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PROBLEM SOLVING INSTRUCTION FOR OVERCOMING STUDENTS' DIFFICULTIES IN STOICHIOMETRIC PROBLEMS

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Abstract. The study sought to find out difficulties encountered by high school chemistry students when solving stoichiometric problems and how these could be overcome by using a problem-solving approach. The study adopted a quasi-experimental design. 485 participants drawn from 8 highs schools in a local education district in Zimbabwe participated in the study. A validated stoichiometry achievement test was used to collect data at pre-test and post-test stages. The researchers also prepared a difficulty identification index to analyse the difficulties encountered by students. Quantitative data was analysed using inferential statistics and ANCOVA. From the findings, the difficulties identified were lack of understanding of the mole concept, inability to balance chemical equations, use of inconsistent stoichiometric relationships, identifying the limiting reagent, determination of theoretical yields and identification of substances in excess. The study also found that the use of problem-solving instruction as effective in remedying the identified difficulties in comparison to the conventional lecture method. It was strongly recommended that chemistry educators should analyse and understand student difficulties if they are to assist the learners to become confident and efficient problem solvers. Furthermore chemistry educators should implement the problem-solving pedagogical technique as a means of addressing the difficulties students have in stoichiometry problem-solving.

Key words: stoichiometry; difficulties; problem-solving, chemistry educators

1. Introduction

The academic performance of students in any subject serves as an important indicator of the quality and effectiveness of teaching and learning which in turn can be used as an index to determine the extent to which educational objectives in the intended subject are being attained (Adesoji, Amilani & Dada, 2017). Chemistry, being the central science, derives its reputation as a difficult subject primarily from its dominant problem-solving nature. Furthermore, the subject being a physical science course involves problem solving (Ogunleye, 2009). Because of its complex nature and also that it is a conceptually difficult subject in the school curriculum, it becomes critically important for chemistry educators to be aware of the difficulties students encounter as they learn the subject so that appropriate measures can be taken to address these difficulties (Gegios, Salta & Koinis 2017).

One of the key competences regarded as critical in science and chemistry education is the ability to solve chemical problems. An important areas in chemistry teaching and learning which possess a lot of challenges to students is stoichiometry problem solving (Kimberlin & Yezierski, 2016). Earlier studies by Sanger (2005) as well as Mulford (2002) have revealed the sources of these difficulties as caused by misconceptions students have regarding the concept of limiting reactants, balanced equations, stoichiometric ratios and confusions regarding subscripts and coefficients. Furthermore BouJaoude & Barakat (2000) consider stoichiometry as an abstract and difficult topic to teach as well as the teaching of stoichiometric calculations as challenging.

Other researchers such as Chandrasegaran et al (2009) highlight that the difficulties encountered by students during stoichiometry problem-solving can be attributed to a number of conceptual issues. Dahsah & Coll, (2008) also note that the limited proficiency of students in mathematics also contributes to the difficulties they encounter in stoichiometry problem solving. Studies by Fach et al

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(2007) have documented the overreliance of students on algorithms when performing stoichiometric calculations without making attempts to reason out their solutions. Such students as noted by Cracolice et al (2008) demonstrated their ability to use algorithms in solving traditional problems but lacking the conceptual understanding when faced with novel problems. Other researchers (Dahsah & Coll, 2007; Gauchon & Méheut, 2007; Chandrasegaran, et al., 2009) have identified students' inadequate understanding of the mole concept as a cause of their difficulties in stoichiometry.

From the foregoing discussion, it has been shown that students have difficulties in stoichiometry problem-solving as a result of lack of understanding of a number of concepts related to stoichiometry that influence their ability to solve stoichiometry problems. Thus, this research aims to examine the difficulties chemistry students encounter as they solve stoichiometry problems. Consequently, when chemistry educators understand the difficulties students experience when solving stoichiometric problems they will be able to design appropriate instructional strategies that can be implemented to address these difficulties thus assisting students to be conceptual problem solvers. In this study the use of problem-solving instruction based on Ashmore, Frazer & Casey (1979) as well as Selvaratnam-Frazer (1982) in remedying these difficulties will be investigated.

1.1. Purpose of Study

The study attempts to investigate the difficulties encountered by chemistry students when solving stoichiometry problems and how these difficulties can be overcome using a problem- solving approach.

1.2. Research Questions

The following research questions guided the study:

1. What are the difficulties encountered by chemistry students when solving stoichiometric problems?

2. How effective is problem-solving instruction in overcoming these difficulties?

1.3. Hypothesis of the study

Problem solving instruction significantly improve students' stoichiometric problem solving competence.

