrained in career choice and restricted from a full and rewarding participation in society by a failure to develop problem solving capabilities and skills. Problem solving in chemistry is regarded as a very difficult task for secondary school chemistry students because of its complex intellectual processes. As a result, it is seen as one of the principal causes of scholastic failure in school chemistry (Adigwe, 2014; Chandrasegaran, Treaqust, Walddrip & Chandrasegaran, 2008: Baujoude & Barakat, 2003,). Research reports (Adigwe 2012 & 2014; Arova, 2007; Baujaoude & Barakat, 2000, 2003; Bodner & Herron, 2002,) on problem solving in quantitative chemistry indicate that students' failure to successfully solve problems was due to difficulties they experience in the crucial phases of problem-solving processes and conceptual understanding. Essential chemistry concept that is inadequately mastered by students is stoichiometry (Potgieter & Davidowitz, 2010). This assertion concurs with a study conducted by Potgieter, Rogan and Howie (2005) who found that first year students in South Africa perform poorly in stoichiometry and mole concepts.

Therefore, the study sought to explore mathematical problem-solving skill and conceptual understanding as correlates of students' achievement in stoichiometry content of secondary school chemistry.

Purpose of the Study

The purpose of this study is to explore mathematical problem-solving skills and conceptual understanding as correlates students' achievement in stoichiometry content of secondary school chemistry. The following objectives were stated to attain the above-mentioned purpose:

1. Ascertain the relationship between mathematical problem-solving skill, conceptual understanding, and students' achievement in stoichiometry
2. To determine the composite contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry.
3. To determine the relative contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry.

Research Questions

1. What is the relationship between mathematical problem-solving skill, conceptual understanding, and students' achievement in stoichiometry?
2. What is the composite contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry?
3. What is the relative contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry?

Research Methodology

The research design employed for this study was the non-experimental correlational design. Students' score in Stoichiometry were treated as the dependent variable while Mathematical problem-solving skill and conceptual understanding of chemical concepts were treated as the independent variables.

The population for this study comprised of all the co-educational Senior Secondary School year two (SSS II) Chemistry students in the 316 public senior secondary schools in Lagos State.

Simple random sampling technique was adopted in selecting one Local Government Area (LGA) from the 20 LGAs in Lagos State and in selecting ten public senior secondary schools within the selected LGA. The sample consists of 264 SSS II Chemistry students selected from the ten public senior secondary schools.

The following research instruments were employed in the study:

1) Mathematical Problem-Solving Skill Test (MPST)
2) Stoichiometry Achievement Test (SAT)
3) Conceptual understanding Test (CUT)

The MPST and SAT were developed by the researchers while the CUT was adapted from Gultepe, Yalcin and Kilic, (2013). The MPST consists of twenty (20) multiple choice items in mathematics to determine students' mathematical problem-solving skill using four options (A, B, C, and D) format. Three experts in item construction with background in mathematics and chemistry did face and content validation the instruments. The items were written bearing in mind their similarity to stoichiometry concept problems in terms of logic process or practicing with same mathematical operations. Ten (10) items require the use of computational skills while the remaining Ten (10) items require the use of application skills.

The SAT instrument consists of thirty (30) multiple choice items that assess students' achievement in Stoichiometry concept. Stoichiometry permeates the "O" Level Chemistry Syllabus and of particular importance in the following chemical concepts: mole concept, writing and balancing of chemical equations and formula, chemical calculations (molar mass of compound, percentage of an element in a compound /percent yield, empirical and molecular formulae, mass-mass calculation, mass-volume calculation, Limiting reagent).

The CUT was adapted from Gultepe, Yalcin, & Kilic, (2013) and slightly modified in its statements structure. It comprises of ten (10) multiple-choice questions that tested the conceptual understanding of macroscopic and submicroscopic levels of related stoichiometry topics. These questions are related stoichiometry topics such as balancing of chemical equation, mole concept, molecules, compounds and mixture, and chemical reactions.

