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Senior High School Students' Understanding and Difficulties with Chemical Equations

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Abstract

Over the years, chemistry reports of the West African Examination Council Chief Examiners have consistently alluded to students' inability to write correct chemical equations in the Senior Secondary School Certificate Examinations. This study probes these difficulties. This study employs a cross-sectional survey using both quantitative and qualitative methods. The sample used for the study consisted of 334 SSS 3 elective science students in the 2008/2009 academic year drawn from all schools offering elective science in the New Juaben Municipality of the Eastern Region of Ghana. The instruments used for data collection were achievement tests and interviews. Some of the key findings of this study include: (a) students' inability to balance equations of combustion reactions involving hydrocarbons; (b) students' inability to predict correct products of reactions due to difficulty in writing the correct formulae of the products predicted; and (c) students' inability to translate reactions in statement form into symbol equations. This study recommends that secondary school teachers provide more exercises related to these difficulties to students and that they make time for students to explain or discuss their answers.

Keywords: Senior High School Students, Chemical Equation Understanding, Chemical Equation Difficulties

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INTRODUCTION

One of the most important ways in which chemists can communicate information about a reaction is through the writing of chemical equations. These equations enable chemists from different countries to simply and without error communicate with one another.

Chemical equations can be defined as symbolic and quantitative representations of the changes that occur in the process of chemical reactions, based on the principle that matter is neither created nor destroyed during chemical reactions. For example the chemical equation ${}_xA + {}_yB \rightarrow {}_pC + {}_qD$ shows that A and B are the reactants while C and D are the products. The subscripts x, y, p and q are the stoichiometric coefficients which represent the relative amount of substance of the reactants and products. The single-headed arrow indicates the direction of the reaction and shows that the reaction is an irreversible one. The arrow means “gives”, “yields” or “forms” and the plus (+) sign means “and”.

However, studies have shown that the ability to write chemical equations correctly is not a simple one (Gower, 1977; Suderji, 1983; Savoy, 1988). It is one that requires a functional understanding of the requisite subordinate concepts of atoms and atomicity, molecules and molecular formula, atomic structure and bonding, valency, use of brackets, radicals, subscripts and coefficient and molar ratio (Savoy, 1988).

Studies conducted by Savoy (1988) and Hines (1990) have reported that chemistry students often have great difficulties in both acquiring and using the skills required to balance chemical equations. A similar study conducted by Johnstone, Morrison and Sharp (1976) in Scotland revealed that students in senior high schools are rarely confident about writing chemical equations and then carrying out calculations based on them. A study by Anamuah-Mensah and Apafo (1986) likewise revealed that students in Ghanaian senior high schools have difficulties in learning certain chemical concepts, including chemical combination. Approximately two-thirds of the students who took part in the study indicated that the topic chemical combination was either difficult to grasp or never grasped. Findings from research conducted by Lazonby, Morris, and Waddington (1982), Schmidt (1984) and Bello, (1988) have shown that students’ persistent difficulties in solving stoichiometric problems are partly associated with their inability to represent chemical equations correctly.

Chief Examiners’ (CE) reports available through the West African Examinations Council (WAEC) confirm that senior high school students experience difficulty when writing chemical equations. The 1994 CE report showed that most candidates were unable to write balanced chemical equations for the Senior Secondary School Certificate Examination (SSSCE) chemistry paper. The 1995 CE report followed suit and reiterated that many candidates demonstrated problems when writing chemical equations. In 1999, the CE report indicated that students were unable to write equations for reactions between Bronsted Lowry bases and concentrated HCl. In 2001, the CE reported that the writing of ionic equations was poorly handled by candidates. The 2004 chemistry theory paper required candidates to write a balanced chemical equation for the production of oxygen when $KClO_3$ is heated and then calculate the volume of the dry oxygen gas evolved. The examiners’ CE report for the above question noted that candidates had problems writing the equation correctly and hence could not get the correct mole ratio.

Based on the above, it is clear that over the years, students have experienced serious problems when writing chemical equations even though this is a basic requirement in chemistry. Without the proper writing of the chemical equation, students cannot subsequently solve or analyze equations. This study thus investigates how students write chemical equations given that this skill is central to the development of further chemistry knowledge and skills. This study was guided by the question: what difficulties do SSS 3 students have when writing chemical equations?

METHODOLOGY

This study investigates how students understand the writing of chemical equations and their difficulties encountered when writing such equations. A cross-sectional survey was used to accomplish this. The study involved two stages so as to incorporate mixed methods - quantitative and qualitative - to collect data. In the first stage, an achievement test focused on writing chemical equations was administered to SSS 3 elective science students drawn from seven senior high schools in the New Juaben Municipality of the Eastern Region of Ghana. The second stage involved group interviews with students who answered items on the test incorrectly. The interview was conducted to gain a better understanding of the reasons for their errors.