2. Methodology

2.1. Research design

The study adopted the quasi-experimental research design using pre-test, post-test non-equivalent control groups. The advantage of using this design is that it is easier to set up than true experimental designs (Fatade, Mogari, & Arigbabu, 2013) but lacks randomisation of subjects to treatment conditions. Adopting quasi-experimental design in this study allowed the researchers to use intact groups in real classroom settings since it was not necessary to randomly assemble students for any intervention during the school hours so as not to disrupt the smooth running of the school programmes. Students in control and experimental groups participated in the study in their natural classroom conditions. Both groups received instruction in stoichiometry from their teachers except that those teachers implementing the intervention had been trained on the use of the intervention in the teaching of stoichiometry. The teachers were trained for one week and implemented the intervention for two weeks in their classrooms. The entire study was completed in five weeks.

2.2. Participants

The sample of the study comprised of 485 Advanced level chemistry learners from 8 high schools in Gweru district, Zimbabwe. The school contexts for the classes in both groups were similar in terms of the teacher backgrounds, resource levels, language issues, socio-economic background of the students. The sample was divided into two groups. The control group consisted of 250 learners while the experimental group consisted of 235 learners.

2.3 Instrumentation

The instrument for data collection was an achievement test in stoichiometry. The test consisted of both multiple choice and open ended items. The test was validated by experts in chemistry education. The internal consistency of the test was evaluated using Cronbach alpha coefficient and found to be 0.84, which is an acceptable level of reliability. The data was analysed using an independent samples t-test and analysis of covariance.

2.4 Data collection procedure

Prior to the commencement of the study the teachers from the experimental schools had to be trained on the use of problem-solving instruction in teaching stoichiometry. During the second week an achievement test in stoichiometry as was administered to the students as a pre-test and the students took one and half hours to complete the test. The subsequent two weeks were used to implement the intervention: the experimental group was taught using problem-solving instruction while the control group was taught using the conventional lecture method. After the implementation of the intervention (5th week) a stoichiometry achievement test was administered as post test.

3. Results

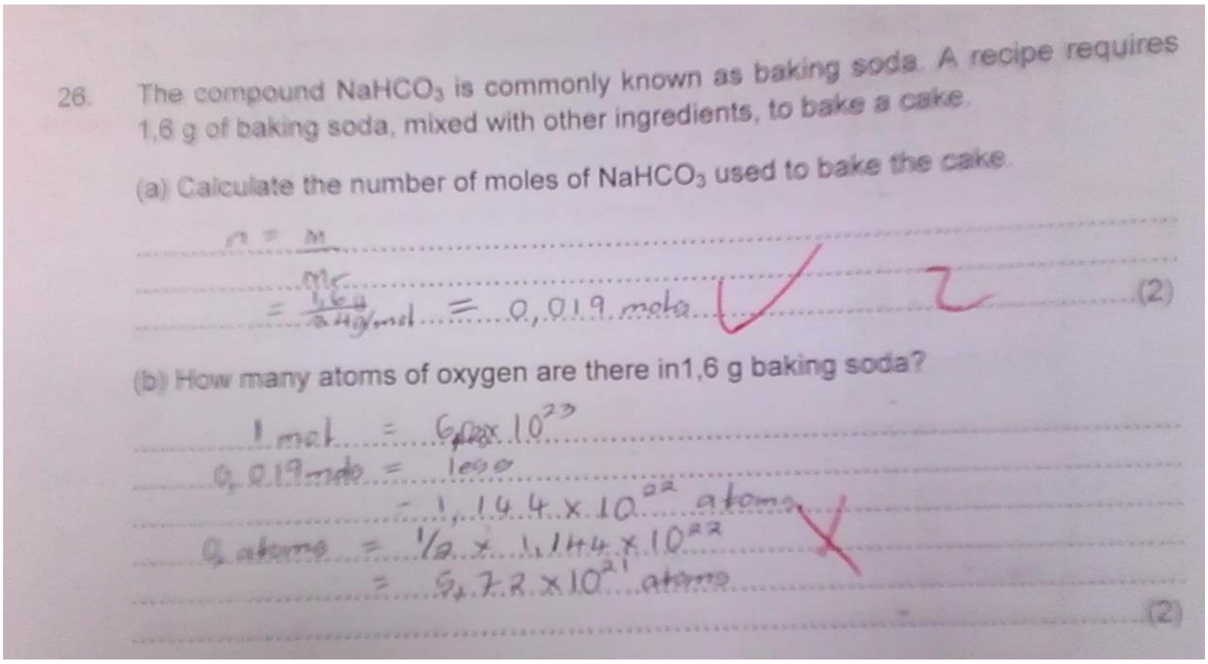
3.1 Research Question one: What are the difficulties encountered by chemistry students when solving stoichiometric problems?

