# SENIOR HIGH SCHOOL CHEMISTRY STUDENTS' CONCEPTUAL UNDERSTANDING OF BALANCING SIMPLE CHEMICAL EQUATIONS

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***Abstract: Most senior high school (SHS) students have learning difficulties in balancing simple chemical equations (BSCE) as a concept. This study was designed to explore the kinds of conceptual understanding of SHS chemistry students towards the concept under study with the intent of identifying and isolating their possible misconceptions. Eighty-five (85) first year chemistry students of 2 intact classes from a SHS in the Cape-Coast Metropolis in the Central Region of Ghana were purposively selected and used as a sample size for the study. An adapted interview schedule from Haider (1995) was used in the form of survey to explore the kinds of the conceptions these students had on BSCE. Types of students' conceptual understanding of the concept were evaluated with a scheme originally developed by Piaget. The descriptive statistics (frequency and percentage) of the students who had various kinds of misconceptions were calculated. The findings from the study revealed that the students' conceptual understanding of BSCE concept spanned from sound understanding to no understanding. Eleven (11) common patterns of misconceptions were identified among the students. It was recommended that chemistry teachers should use innovative strategies to probe students' conceptual understanding that are often in conflict with the accepted scientific explanations on various scientific concepts and adopt effective interventions to deal with such conceptions.***

***Keywords:- Conceptual, misconceptions, alternative, sound understanding, partial understanding.***

## I. INTRODUCTION

Studies by (Johnstone, 1993; Khoo & Koh, 1998) have shown that many senior high school (SHS) students have learning difficulties in understanding basic concepts in chemistry. Studies done in chemical education by (Staver, 1989; Herron, 1990; Abraham, 1990) have assigned various reasons for such learning difficulties among students at all levels of education. One reason that has been incriminated as the major cause of students' learning difficulties was the misconceptions (alternate conceptions) held on by the students.

Abraham (1990) and Herron (1990) stated that the major impediment to successful chemical problem solving was the learners' misconceptions. Studies by (Yarroch, 1985; Glynn, Yeany & Britton, 1991; Eminah & Assafuah-Drokow, 2010) on students' misconceptions have reported that these misconceptions are always in conflicts with the accepted scientific views and the presence of such misconceptions make it difficult for students to grasps the needed scientific concepts. Wandersee, Mintzes and Novak (1994) also reported that misconceptions developed by the students are mainly based on their intuitions from their persistent interactions with their environment which are often in conflict with the accepted scientific explanations. Zoller (1990) also pointed out that these misconceptions provide sensible and coherent understanding of the physical world of the learners' point of view and such misconceptions are found to be firm rooted and resist change by normal classroom teaching.

Currently, a lot of research interest had been generated among chemical educators to probe into students' conceptual understanding on various chemical concepts and identify the conceptions held by these students. Studies by (Yarroch, 1985; Glynn, Yeany & Britton, 1991; Apafo, 1992; Eminah & Assafuah-Drokow, 2010) on probing students' conceptual understanding of chemical concepts, have revealed that learners of all ages and at different education levels hold misconceptions about a wide range of chemical concepts prior to their formal studying of science in schools. For example, in a study on electrochemistry problem-solving approach, Eminah and Assafuah-Drokow (2010; p 61) recommended that "the research subjects held several ideas about Faraday's law of electrolysis (FLE) and related electrochemistry topics that conflict with the accepted scientific views".

Glynn, Yeany and Britton (1991) indicated that it not unusual for students to begin the school year with a lot of misconceptions, sit in class, pass with good grades and end up carrying the same misconceptions. This statement implies that students often come to school with varied misconceptions that need to be identified and help erase such misconceptions from their minds else these students would carry such misconceptions throughout their life time.

