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Diagnosis of Students' Difficulties in Balancing Chemical Equations in Some Selected Senior Secondary Schools in Ibadan, Nigeria

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ABSTRACT

Researchers are concerned about students' difficulties in balancing chemical equations and are working to correct these inaccuracies. The survey identified difficulties among science students in public senior secondary schools in Ibadan, Nigeria. A descriptive research design was used; 188 respondents from six public senior secondary schools in Ibadan provided data for the study. The Chemical Equation Diagnostic Test was developed and validated utilizing test-retest methodology (r=0.86). The data demonstrates the incapacity of students to identify limiting reagents (96.56%), reactants in a reaction (48.4%), understand moles (76.1%), understand atomicity (79.3%), determine the number of elements present in a compound (22.9%); identify the physical states of elements (54.3%); and calculate the valency of elements (79.3%). According to the outcome, students have several difficulties balancing chemical equations. It is advised that teachers diagnose such difficulties by recognizing the numerous ways students struggle to balance chemical equations. Addressing such difficulties will reduce students' misconceptions about chemistry, improve their conceptual knowledge of chemistry, and increase the number of students who may wish to pursue advanced courses in chemistry and science-related fields.

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1. INTRODUCTION

A chemical equation is the language of chemists in which they summarize chemical reactions; it is an international language for expressing chemical reactions; it is a way of reducing words into chemical equations; it is a means of communication among chemists. A chemical equation shows the coefficients of the atoms, which is the number of moles of the atoms; the subscripts, which is the number of molecules of atoms for both the reactants and the products; the physical states of both the reactants and the products; the number of atoms in the bracket and the yield arrow pointing from reactants to the products. Every aspect of chemistry has a chemical equation built into it; the nature, the properties, and the composition of matter in chemistry are represented and summarized by a balanced chemical equation. It outlines the components of a chemical reaction concerning the reactants and the products in the chemical reaction, indicating the number of moles involved in the reaction and a clear representation of the chemical process [1]. For instance, if 2moles of liquid A reacts with 1 mole of solid B to form 3 moles of gas CD, the reaction can be represented thus:

$$2A_{(l)} + B_{(s)} \rightarrow 3CD_{(g)}$$

From the equation, the subscripts l, s, and g represent the physical states, and A and B are reactants (limiting reagents). In contrast, the CD represents the product (theoretical yield); the number of moles (Stoichiometric coefficients) of A is 2, B is 1, while CD is 3; the arrow is called the yield arrow pointing to the product, which can be a double for a reversible reaction.

A chemical equation, according to Amos [1], [2], is a numerical and symbolic representation of changes in chemical reactions that follow the mass conservation law. Since matter cannot be created or destroyed during a chemical reaction, the mass of the reactants and products combined is guaranteed to be identical by this law. According to Helmenstine [1], a chemical equation describes a chemical reaction. Chemical formulae represent chemical equations and are a symbolic means of communication among scientists and researchers. Using chemical formulae, they can easily convey the composition of a compound without having to write lengthy descriptions. This universal language allows clear and concise communication within the scientific community [3]. By implication, any small mistake in writing chemical formulas or any deviation from the law of conservation of mass can completely change the compound's identity; balancing chemical equations calls for careful attention to detail.

Baah & Anthony-Krueger [4] Emphasized the significance of chemical formulas and the knowledge of IUPAC nomenclature, saying that learning and comprehending chemistry and all other topics that are related to correctly naming and writing a chemical formula depends on students' ability to write the names of compounds according to IUPAC rules. The significance of chemical equations extends beyond elemental stoichiometry, as they influence many other areas of chemistry, such as reaction rates, equilibrium, redox reactions, chemical bonding, and the synthesis of complex molecules, which are all interconnected through the language of chemical equations. Additionally, specialized fields like organic chemistry, thermochemistry, and polymer synthesis heavily rely on chemical equations to model and analyze chemical processes. This fundamental aspect of chemistry is essential for comprehending the complexities of the physical environment, showcasing the wide-reaching impact of chemical processes in nature [5].