To identify the difficulties encountered by students when they are engaged in stoichiometric problem-solving, the researchers had to analyse the solutions given by students as they were answering open ended items during the pre-test. The responses of the participants were characterised by several difficulties as depicted in table 1 below.

Table 1: Analysis difficulties encountered chemistry students in a stoichiometry pre-test

Nature of difficulty	Percentage of students showing the difficulty	
	Experimental	Control
Understanding the mole concept	61	66
Balancing chemical equations	57	55
Use of inconsistent stoichiometric relationships	78	78
Identifying the limiting reagent	88	88
Determination of theoretical yields	84	85
Identification of substances in excess	72	72

An analysis of Table 1 shows that only six difficulties were encountered by students during stoichiometric problem-solving. In the following we discuss some of the students' difficulties related with stoichiometric problems.



26. The compound $NaHCO_3$ is commonly known as baking soda. A recipe requires 1,6 g of baking soda, mixed with other ingredients, to bake a cake.

(a) Calculate the number of moles of $NaHCO_3$ used to bake the cake.

$n = \frac{m}{Mr}$

$= \frac{1,6\,g}{84\,g/mol} = 0,019$ mols ✓ 2

(2)

(b) How many atoms of oxygen are there in1,6 g baking soda?

1 mol = $6,02 \times 10^{23}$

0,019 mols = [illegible]

= $1,144 \times 10^{22}$ atoms ✗

O atoms = $\frac{1}{2} \times 1,144 \times 10^{22}$

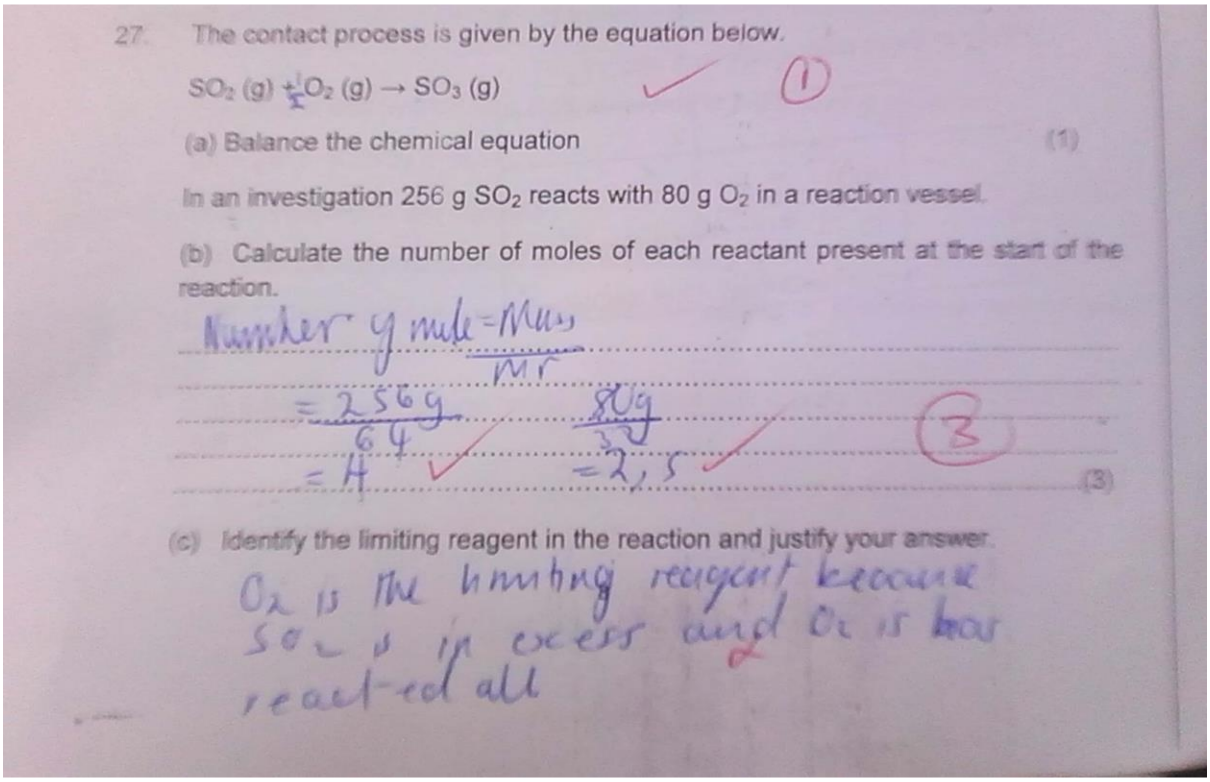
= $5,72 \times 10^{21}$ atoms

(2)