The study of balancing of chemical equations is an aspect of the broad topic "stoichiometry and chemical reaction" which has been part of both elective chemistry and integrated science syllabuses in Ghanaian SHS for several years. Several pioneer studies (Yarroch, 1985; Ben-Zvi, Eylon & Silberstein, 1988; Missen & Smith, 1989; Staver, 1989; Anamuah-Mensah & Apafo, 1986; Apafo, 1992) have reported that most students had a wide range of conceptual understanding towards balancing simple chemical equation (BSCE) concept and also held several misconceptions about it that has resulted in learning difficulties among the students across the globe.

In a study, Yarroch (1985) concluded that majority of the students had misconceptions in writing correct chemical equations. On their parts, Ben-Zvi, Eylon and Silberstein (1988) also reported that most students had difficulties in learning balancing of chemical equations because their conceptual understanding was constrained by the surface features of representations. In a similar study, Missen and Smith (1989) opined that students have several conceptions in finding the proper stoichiometric coefficients for a given chemical equations. In another study, Staver (1989) found that students commonly harbour misconceptions on BSCE concept and these hinder their stoichiometry problem solving approaches.

From the above analyses, it presupposes that students' learning difficulties on BSCE concept coupled with its associated misconceptions is universal. Campanario and Ballesteros (1991) indicated that balancing chemical equations is one of the tasks a chemist encounters in both practicals and theory. Their study further stated that to 'balance' a chemical equation is one of the most familiar "initiation ceremonies" of any future chemist. This means that for a student to become a good chemist, he/she have to get a firm grasp of this concept.

Since understanding of BSCE concept is one of the most familiar "initiation ceremonies" of any future chemist, it is imperative to probe SHS chemistry students' conceptual understanding on BSCE concept. It is in the light of this, that this study was undertaken to help explore the kinds of conceptions Ghanaian SHS chemistry students have on the BSCE concept with the intent of identifying and isolating their possible misconceptions.

**Statement of the Problem**

Studies conducted by (Anamuah-Mensah & Apafo, 1986; Apafo, 1992) have shown that Ghanaian SHS students have learning difficulties with regards to BSCE concept and also held a lot of misconceptions about the concept. The WAEC Chief Examiner's reports over the years (2009 - 2015) have revealed that SHS students perform poor when it comes to balancing various chemical equations such as simple chemical equations; redox half reactions; organic reactions and among others.

In many countries several attempts have been made to probe into this concept to explore the kinds of conceptions students have on BSCE concept. However, in Ghana, only a few studies have been conducted in this regard. Therefore, this study was undertaken to assess the kinds of conceptions Ghanaian SHS chemistry students have on the BSCE concept that are in conflicts with the accepted scientific views and explanations with regards to this concept.

**Purpose of the Study**

The main purpose of the study is to explore the kinds of conceptions Ghanaian SHS chemistry students have on the BSCE concept with the intent of identifying and isolating their possible misconceptions. Specifically, the research intends to:

1. Examine SHS chemistry students' kinds of conceptions on BSCE concept.
2. Identify SHS chemistry students' common patterns of misconceptions on BSCE concept?

**Research Questions**

The following two (2) investigative questions directed research activity in the study:

1. What kinds of conceptions do SHS chemistry students' have on BSCE concept?
2. Are there any common patterns of misconceptions held by SHS chemistry students on BSCE concept?

## II. METHODOLOGY

**Research Design**

The design used in this study was descriptive survey design employing a case-study approach. The descriptive survey design was adopted because it provides flexibility in seeking opinions from wide range of respondents. The case study method was also employed because it provides a holistic and an in-depth understanding of the expected behaviours (in this study, the conceptual understanding) to be exhibited by the SHS chemistry students.

**Sample and Sampling Procedure**

The sample size consisted of 85 first year chemistry students of two (2) intact elective science (science A and science B) classes of a selected SHS in the Cape - Coast Metropolis in the Central Region of Ghana. The science A class consisted of 43 students made up of 26 boys and 17 girls whereas science B class consisted of 42 students made up of 28 boys and 14 girls. This class was purposively selected due to its large size compared with other science classes in the Metropolis. The students in the school were selected for the study because of their willingness to participate in the study. The first year chemistry students were chosen because the students were studying the topic under study at the time of conducting this research.