All branches and aspects of chemistry rely heavily on chemical equations. Students must comprehend elements, symbols, and IUPAC nomenclature to write chemical formulas and understand chemical formulae before they can write a balanced chemical equation. According to Salifu et al. [6], chemical equations provide the basis for interacting with chemical compounds in terms of their elements and symbols, making it convenient for them to name and write a balanced chemical equation. Chemical equations are helpful in chemists; chemical reactions are everywhere, and they are a powerful tool and fundamental concept in chemistry, in which other concepts are explained. It is present in other science subjects such as biology, agricultural science, geography, and physics. A balanced chemical equation can account for photosynthesis, rainfall, nitrogen cycle, lightning and thunder, and other natural phenomena.

As important as it is, previous research has indicated that pupils struggle to balance chemical equations. Balancing chemical equations is a challenging and abstract concept in chemistry education. Nitereka et al. [7], Njoku and Attah [8], and Salifu et al. [6] noted that students may struggle to write and balance chemical equations. Olatunde [9] identified that students cannot balance a chemical equation, they cannot identify products and reactants, they use the wrong letters to represent atoms, they misuse small letters to name elements, they lack basic knowledge of radicals and valency, they lack accuracy in balancing chemical equation, and they cannot make sense of subscripts in a reaction. A similar study by Celikkiran [10] noted that students failed to make sense of the subscript of chemical formulae and valency. Ekere [11], Baah and Ampiah [12], Yitbarek [13], and Johnstone [14] collectively recognized that students commonly struggle with balancing chemical equations.

WAEC [15] recognized students' inadequacy in balancing chemical equations. This difficulty is part of a broader pattern where students face challenges in topics related to reaction stoichiometry, particularly in understanding mole ratios, chemical concepts, mole concepts, and compound formulas, writing the names of chemical formulae and symbols to represent ions, and balancing chemical equations among others. Amos [2] and Adigwe [16] recognized that students struggle to solve chemical equations. Temechegn et al. [17] advanced the idea that students' assessments of the difficulty of chemistry are influenced by the incomprehensible nature of many chemical concepts, the instructional strategies used in the classroom, the availability of teaching resources, and the intricate vocabulary used in the discipline are accurate. Certain factors can make it more difficult for students to learn more complex subjects that rely on these fundamental concepts.

Chibuye and Mupela [18] highlighted the poor performance in balancing chemical equations in Zambia and other African and Caribbean countries, where students perform poorly when balancing chemical equations. Salifu et al. [6] emphasized the challenge colleges of education, science teachers, and students face in creating interest in effectively teaching this topic. Temechegn et al. [17] emphasized that a lack of understanding in balancing chemical equations can hinder students' grasp of advanced chemistry concepts. If this issue is not resolved, students will have a variety of misconceptions about other chemistry concepts; they will have poor quantitative and qualitative skills; they will struggle to understand reaction stoichiometry; they will find it challenging to explain their ideas, particularly the results of their experiments, to others; and they will continue to struggle with learning chemistry at all levels, which may discourage students from enrolling in advanced courses. Students may find it difficult to accurately balance equations if they do not fully grasp those underlying principles [13]. In resonance with

Taber [19], students' inadequate comprehension of the balancing of chemical equations can adversely affect their capacity to comprehend other concepts in chemistry, and anyone who teaches it needs to have a solid comprehension of the rigid regions because even the teacher could find it challenging [20].

Researchers have expressed concern about students' challenges in balancing chemical equations, and they have taken steps to address this threat to raise students' proficiency in balancing chemical equations and chemistry studies in general. Previous studies applied different teaching strategies to teach the balancing of the chemical equations without a prior diagnosis of students' difficulties; other studies identified variables like gender, instructional materials, and teacher's experience, among others. Despite these efforts, students' low achievement and difficulties in balancing chemical equations, as reported by several studies and examination bodies, justify the need for this study.