Figure 1. A solution of Problem 26

In Figure 1 the learners could calculate the number of moles asked in (a) part, but in the (b) part of the question which required them to demonstrate an understanding of the mole concept and its relationship to Avogadro's number and the number of particles they were found wanting. They used an inconsistent relationship leading to the wrong solution. The student failed to note that what was to be converted were 3 moles of oxygen atoms not molecules. The learner showed that they lacked understanding of the mole concept. This difficulty was found in the majority of the learners in both the experimental and control group.

The identification of limiting reagents is still problematic for most student as illustrated in Figure 2. Problem 27 reveals that the majority of the students (88%) had difficulties in identifying the limiting reagent as well as justifying their solutions. They randomly selected one of the given masses as the limiting reagent without using the stoichiometry of the reaction. They identified the limiting reagent as the one with the smallest mass.



27. The contact process is given by the equation below.

$SO_2\ (g) + \frac{1}{2}O_2\ (g) \rightarrow SO_3\ (g)$ ✓ ①

(a) Balance the chemical equation (1)

In an investigation 256 g SO_2 reacts with 80 g O_2 in a reaction vessel.

(b) Calculate the number of moles of each reactant present at the start of the reaction.

Number of mole = $\frac{Mass}{Mr}$

$= \frac{256g}{64}$ $\frac{80g}{32}$ ③

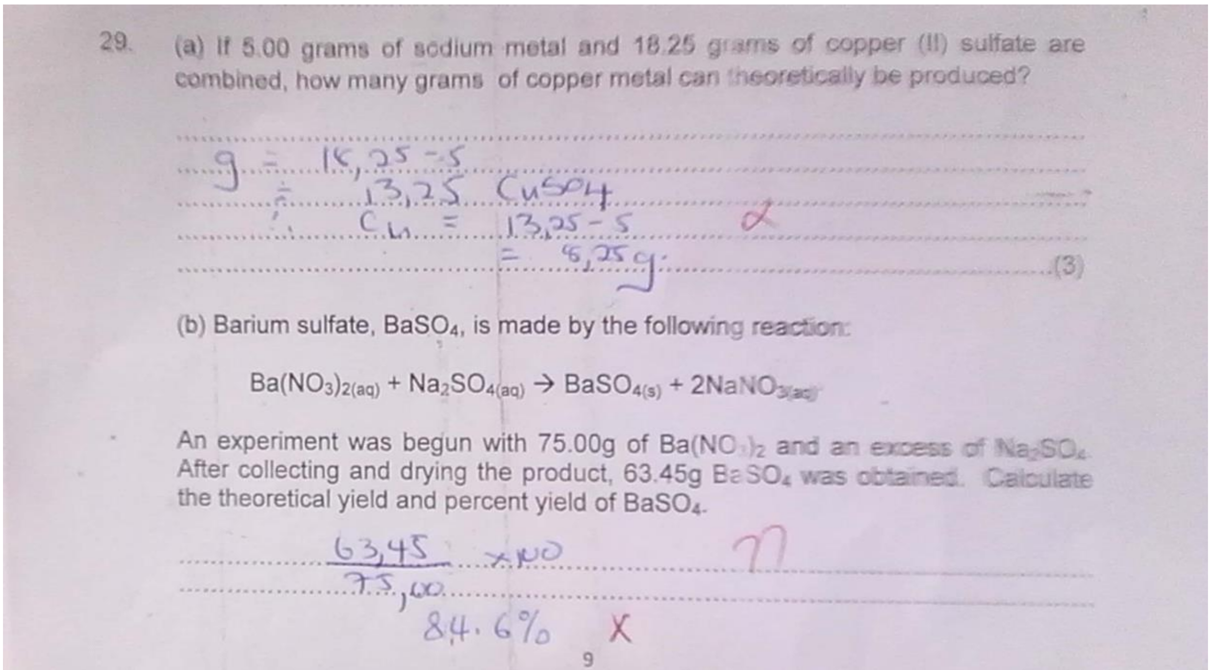
$= 4$ ✓ $= 2,5$ ✓ (3)

(c) Identify the limiting reagent in the reaction and justify your answer.