**Research Instrument**

Students' interview schedule was the main research instrument used to collect data from the respondents. In addition, written documents such as diary notes and audiotapes were made to augment information that was obtained from the main instruments.

**Coding Scheme for Scoring Students' Conceptions from the Interview Schedule**

Types or kinds of students' conceptual understanding of the BSCE concept were evaluated with a scheme that was originally guided by the work of Piaget. While studying pupils' understanding of the conservation concepts, Copeland (1984) indicated that Piaget classified pupils' understanding into three categories: no understanding, partial understanding and sound understanding.

To adapt this categorization scheme to the misconceptions research, researchers added more categories. For example, Renner, Brumby and Shepherd (1981) added specific misconceptions. Simpson (1986) also added partial understanding with specific misconceptions. Therefore, in its present form, the coding scheme for scoring consists of five categories:- sound understanding, partial understanding, partial understanding with specific misconception, misconception and no understanding. The degree of conceptual understanding and criteria for scoring the varied conceptions have been presented in Table 1 below:-

**Table 1: Conceptual Understanding Coding Scheme for Students' Interview Schedule**

| Degree of understanding | Criteria for Scoring |
|---|---|
| Sound understanding (SU) | Responses that contain all parts of the scientifically accepted concept. |
| Partial understanding (PU) | Responses that contain a part of the scientifically accepted concept. |
| Partial understanding with a specific misconception(PU/SM) | Responses that show understanding of the concept, but that also contain a misconception. |
| Specific misconception (SM) | Scientifically incorrect responses. |
| No understanding (NU) | Blank, repeats question, irrelevant or unclear response, no explanation given for choice of answer. |

Source (An adapted interview schedule from Haider, 1995)

This scheme was selected and used for this study because it enables the study to look at the data from two angles:- first, subjects' responses can be separated into different levels of understandings; and second, subjects' misconception can be further analyzed into different patterns. This coding scheme has been used globally by other researchers (e.g. Haidar & Abraham, 1991; Westbrook & Marek, 1991) which gave cogent results, attesting to the fact that the scheme is reliable and thus, its usage for this present study.

**Data Collection Procedure**

For an effective data collection, familiarisation visits were made and permission was also sought from the school authorities to carry out the study in the school. Permission was also sought from the subject teachers concerned. Before the actual study, the chemistry teacher introduced the researcher to the students of the two intact chemistry classes. The interview schedule (see Appendix A) was administered to each student at a time in a face-to-face interactive session in their respective classroom. Each student was asked to answer the questions in the interview schedule in my presence giving the researcher opportunity to ask follow up questions where it became necessary. This ensured 100% collection of the schedule. Interview sessions lasted for 3-10 minutes for each respondent.

**Data Analysis Method**

The study employed both quantitative and qualitative methods of data analysis. The quantitative analysis was done to find out each student's conceptual understanding on BSCE of the two (2) given simple chemical equations. This was done using descriptive statistics mainly frequency and percentage. The qualitative analysis was done to find out the common patterns of misconceptions held by the students on the two given simple chemical equations. This was done by critically examine each student's responses provided for each of the two given chemical equations.

## IV. RESULTS AND DISCUSSION

### Analysis of the Results

The analyses of the results were done to answer the 2 research questions posed by the study.

**Research Question 1: What kinds of conceptions do SHS chemistry students' have on BSCE?**

In responding to research question 1, all the 85 SHS chemistry students' answers to the two simple chemical equations in the interview schedule (see Appendix A) were analysed using conception coding scheme shown in Table 1 above.