Population

The target population for this study was all SSS 3 elective science students in the 2008/2009 academic year in the New Juaben Municipality of the Eastern Region of Ghana. These students had studied chemistry for almost three years and thus were able to make a meaningful contribution to the study.

Sample

The sample consisted of 334 SSS 3 elective science students. The sample was drawn from all the schools in the population. The schools were labeled with letters and the breakdown of students who participated in the study by school are: A: 70 (58.3%), B: 30 (88.2%), C: 80 (58.9%), D: 55, (51.0%), E: 42 (97.7%), F: 35 (100.0%), G: 22 (56.4%) The mean age of the students was 17 years with a standard deviation of 1.8 years.

Instruments and Data Collection Procedure

The main instruments used in this study for data collection were an achievement test and an interview. The test was comprised of three parts. In Part I, students were given six complete but unbalanced equations of different reactions and were expected to balance each equation. Each equation that was balanced correctly carried 1 mark. The purpose of this section was to identify the difficulties students have when balancing chemical equations. In Part II, students were given five incomplete equations for different reactions and were asked to complete each equation by predicting the correct products and then balance the equations after making their predictions. The correct prediction of products and correct balancing of each equation carried 2 marks. The purpose of this section was to identify the difficulties students have predicting the products of reactions. Finally, in Part III, students were given four complete reactions in statement form and were expected to translate each reaction into an equation in symbols and then balance the equation. Each correct and balanced equation carried 2 marks. The purpose was to identify student difficulties translating reactions from statement form to equations in symbols.

In order to test this instrument, the items were developed by the researcher and administered to SSS 3 elective science students at the University Practice Senior High School, Cape Coast, a school not included in the main study. Student responses gathered from this first test were used to guide the construction of the final achievement test. The achievement test was then shared with chemistry lecturers in the Department of Science and Mathematics Education and their suggestions and input on the validity of the instrument were collected. Finally, the instrument was pilot-tested with a sample of 54 elective science students from Ofori Panyin Senior High School in Tafo in the Eastern Region of Ghana. The Statistical Package for Social Sciences (SPSS) was used to determine the Cronbach alpha coefficient of reliability for the items in the pilot-test. An alpha value of 0.92 was obtained for the items in the chemical equations test. The difficulty and discrimination index for each item was determined and items found to be too difficult or too easy were deleted.

The test was administered to the students in their various schools and the answered scripts were collected immediately after the test. The test lasted for two hours and it took five days for all schools to take the test. After the scripts were marked, the names of students who encountered difficulty in the tests were recorded. The researcher then returned to the individual schools and used the group interview schedule to interview those students. The interview was unstructured and the purpose was to determine why students answered questions incorrectly.

Percentages were used to explain students' performance on the test. Qualitative data gathered during the interview was transcribed and used as an explanation of the answers provided by students on the test.

RESULTS AND DISCUSSION

In Part I of the test, students were given six complete but unbalanced equations of reactions and tasked with balancing each equation. The six equations given to the students were:

a. $N_2 + H_2 \longrightarrow NH_3$

b. $Al(OH)_3 \longrightarrow Al_2O_3 + H_2O$

c. $Mg + HCl \longrightarrow MgCl_2 + H_2$

d. $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$

e. $CaO + NH_4Cl \longrightarrow CaCl_2 + NH_3 + H_2O$

f. $Pb(NO_3)_2 + KI \longrightarrow PbI_2 + KNO_3$

The correct balancing of an equation carried 1 mark and so the maximum mark for part 1 was 6 marks. The performance of the schools is shown in Table 1. Generally, students' ability to balance the given chemical equations was good. The performance of students on equation (d) was, however, quite poor – less than one quarter of the students balanced this equation correctly. Of the 334 students who participated in the study, only 21.3% were able to balance equation (d) correctly. The expected answer was

$$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$$

The reasons given by students for their wrong answers are presented in Table 2.

Table 1: Performance by school when balancing chemical equations in Part I

Schools	N	Qa	Qb	Qc	Qd	Qe	Qf
A	70	60 (18.0%)	40 (12.0%)	60 (18.0%)	14 (4.2%)	40 (12.0%)	53 (15.9%)
B	30	30 (9.0%)	29 (8.7%)	29 (8.7%)	10 (3.0%)	26 (7.8%)	29 (8.7%)
C	80	77 (23.1%)	69 (20.7%)	77 (23.1%)	29 (8.7%)	64 (19.2%)	73 (21.9%)
D	55	54 (16.2%)	46 (13.8%)	53 (15.9%)	8 (2.4%)	46 (13.8%)	52 (15.6%)
E	42	25 (7.5%)	14 (4.2%)	28 (8.4%)	2 (0.6%)	16 (4.8%)	18 (5.4%)
F	35	32 (9.6%)	25 (7.5%)	34 (10.2%)	5 (1.5%)	23 (6.9%)	29 (8.7%)
G	22	19 (5.7%)	14 (4.2%)	25 (7.5%)	3 (0.9%)	14 (4.2%)	18 (5.4%)
Overall	334	297 (88.9%)	237 (71.0%)	300 (89.8%)	71 (21.3%)	229 (68.6%)	272 (81.4%)