O_2 is the limiting reagent because SO_2 is in excess and O_2 is has react-ed all

Figure 2. A solution of Problem 27

The determination of theoretical yield and percent yield proved to be difficult for the majority of the students as illustrated in Figure 3.



29. (a) If 5.00 grams of sodium metal and 18.25 grams of copper (II) sulfate are combined, how many grams of copper metal can theoretically be produced?

g = 18,25 − 5

= 13,25 $CuSO_4$

∴ Cu = 13,25 − 5

= 8,25 g (3)

(b) Barium sulfate, $BaSO_4$, is made by the following reaction:

$Ba(NO_3)_{2(aq)} + Na_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2NaNO_{3(aq)}$

An experiment was begun with 75.00g of $Ba(NO_3)_2$ and an excess of Na_2SO_4. After collecting and drying the product, 63.45g $BaSO_4$ was obtained. Calculate the theoretical yield and percent yield of $BaSO_4$.

$\frac{63,45}{75,00} \times 100$

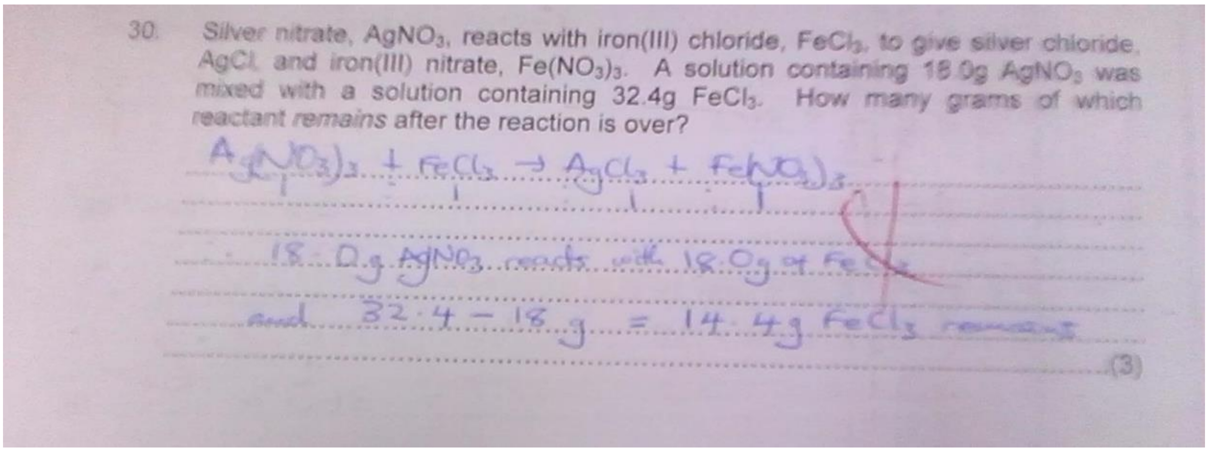
84.6% X

9

Figure 3. A solution of Problem 29

The learners demonstrated a lack of understanding of what theoretical yield was and that theoretical yield was an experimentally determined number. In 29(a) more than half of the learners (57%) could not provide a balanced equation to depict the process, while in item 29(b), 84% could not use the given equation to perform the calculations required. The learners could not calculate the percentage yield.

The other difficulty demonstrated by the learners was inability to identify substances present in excess of the stoichiometric amounts. Figure 4 provides an illustration of this difficulty.



30. Silver nitrate, $AgNO_3$, reacts with iron(III) chloride, $FeCl_3$, to give silver chloride, $AgCl$, and iron(III) nitrate, $Fe(NO_3)_3$. A solution containing 18.0g $AgNO_3$ was mixed with a solution containing 32.4g $FeCl_3$. How many grams of which reactant remains after the reaction is over?

$Ag(NO_3)_3 + FeCl_3 \rightarrow AgCl_3 + Fe(NO_3)_3$

1 1 1 1

18.0g $AgNO_3$ reacts with 18.0g of $FeCl_3$

and 32.4 − 18 g = 14.4g $FeCl_3$ remains

(3)

Figure 4. A solution to Problem 30

The solution presented in Figure 4 shows the learners' inability to write balanced chemical equations, a skill critical to solving stoichiometric problems. The vignette clearly shows that the learner did not actually understand the goal of the problem in terms of what the question required. The task of the learner was to use the given information to determine the amount in excess. This difficulty was common in 72% of the learners in both groups. Had the respondents managed to define the goal of the problem, by identifying the mass that was to be found they could have correctly answered the question

3.2 Research Question two: How effective is problem-solving instruction in overcoming these difficulties?

To address this question a comparative analysis of problem-solving instruction and the conventional lecture method was done by comparing the number of students encountering difficulties before (at pre-test) and after the intervention (post-test). The data is shown in table 2 below.