Balancing the first equation in the interview schedule requires students to note that there are two oxygen atoms on the reactant (left) side and only one atom on the product (right side) side of the equation. In order to balance the oxygen on the reactant side, 2 must be placed in front of the CO on the product side of the equation. This simple operation was achieved by 43 students (50.59%). A total of 17 students (20. 00%) showed partial understanding by failing to reduce co-efficient of the chemical species to the lowest terms. For example, $4C + 2O_2 \rightarrow 4CO$. They placed a 4 in front of C atom and a 2 in front of O atom on the left side whilst a 4 is placed in front of the CO atoms. They failed to realize that the coefficient can be reduced by a factor of 2. In addition, 8 subjects (9.41%) showed partial understanding with specific misconception by changing the subscript ($_2$) of the reactants into its products ($CO_2$). For example, $C + O_2 \rightarrow CO_2$.

A total of 12 subjects (14.12%) showed specific misconception by placing co-efficient in the middle of the formula; changing the subscripts into coefficients and also by putting ½ in front of C atom. They failed to realise that carbon is monatomic element but not diatomic molecule. Finally, 5 subjects (5.88%) showed no understanding of the concept at all by failing to put any coefficient number in the spaces provided. The distribution of all the 85 students conceptual understanding on balancing the first chemical equation are presented in Table 2 below:

**Table 2: Distribution of Students' Conceptual Understanding on Balancing First Equation**

| Students varied conceptions | Frequency | Percentage (%) |
|---|---|---|
| Sound understanding | 43 | 50.59 |
| Partial understanding | 17 | 20.00 |
| Partial understanding with specific misconception | 8 | 9.41 |
| Specific misconception | 12 | 14.12 |
| No understanding | 5 | 5.88 |
| **Total** | **85** | **100** |

Chemical Equation 1 given in the interview schedule: $\_\_ C + \_\_O_2 \rightarrow \_\_CO$

**Correct Balancing for the chemical equation 1:** $\underline{2}\,C + O_2 \rightarrow \underline{2}\,CO$

Source (Students' Interview Schedule, 2018)

On the other hand, the second simple chemical equation was little more complex than the first equation. In balancing the second equation, students were asked to think aloud while balancing the equation and were interrupted when necessary. It was found out that, students were operating two algorithm sub-processes, the second of which is a little longer as described by Yarroch (1985).

In the first sub-process, the students did an initial checking and manipulation of the coefficients of each element in the equation. When students select an element symbol that has not been already balanced, they calculate its number of atoms on each side of the equation. If the number of atoms on both sides is not equal, they operate on the elements using coefficients until they get them equal. Then, they select another element and repeat the process. In the second sub-process, they rechecked any imbalances that might have resulted from the first sub-process. This sub-process was repeated until the equation was completely balanced.

As indicated in Table 3, most students selected the iron first and put 2 in front of its symbol on the product side of the equation. Then, they selected the oxygen, counted its atoms and found them to be 4 on the reactant side and only 2 on the product side of the equation. So, they put 2 in front of $CO_2$ to balance the oxygen. Then, they selected the carbon, counted its atoms and found 2 on the product side of the equation and only 1 on the reactant side of the equation. Therefore, they put 2 in front of CO to balance the carbon atoms.

Eleven (11) students representing 17.86% stopped at this stage; and these students were considered to hold partial understanding of the concept. The distribution of all the 85 students' conceptual understanding on balancing the second chemical equation are presented in Table 3 below:

**Table 3: Distribution of Students' Conceptual Understanding on Balancing Second Equation**

| Students varied conceptual understanding | Frequency | Percentage (%) |
|---|---|---|
| Sound understanding | 7 | 8.24 |
| Partial understanding | 11 | 12.94 |
| Partial understanding with specific misconception | 22 | 25.88 |
| Specific misconception | 29 | 34.12 |
| No understanding | 16 | 18.82 |
| **Total** | **85** | **100** |

Chemical Equation 2 given: --- $Fe_2O_3$ + --- CO → --- Fe + ---$CO_2$

**Correct Balancing for chemical Equation 2**: $Fe_2O_3$ + 3CO → 2Fe + $3CO_2$

Source (Students' Interview Schedule, 2018)

Data in Table 3 above shows that 7 students representing 8.24% continued to the second sub- process and completed balancing the equation successfully. They rechecked the coefficients of each element and found iron and carbon to be balanced, but not the oxygen. Where there were 5 atoms on the reactant side and only 4 on the product side of the equation, they put 3 in front of each $CO_2$ and CO to balance the equation. Finally, they rechecked the rest of the elements and found them to be balanced. A total of 22 students (25.88%) who found that they could not balance the equation in the first sub-process switched and put coefficients in front of Fe on the product side of the equation. They could balance only few elements and were considered to hold partial understanding with specific misconceptions.