The research instruments used in this study were validated by three experts including a WAEC Chemistry and mathematics subject officers, and an expert in Chemistry Education with reputable track record. The items were validated with respect to clarity and appropriateness and hence, affirmed to have face and content validity. The reliabilities of the MPST, CUT and SAT instruments were determined by test re-test reliability method of two weeks interval, and the scores generated in the two administrations were correlated using Pearson Product Moment Correlation Coefficient. The re-test reliability coefficient for MPST instrument was 0.87, while the re-test reliability coefficient for CUT and SAT instrument was 0.89 and 0.86 respectively.

After receiving the consent of the appropriate school authorities, the three instruments MPST, CUT and SAT were administered on the participants at the regularly scheduled class period. The data collected were analysed along the stated research questions and hypotheses. The test scores obtained from administering the research instruments

(MPST, SAT, and CUT) was coded and inputted to the computer using Statistical Package for Social Sciences (SPSS) for analysis and the research hypotheses were tested using multiple regression analysis α = 0.05.

Research Question one: What is the relationship between mathematical problem-solving skill, conceptual understanding, and students' achievement in stoichiometry?

Table 1: Relative Influence of Mathematical Problem-Solving Skill and Conceptual Understanding on Students' Achievement in Stoichiometry

Variables	Mean	SD	N	SAT	MPST	CUT
SAT	60.70	20.88	264	1.00		
MPST	61.44	15.10	264	0.37	1.00	
CUT	54.77	17.37	264	0.22	0.30	1.00

SAT: Students' Achievement in Stoichiometry
MPST: Mathematical Problem-Solving Skill
CUT: Conceptual Understanding

The result on the Table 1 reveals the relative influence of mathematical problem-solving skill, conceptual understanding, and students' achievement in stoichiometry. Mathematical problem-solving skill is having a mean score of 61.44 while conceptual understanding is having a mean score of 54.77. This revealed that mathematical problem-solving skill is having much influence on students' achievement in stoichiometry than conceptual understanding. The description of the relationship that exists between the SAT and MPST; r = 0.37, r = 0.22 for SAT and CUT and, r=0.30 for MPST and CUT. These results indicated that MPST have a higher correlation value to the SAT than CUT.
Research Question 2: What is the composite contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry?

Table 2: Composite Effect of the Students' Beliefs and Intentions on their Environmental Responsible Behaviour

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.834[a]	.695	.693	11.571

Predictors: (Constant), MPST: Mathematical Problem-Solving Skill; CUT: Conceptual Understanding

As shown in the Table 2a, the adjusted R value (0.693) has a fit and the two independent variables (Mathematical Problem-Solving Skill and Conceptual Understanding) together correlated (R=0.834) with dependent variable (Students' Achievement in Stoichiometry). The constructed multiple regression model indicated that the independent variables account for 69.5% of the variance in the dependent variable ($R^2 = 0.695$). The remaining percentage could be due to other factors not investigated in this study while part of it might be due to error.

Table 2b: ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	16836.612	2	7112.127	297.84	.000[b]
	Residual	71321.531	261	315.959		
	Total	109658.186	263			

a. Dependent Variable: Students' Achievement in Stoichiometry
Predictors: (Constant), MPST: Mathematical Problem-Solving Skill; CUT: Conceptual Understanding

Table 2b shows that the multiple regression adjusted R^2 of the variables is statistically significant {F (2,263) = 297.84; p<0.05}. This implies that 69.5% of the variance of the dependent variable is attributable to the joint contribution of MPST and CUT
Research Question 3: What is the relative contribution of mathematical problem-solving skill and conceptual understanding to the prediction of students' achievement in stoichiometry?

Table 3: Relative Contribution of the Independent Variables to the Prediction

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig
	Beta (β)	Standard Error	Beta (β)		
(Constant)	2.535	3.018		0.840	.402
MPST	.321	.063	.232	5.063	.000
CUT	.794	.055	.661	14.393	.000

* = Significant at 0.05 level of significance

From Table 3, the result of relative contributions of the independent variables to the prediction of students' achievement in stoichiometry revealed that MPST and CUT contributed differentially to the prediction. However, MPST (ß=.232; t=5.063; *p*<0.05) and CUT (ß=.661; t=14.393; *p*<0.05) are the potent significant positive contributors to the prediction of students' achievement in stoichiometry.