Table 2: Stoichiometry difficulties analysis to compare instructions at post-test

Nature of difficulty	Percentage of students showing the difficulty	
	Experimental	Control
Understanding the mole concept	10	48
Balancing chemical equations	8	30
Use of inconsistent stoichiometric relationships	30	60
Identifying the limiting reagent	27	65
Determination of theoretical yields	25	64
Identification of substances in excess	18	58

Table 2 shows the number of students encountering the difficulties identified after the implementation of the intervention. Figure 1 depicts the graphical display of the data.

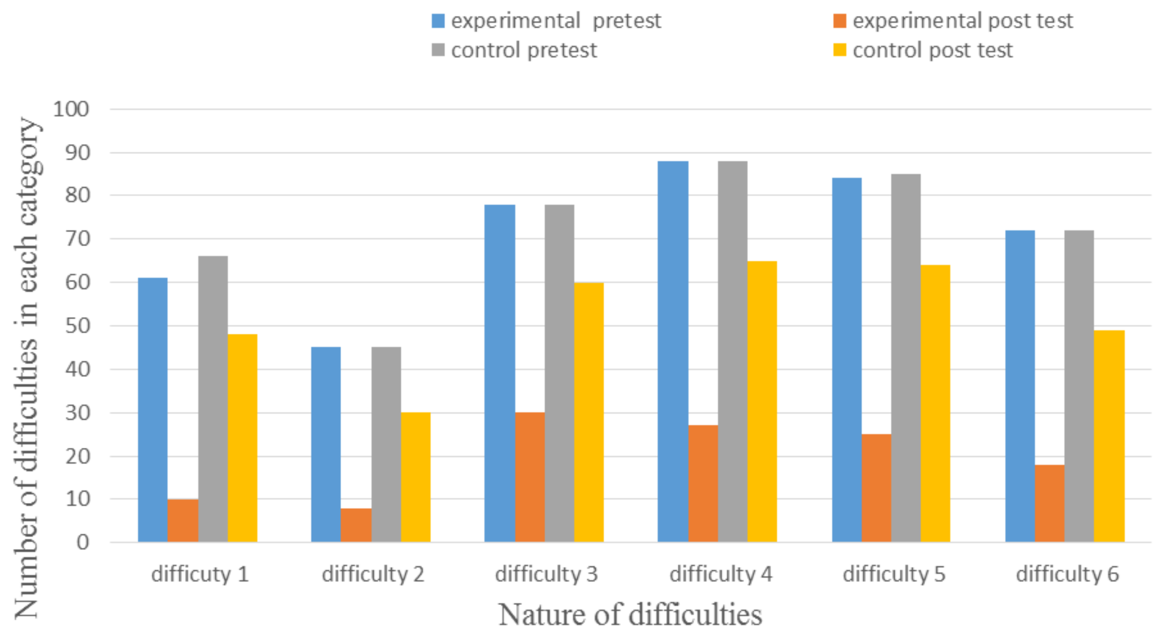


Figure 5. Students’ difficulties in stoichiometry at pre-test and post-test stages

Figure 5 shows that the use of problem-solving instruction is more effective in remedying the difficulties students have in stoichiometry problem-solving than the conventional lecture method. Results show that problem-solving instruction generally manage to improve the problem-solving abilities of students as seen in the reduction of the number of student encountering the various difficulties at the post test stage. For instance, Figure 1 shows that problem-solving instruction reduced difficulty 1 from 61% at the pre-stage to 10% at the post-stage giving an effective rate of 83% in comparison to 27% in the conventional (control) conditions.

Analysis of Group Difference on the pre-test and post-test

The quantitative data from the stoichiometry test were analysed by applying independent samples t-test as shown in Tables 3 and 4

Table 3: Comparison of experimental and control groups on the pre-test scores

Instructional Model	Groups	N	M	SD	t	df	p
Ashmore, Casey, Fraser	Experimental	117	40.25	3.98	0.10	238	.876
	Control	123	40.20	3.65			
Selvaratnam-Fraser	Experimental	118	38.72	4.46	0.67	243	.605
	Control	127	38.34	4.43			

Table 3 above, indicates that there was no statistically significant difference between experimental and control group on the stoichiometry pre-test (df = 238, t = 0.10, $p > 0.05$). The results show that both the experimental and control groups performed nearly the same on the stoichiometry pre-test. This enables one to infer the effect of the intervention after the post-test.