A total of 29 subjects (34.12%) had specific misconceptions; about (12 out of 29) students put fractions in front of atoms instead of molecules, whiles the other 17 students changed the subscript of CO in the first equation and put $CO_2$ instead. Finally, 16 students (18. 82%) showed no understanding by failing to place any coefficients in the spaces provided. The results obtained from balancing the two given equations are presented into a bar chart in Figure 1 below:

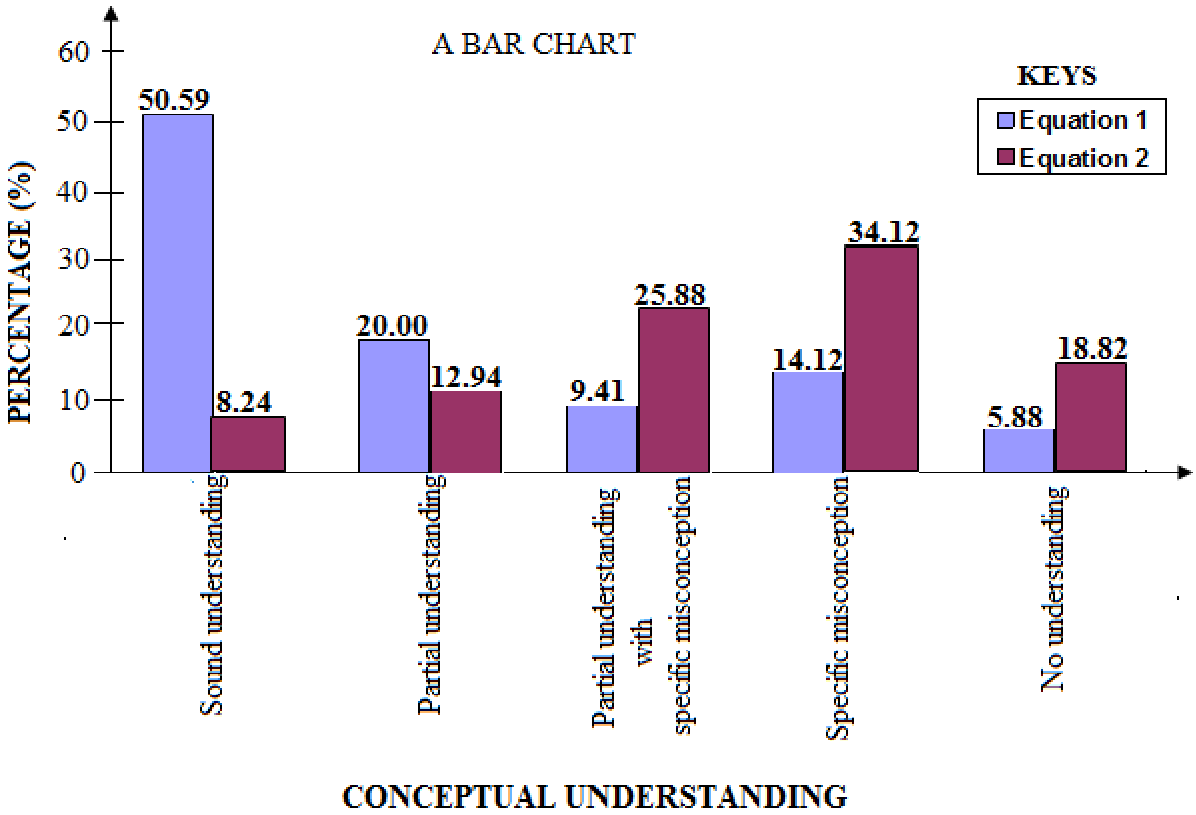


Figure 1: Students' conceptual understanding of balancing first and second chemical equations.