Discussion

The study found out that there is a relative effect of mathematical problem-solving skills and conceptual understanding on students' achievement in stoichiometry (see Tables 1a &1b). This indicates that conceptual understanding and mathematical problem-solving skill are important for students' success in in stoichiometry and as a result both the quantitative (mathematical problem solving) and qualitative (conceptual understanding) nature of stoichiometry should be given attention while teaching. This is because stoichiometry concepts deal with a lot of reasoning and algebraic manipulations and usually, students use to solve problem in stoichiometry by writing and balancing chemical equations, input stoichiometry coefficients, mole ratios of reactants and products etc. And this requires the learners to understand the chemical reactions involve and to use ratios and proportions which are important topics in mathematics. The finding is consistent with Chiu's (2001) results about algorithmic problem solving and conceptual understanding of high school students in Taiwan where she defined students as high problem solvers and high conceptual thinkers. This finding also corroborates that of Sawrey (1990) who argued that paying attention to both quantitative and qualitative nature of chemistry simultaneously is germane to student successive learning.

Table 2a shows that mathematical problem-solving skill has the greater contribution to students' achievement in stoichiometry. This might be due to fact that both algebraic problem solving in mathematics and stoichiometry problem solving in chemistry involve finding relationship. Also, some of the topics in mathematics such as ratios could be regarded as a prerequisite in learning and solving stoichiometry because students could easily transfer their knowledge of algebra to solve stoichiometry problems. These finding correlates that of BouJaoude and Barakat (2003) who claim that learners who cannot manipulate numbers readily find it difficult to learn the mole concept and solve problems based on the mole concept. Also, in line with Childs and Sheehan (2009) and Aje (2005) who found that students with a strong mathematical ability had little difficulty balancing chemical equations and solving gas problems. The finding also corroborates the report from Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, (2009), that learners with a strong mathematical ability found it easy to balance chemical equations and solve gas problems.

Table 2b shows the contribution of the conceptual understanding (CU) to students' achievement in stoichiometry, although the value (33%) is lesser than that of mathematical problem-solving skill. This finding is agreement with that of Cracolice et al. (2008) who found that students' success on algorithmic questions was higher than on conceptual questions in stoichiometry content of chemistry. But the study still found a reasonably high value of conceptual understanding's contribution. This positive contribution of CU to students' achievement might be due to learner's fluency and flexibility in recalling relevant information which could have increase their chance of being successful in solving problems in stoichiometry topics. This is in line with Williamson, Huffman, and Peck (2004) who penned that conceptual understanding would provide the learner with many benefits, such as a better comprehension of chemical concepts and more effective problem-solving skills. It also corroborates the finding of Harrison and Treagust, (2002) who reported that lacking conceptual understanding of the particulate nature of matter could cause difficulties in learning subsequent chemistry topics.

Conclusion and Recommendations

The results from this study indicate that mathematical problem solving, and conceptual understanding skills play an effective role on students' solving problems in stoichiometry aspect of chemistry correctly. Therefore, mathematical problem-solving and conceptual understanding skills could be used to predict students' achievement in stoichiometry aspect of secondary school chemistry. If one of the important objectives of chemistry education is to help students develop understanding of concepts and acquire skills in problem solving, then, we must endow them with opportunities through oriented curricula, teaching materials and teaching strategies to develop sound mathematical problem solving and conceptual understanding skills.

Based on the findings of the study the following recommendations were made:

- Previous students' performance in mathematics should be used as prognostic assessment of students in chemistry class at the beginning of a term or a session. And the students' mathematics status could also serve as an aid in counselling and remediation in chemistry class.
- When teaching students how to solve numerical problems in stoichiometry, teachers should ask students to think rather than to simply memorize and use algorithms without understanding to derive qualitative, non-mathematical procedures for the problems and this could facilitate conceptual (qualitative) understanding.

- Mathematics teachers should be advised by the appropriate authority to lay emphasis on those mathematics skills/contents that relate significantly to chemistry to create room for better understanding and performance in chemistry.
- The curriculum planners/developers should also see the need to arrange the related topics in both subjects close to each other, such that the knowledge acquired in mathematics could be applied almost immediately to solve problems in chemistry class.

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