To compare the effect of problem-solving instruction and the conventional lecture method an independent samples t-test was conducted. The data are shown in table 4 below.

Table 4: Comparison of experimental and control groups on the post-test scores

Instructional Model	**Groups**	**N**	**M**	**SD**	**t**	**df**	**p**
Ashmore, Casey, Fraser	Experimental	117	56.72	1.16	102	238	.001
	Control	123	41.62	1.13			
Selvaratnam-Fraser	Experimental	118	55.69	0.99	156	243	.001
	Control	127	39.58	1.07			

The mean difference between the experimental and control classes after the intervention was significant *(t=102, p=.001) and (t=156, p=.001)* respectively. Thus, the results confirmed that there was a statistically significant difference in the post-test achievement scores between students exposed to the problem-solving instruction and those exposed to the conventional lecture method.

The main effect of Selvaratnam-Frazer and Ashmore, Casey and Fraser problem-solving instructional strategies on the performance of students in solving stoichiometry problems was statistically tested through ANCOVA analysis. The following null hypotheses (**Ho**) was tested at 0.05 levels of significance.

Null hypothesis: Ho: There is no significant difference between experimental and control groups in problem solving performance of students.

The result in Table 5 show that the problem-solving instruction is a significantly improves the ability of students to solve stoichiometry problems. The probability level of 0.05 is greater than 0.000 ($P > 0.05$) as seen in table 5. Thus the hypothesis H_0 of no significant difference is rejected. This implied that there was a significant difference in the mean scores of subjects exposed to the two problem-solving models and those not exposed.

Table 5: ANCOVA analysis of between-subjects effects

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Pretest	4.306	1	4.306	3.470	.088
Group	31139.872	2	15610124	12695.587	.000

4. Discussion

The finding of the study revealed that the types of difficulties encountered by chemistry students as they solve stoichiometric problems are lack of understanding of the mole concept, inability to balance chemical equations, use of inconsistent stoichiometric relationships, identifying the limiting reagent, determination of theoretical yields and identification of substances in excess. The findings are consistent with (Sheehan & Childs, 2009; Moss & Pabari 2010; Furio et al., 2002) who note that the mole concept as an important topic of which failure to understand the concept results in difficulties in understanding stoichiometry problems.

The findings are also in accord with Sanger (2005) and Nyachwaya et al. (2014) who have revealed that if students have difficulties in balancing chemical equations they will not be able to understand and solve stoichiometry problems properly. Furthermore, the findings show that learners have problems with the concept of the limiting reagent a misconception which hampers their success in stoichiometry problem-solving. This confirms earlier findings by Chandrasegaran, et al., (2009) aswell as Sostarecz & Sostarecz (2012) if students cannot identify the limiting reactant then they will have difficulties in determining theoretical as well as actual yields.

The results of the study further demonstrate the superiority of problem-solving instruction to the conventional lecturer method in successfully fostering their problem- solving performance of learners which is consistent with earlier studies in physical science, chemistry and biology problem solving learning respectively (Cheng et al., 2017 ;She et al., 2012; Yu et al., 2010).

5. Conclusion

The study has gathered evidence supporting the view that the recurrent difficulties encountered by high school chemistry students in solving stoichiometric problems results from lack of conceptual understanding of the basic stoichiometric concepts such as the mole concept, balancing chemical equations, deducing the limiting reagent. Consequently, chemistry educators should ensure that their students understand these concepts before the can solve quantitative numerical problems. Secondly, problem-solving instruction is more effective and superior to conventional lecture method in remedying student difficulties relating to stoichiometry problem-solving.

6. Recommendations

Chemistry educators should analyse and understand student difficulties if they are to assist the learner to become confident and efficient problem solvers.

Chemistry educators should implement the problem-solving pedagogical technique as a means of addressing the difficulties students have in stoichiometry problem-solving.

Chemistry book writers and publishers should present content in a simple, logical and coherent manner so as to minimise the occurrence of student difficulties in stoichiometry.

References

[1] Adesoji, F.A., Omilani, N.A. & Dada, S.O. (2017). A Comparison of Perceived and

Actual; Students' Learning Difficulties in Physical Chemistry, *International Journal of Brain and Cognitive Sciences*. 6(1), 1-8.