Table 2: Students' reasons for balancing equation (d) incorrectly (N = 264)

Number and Percentage of Students	Reasons for Inability
106 (40.2%)	They tried their best but still the equation was a difficult one to balance
120 (45.5%)	The appearance of odd and even numbers in the process of balancing the equation was confusing
38 (14.4%)	In balancing the equation, we did not know whether to write the numbers in front or behind the compounds

In Part II, students were given five incomplete equations of reactions and were expected to complete each equation by predicting the products in symbols. The incomplete equations were:

a. $CO_2 + CaO \longrightarrow$

b. $C_4H_{10} + O_2 \longrightarrow$

c. $Ca(OH)_2 + H_3PO_4 \longrightarrow$

d. $CaCO_3 + heat \longrightarrow$

e $AgNO_3 + NaCl \longrightarrow$

The expected balanced equations were:

a. $CO_2 + CaO \longrightarrow CaCO_3$

b. $2C_4H_{10} + 13O_2 \longrightarrow 8CO_2 + 10H_2O$

c. $3Ca(OH)_2 + 2H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6H_2O$

d. $CaCO_3 + heat \longrightarrow CaO + CO_2$

e $AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$

The performance of the schools on this question is shown in Table 3. Of the five questions, performance on three questions (a, d, and e) was satisfactory, but performance on (b) and (c) was poor. Less than half of the students from any of the schools predicted the products of reactions (b) and (c) correctly. Students' responses and reasons for this poor performance are presented in Tables 4 and 5 respectively.

The main difficulty for students who could not predict the products of reaction (b) was their lack of knowledge of the fact that when a hydrocarbon is burnt in oxygen, it yields carbon (IV) oxide and water. For reaction (c), the main difficulty was the inability to write the correct formula for calcium tetraoxophosphate (V).

For Part III, students were given four complete reactions in statement form and were expected to translate each statement reaction into an equation in the form of symbols and then balance the entire equation. The statement reactions were:

a. Barium chloride reacts with potassium tetraoxosulphate (VI) to form barium tetraoxosulphate (VI) and potassium chloride
b. Potassium hydroxide reacts with tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water
c. Decomposition of potassium trioxochlorate (V) on application of heat to form potassium chloride and oxygen
d. Combustion of propane to form carbon (IV) oxide and water

Table 3: Performance by school when predicting products of reactions in Part II

Schools	N	Qa	Qb	Qc	Qd	Qe
A	70	43 (12.9%)	8 (2.4%)	5 (1.5%)	36 (10.8%)	34 (10.2%)
B	30	27 (8.1%)	2 (0.6%)	2 (0.6%)	19 (5.7%)	17 (5.1%)
C	80	63 (18.9%)	27 (8.1%)	30 (9.0%)	50 (15.0%)	60 (18.0%)
D	55	52 (15.6%)	3 (0.9%)	15 (4.5%)	45 (13.5%)	46 (13.8%)

E	42	15 (4.5%)	0 (0%)	1 (0.3%)	13 (3.9%)	9 (2.7%)
F	35	30 (9.0%)	1 (0.3%)	3 (0.9%)	21 (6.3%)	20 (6.0%)
G	22	17 (5.1%)	1 (0.3%)	1 (0.3%)	13 (3.9%)	13 (3.9%)
Overall	334	247 (74%)	42 (12.6%)	57 (17.1%)	197 (59.0%)	199 (59.6%)

Table 4: Students reasons for predicting the products of reaction (b) incorrectly (N = 292)

Products Provided by Students	**Reasons for Providing Such Products**	**Number and Percentage of Students**
$C_4H_{10}O_2$	Because C_4H_{10} reacted with O_2	72 (24.7%)
$2C_2H_5 + O_2$	Because C_4H_{10} on burning, will split into 2 moles of C_2H_5 with O_2 released	82 (28.1%)
$C_4 + H_2O$	Because carbon and water will be the products	48 (16.4%)
$CO_2 + H_2$	Because carbon (IV) oxide and hydrogen gas will be the products	56 (19.2%)
No response	Because of lack of knowledge about combustion reactions involving hydrocarbons	34 (11.6%)