Figure 1 above reveals that there are more kinds of conceptions exhibited by the students in equation 2 than equation 1. This might be due to the complexity nature of equation 2 than equation 1 (see Appendix A).

**Research Question 2: Are there any common patterns of misconceptions held by SHS chemistry students on BSCE?**

To investigate common patterns of misconceptions held by SHS chemistry students on BSCE, the common errors and mistakes made by all the 85 SHS chemistry students on the two given chemical equations in the interview schedule were analysed and are presented in Table 4 below:

**Table 4: Students' Common Patterns of Misconceptions on BSCE**

| No. | Identified Misconceptions of Students on Balancing of Chemical Equations. |
|---|---|
| 1 | Changing the formulae by changing the position of subscripts.<br>Examples:- $C + O_2 \rightarrow (CO)_2$<br>$Fe_2O_3 + CO \rightarrow Fe_2 + CO_4$ |
| 2. | Failing to realize that the balancing of one element in a formula may affect the elements in other formulae in the equation.<br>Examples:- $2C + O_2 \rightarrow 2CO$<br>$Fe_2O_3 + 3CO \rightarrow 2Fe + CO_2$ |
| 3 | Multiplying through reactants and products by a common coefficient.<br>Examples:- $2C + 2O_2 \rightarrow 2CO$<br>$2Fe_2O_3 + 2CO \rightarrow 2Fe + 2CO$ |
| 4. | Changing formulae of compounds or elements by adding and subtracting subscripts.<br>Examples:- $C + O_2 \rightarrow CO_3$<br>$Fe_2O_3 + CO \rightarrow Fe_2 + CO_4$ |
| 5 | Changing formula of products to correspond to that of reactants.<br>Examples:- $C + O_2 \rightarrow CO_2$<br>$Fe_2O_3 + 3CO_2 \rightarrow 2Fe_3 + 3CO_2$ |
| 6 | Failing to reduce coefficients of the chemical species to the lowest terms.<br>Examples:- $4C + 2O_2 \rightarrow 4CO$<br>$2Fe_2O_3 + 6CO \rightarrow 4Fe + 6CO_2$ |
| 7. | Changing some subscripts of the reactants into coefficients of the products.<br>Examples:- $C + O_2 \rightarrow 2CO$<br>$Fe_2O_3 + CO_2 \rightarrow 2Fe + 3CO_2$ |
| 8. | Changing formulae of compounds or elements by adding subscripts.<br>Examples:- $C + O_2 \rightarrow CO_3$<br>$Fe_2O_3 + 3CO \rightarrow 2Fe + 6CO_4$ |
| 9 | Incoherent / inconsistent approaches to balancing of chemical equations.<br>Examples:- $2C + O_2 \rightarrow 2CO_2$<br>$2Fe_2O_3 + 3CO \rightarrow 4Fe + 3CO_2$ |
| 10 | Placing a coefficient in the middle of a formula.<br>Examples:- $2C + O_2 \rightarrow 2C2O$<br>$2\ Fe2O_3 + 3CO \rightarrow 4Fe + 3CO_2$ |
| 11 | Putting fractions in front of atoms instead of molecules.<br>Examples:- $\frac{1}{2} C + O_2 \rightarrow CO$<br>$Fe_2O_3 + 3CO \rightarrow \frac{1}{2} Fe + CO_2$ |

Source (Students' Interview Schedule, 2018)

Data in Table 4 reveals that SHS chemistry students had several misconceptions on BSCE. From Table 4, eleven (11) common patterns of misconceptions were identified in the students' responses to balancing of the two given equations. Some identified common patterns of misconception include putting fractions in front of atoms instead of molecules; changing formulae of compounds by adding and subtracting subscripts; and many others as shown in Table 4 above. The presence of these varied misconceptions indicated that SHS chemistry students have not developed appropriate and better conceptual understanding of the BSCE concept.