[2] BouJaoude, S. & Barakat, H. (2000). Secondary school students' difficulties with stoichiometry. *School Science Review*, 81, 91-98.

[3] Chandrasegaran, A. L., Treagust, D. F., Waldrip, B. G. & Chandrasegaran, A. (2009). Students' dilemmas in reaction Stoichiometry problem-solving: deducing the limiting reagent in chemical reactions. *Chemistry Education Research and Practice*, 10, 14-23.

[4] Cheng, Shu-Chuan,. She, Hsiao-Ching. & Huang , Li-Yu. (2017). The Impact of Problem-Solving Instruction on Middle School Students' Physical Science Learning: Interplays of Knowledge, Reasoning, and Problem Solving. *Eurasia Journal of Mathematics, Science and Technology Education*. 14(3), 731–743

[5] Cracolice, M. S., Deming, J. C., & Ehlell, B. (2008). Concept learning versus problem-solving: A cognitive difference. *Journal of Chemical Education*, 85(6), 873-878.

[6] Dahsah, C. & Coll, R. K. (2007). Thai grade 10 and 11 students' conceptual understanding and problem-solving ability in stoichiometry. *Research in Science and Technology Education*, 25, 227-241.

[7] Dahsah, C. & Coll, R. K. (2008). Thai grade 10 and 11 students' understanding of stoichiometry and related concepts. *International Journal of Science and Mathematics Education*, 6, 573 -600.

[8] Fach M., de Boer T. and Parchmann I., (2007), Results of an interview study as basis for the development of stepped supporting tools for stoichiometric problems, *Chemistry Education Research and Practice*, **8**, 13-31.

[9] Fatade, A.O., Mogari,D.& Arigbabu,A.A.(2013). Effect Of Problem-Based Learning On Senior Secondary School Students' Achievements In Further Mathematics. *Acta Didactica Naponcensia*, 6(3), 27 – 44.

[10] Furio, C., Azcona, R. & Guisasola, J. (2002). The learning and teaching of the concepts ‘‘amount of substance’’ and ‘‘mole’’: A review of the literature. *Chemistry Education Research and Practice*, 3, 277 - 292.

[11] Gauchon, L., & Méheut, M. (2007) Learning about stoichiometry: from students‟ preconceptions to the concept of limiting reactant. *Chemical Education Research and Practice*, 8, 362-375.

[12] Gegios, T., Salta, K & Koinis, S. (2017). Investigating high-school chemical kinetics: the Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice***.** 2017, **18**, 151-168

[13] Kimberlin, S. & Yezierski, E. (2016). Effectiveness of Inquiry-Based Lessons Using Particulate Level Models to Develop High School Students' Understanding of Conceptual Stoichiometry. *Journal of Chemical Education.* 93, 1002−1009

[14] Moss, K. & Pabari, A. (2010). The mole misunderstood. *New Directions*. 6, 77-86

[15] Mulford, D.; Robinson, W. An inventory for alternate conceptions among first-semester general chemistry students. *Journal of Chemical Education.* 79 (6), 739−744.

[16] Nyachwaya, J.M., Warfa, A.M., Roehrig, G.H. & Schneiderd, J.L. (2014). College chemistry students' use of memorized algorithms in chemical reactions. *Chemistry Education Research and Practice*, 15, 81—93.

[17] Ogunleye, A.O. (2009). Teachers' and Students' Perceptions of Students' Problem-Solving Difficulties In Physics: Implications For Remediation. *Journal of College Teaching & Learning*. 6(7), 85-90

[18] Sanger, M. (2005). Evaluating Students' Conceptual Understanding of Balanced Equations and Stoichiometric Ratios Using a Particulate Drawing. *Journal of Chemical Education*. 82 (1), 131−134.

[19] She, H. C., Cheng, M. T., Li, T. W., Wang, C. Y., Chiu, H. T., Lee, P. Z., ... & Chuang, M. H. (2012). Web-based undergraduate chemistry problem-solving: The interplay of task performance, domain knowledge and websearching strategies. *Computers & Education*, 59(2), 750-761.

[20] Sostarecz, M.C. & Sostarecz, A.G. (2012). A Conceptual Approach to Limiting-Reagent Problems. *Journal of Chemical Education* 89 (9), pp 1148–1151

[21] Yu, W. F., She, H. C., & Lee, Y. M. (2010). The effects of Web-based/non-Web-based problem-solving instruction and high/low achievement on students' problem-solving ability and biology achievement. *Innovations in Education and Teaching International*, 47(2), 187-199.

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