Table 5: Students reasons for predicting the products of reaction (c) incorrectly (N = 277)

Products Provided by Students	**Reasons for Providing Such Products**	**Number and Percentage of Students**
$CaPO_4 + H_2O$	Because salt $CaPO_4$ and water H_2O will be the products	92 (33.2%)
$CaPO_4 + H_2O + H_2$	Because salt $CaPO_4$, water H_2O and hydrogen gas will be the products	73 (26.4%)
$(CaPO_4)_2 + H_2O$	Because salt $(CaPO_4)_2$ and water H_2O will be the products	70 (25.3%)
No response	Because writing the formula of the salt Calcium tetraoxophosphate (V) was a problem.	42(15.1%)

The general performance of the students when translating statement reactions into chemical equations in symbols was poor. For reaction (a) the main difficulties identified were: students' inability to write the correct symbol for Barium and their inability to write the correct chemical formulae for the compounds Barium chloride, Potassium tetraoxosulphate (VI) and Barium tetraoxosulphate (VI). The main difficulty identified in reaction (b) was students' lack of knowledge about the correct formula for tetraoxophosphate (V) acid, which made it difficult for them to write the correct chemical formula for Potassium tetraoxophosphate (V). The difficulties in reactions (c) and (d) included students' inability to write the correct formula for Potassium trioxochlorate (V) and their inability to write the correct formula for Propane.

The following were the expected answers

(a) $BaCl_2 + K_2SO_4 \longrightarrow BaSO_4 + 2KCl$

(b) $3KOH + H_3PO_4 \longrightarrow K_3PO_4 + 3H_2O$

(c) $KClO_3 + \text{heat} \xrightarrow{\text{heat}} KCl + 3/2O_2$

OR

$2KClO_3 + \text{heat} \xrightarrow{\text{heat}} 2KCl + 3O_2$

(d) $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

The performance of the schools is shown in Table 6

Table 6: Performance by school when translating statement reactions into chemical equations in symbols in Part III

Schools	N	Qa	Qb	Qc	Qd
A	70	11 (3.3%)	8 (2.4%)	17 (5.1%)	19 (5.7%)
B	30	8 (2.4%)	2 (0.6%)	10 (3.0%)	12 (3.6%)
C	80	33 (9.9%)	24 (7.2%)	45 (13.5%)	48 (14.4%)
D	55	30 (9.0%)	20 (6.0%)	30 (9.0%)	40 (12.0%)
E	42	4 (1.2%)	0 (0%)	1 (0.3%)	0 (0%)
F	35	7 (2.1%)	3 (0.9%)	13 (3.9%)	17 (5.1%)
G	22	9 (2.7%)	4 (1.2%)	5 (1.5%)	5 (1.5%)
Overall	334	102 (30.5%)	61 (18.3%)	121 (36.2%)	141 (42.2%)

As displayed in Table 6, 232 (69.5%) students could not translate statement reaction (a) into an equation in symbols because writing the correct formulae for Barium chloride, Potassium tetraoxosulphate (VI) and Barium tetraoxosulphate (VI) presented a major problem. Again as shown in Table 6, 273 students could not translate statement reaction (b) into an equation in symbols because writing the correct formulae for tetraoxophosphate (V) acid and Potassium tetraoxophosphate (V) was too challenging. Translating statement reaction (c) into an equation in symbols was also a problem as 63.8% of students could not perform the task because they were unable to write the correct formula for Potassium trioxochlorate (V). Lastly, 57.8% of students could not translate the statement reaction (d) because they were unable to write the correct formula for Propane.

CONCLUSIONS

This study found that following problems among senior high school form 3 elective science students when writing chemical equations:

- Difficulty balancing equations of combustion reactions involving hydrocarbons. This was due to students' superficial knowledge of combustion especially with hydrocarbons.
- Difficulty predicting the correct products of reactions because of the difficulties writing the correct formulae for the products predicted.
- Translating whole reactions in statement form into equations in symbols. This posed the biggest challenge for students given their difficulty with writing the correct formulae of the compounds or species involved in a reaction. For instance students had problems writing the correct formula for compounds like Barium chloride, Potassium tetraoxosulphate (VI) and Barium tetraoxosulphate (VI). The correct formulae for species like Barium ion, tetraoxosulphate (VI) ion, trioxochlorate (V) ion and tetraoxosulphate (VI) ion were also problematic.

Implication for Teaching and Learning

Chemistry teachers should pay particular attention to helping students learn how to write equations for combustion reactions, especially those involving hydrocarbons (with $H > 5$). Chemistry teachers should give students more exercises focused on how to write chemical formulae. They should also make room for students to explain and discuss their answers so as to ascertain their understanding and any potential difficulties.

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