**Discussion of the Results**

The results of this study showed that most of the SHS chemistry students who participated in this study possessed several kinds of conceptions about BSCE concept as shown in Tables 2; 3 and Figure 1. The study revealed that students' conceptions ranged from "sound understanding" through "partial understanding" to "no understanding". It was observed that students had a lot of conceptions on equation 2 than equation 1. This might be due to the complex nature of equation 2 which seemed to generally difficult to the students. The equation 2 requires more steps (i.e. three steps) in balancing it as compared to equation 1 which required only two steps. This implies that as the number of steps involve in BSCE increases, the equation also increases in complexity and thus affects the students' conceptual understanding of the entire process resulting in several kinds of conceptions.

Critical analysis and reflections from students' responses to two given chemical equations (as shown in Table 4) revealed eleven (11) common patterns of misconceptions (errors/mistakes) made by the SHS chemistry students. The presence of these myriad misconceptions on the BSCE concept indicated that these students possessed conceptions that were in conflict with the accepted scientific views and explanations on BSCE concept. Thus, an urgent intervention should be put in place to address these misconceptions.

The findings from this study lend credence to the results of pioneer researchers (e.g. Yarroch, 1985; Ben-Zvi, Eylon & Silberstein, 1988; Missen & Smith, 1989; Staver, 1989; Anamuah-Mensah & Apafo, 1986; Apafo, 1992) that most SHS had a wide range of conceptual understanding towards BSCE concept and also had several misconceptions about it that has resulted in learning difficulties among the students across the globe.

**Conclusions**

It can be concluded from this study that SHS chemistry students' who participated in this study had several kinds of conceptual understanding on BSCE concept and their conceptual understanding spanned from sound understanding through partial understanding to no understanding. Again, it can also be concluded that Ghanaian SHS chemistry students who took part in the study had eleven (11) identified common misconceptions on BSCE concept. Finally, it can be concluded that the presence of these varied conceptions and misconceptions among the students indicated that Ghanaian SHS chemistry students did not understand the principle of the conservation of matter which is the major principle that underpinned the BSCE concept.

## Recommendations

Based on the findings and conclusions drawn from this study, it is recommended that:

1. This study should be replicated elsewhere using a much larger sample. This would provide a basis for more generalisation of conclusions to be arrived at about the kinds of the conceptions SHS chemistry students had on the concept of balancing of simple chemical equations.
2. Chemistry teachers are encouraged to use innovative strategies to probe learners' conceptual understanding on various scientific topics that are often in conflict with the accepted scientific explanations and adopt effective intervention to deal with such conceptions.
3. Chemistry teachers are encouraged to examine and identify students' common misconceptions on any chemistry topic to be taught to students. This would enable the teachers to develop effective strategies to help deal with such misconceptions.

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## APPENDIX A

### INTERVIEW SCHEDULE FOR SHS CHEMISTRY STUDENTS ON BSCE

**Instruction:-** Dear Pupil, this exercise is for **research purposes** and all your responses would be treated **confidential**. Please, responses from this interview are intended for **academic** use only. Kindly indicate your honest response to every question. Thank you for your co-operation.

**Items in the Interview Schedule**

1. Please tell me a little bit about yourself with reference to your name and sex.

   **Name:**............................................................................................... **Sex:**.............................................

2. How do you perform in chemistry when it comes to balancing simple chemical equations?.

   ..........................................................................................................................................................

3. Which aspect(s) of balancing chemical equation is difficult for you?.

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   ..........................................................................................................................................................

4. Consider the following two (2) chemical reactions that occur in the blast furnace in extracting iron (Fe) from its ore as shown below. Could you please balance the below equations by putting the correct coefficient numbers in the spaces provided?

   (i). --- C + --- $O_2$ → --- CO

   ..........................................................................................................................................................

   (ii). --- $Fe_2O_3$ + --- CO → --- Fe + --- $CO_2$

   ..........................................................................................................................................................