2. METHOD

2.1 Research Design: The study adopted a qualitative survey design. A simple random technique was used to select two (2) local government areas from eleven (11) local government areas in Ibadan, Oyo state. Six (6) public senior secondary schools were randomly selected using balloting; intact classes of SS2 science students in each school were used. The total number of participants is 188.

2.1.1 Research Instrument

Chemical Equation Diagnostic Test (CEDT)

The researcher developed the Chemical Equation Balancing Diagnostic Test; it has two sections, A and B. Section A collected the demographic data of respondents, while the section contains the test items with fourteen (14) items. Students' responses were marked as either right (not tricky) or wrong (difficult).

2.1.2 Validity

The drafted copy of the instrument was presented to chemistry educators for correction and amendment. Expert consultation was ensured at this stage to guarantee the content validity of the CEDT during the construction phase.

2.1.3 Reliability

Test re-test was used to calculate the reliability coefficient; the test was first administered to twenty (20) SS II science students of another secondary school comparable to the selected schools. After two weeks, the test was re-administered to the same set of students. The reliability coefficient of the instrument was determined to be 0.82.

Scoring for CEDT: The items in CEDT were marked based on students' responses as either not tricky or challenging.

A copy of the instrument is shown below:

A. $S_{(s)} + 2H_2SO_{4(aq)} \rightarrow H_20_{(?)} + SO_{2(?)}$

Answer questions 1-10 using the chemical equation above

1. What are the limiting reagents in this equation?
2. Identify the reactants in the reaction.
3. What do we call 2 in H_20?
4. What is the name of 2 in 2H from $2H_2SO_4$?
5. How many atoms of elements are present in $2H_2SO_4$?
6. How many elements are present in $2H_2SO_4$?
7. How many atoms of oxygen are present in H_2SO_4?
8. What are the physical states of SO_2 and H_2O in the reaction?
9. Is the equation balanced?
10. What is the valency of Sulphur and Oxygen in SO_2?
11. From the table below, tick the correct formula/formulae

NaCl	Mgcl	NaCl
Mgcl	MgCl	Nacl

12. With 6.5g of granulated zinc and excess copper (II) tetraoxosulphate (VI) solution, what mass of copper is deposited, as per the following equation?
$Zn_{(s)} + CuSO_{4(aq)} \rightarrow Cu_{(s)} + ZnSO_{4(aq)}$
13. Write a balanced chemical equation that results in carbon (IV) oxide, calcium chloride, and water when excess dilute hydrochloric acid is added to calcium trioxocarbonate (IV).
14. Determine how many moles each of the reactants and products are in the following equation:
$4NH_{3(b)} + 3O_{2(g)} \rightarrow 2N_{2(g)} + 6H_2O_{(g)}$

2.3 Scoring of the Test Items and Data Analysis

The test items were marked as right or wrong for the students, with one mark awarded for each proper response and zero for any incorrect one. The qualitative data collected were content analyzed using frequency counts and percentages.

2.3 Procedure

The school administrations permitted the researcher to conduct the study in their schools. Students studying science in SSS 2 were randomly assigned and given a chemical equation diagnostic test. The administration and retrieval of the instrument were assisted by six research assistants and secondary school chemistry teachers from the chosen teachers' association.

2.4 **Data Analysis**

This was done using descriptive statistics of frequency distribution.

3. RESULTS AND DISCUSSION

After conducting research and collecting data, the following data was obtained:

Table 1. Number and percentage of pupils who correctly or incorrectly answered the exam items on the chemical equation diagnostic test

S/N	Item	Right	Wrong	Mean
1.	Ability to identify limiting reagents	7 (3.7%)	181 (96.56%)	1.04
2.	Ability to identify reactants in the reaction	97 (51.6%)	91 (48.4%)	1.52
3.	Ability to say what 2 in H_2O stands for	16 (8.5%)	172 (91.5%)	1.08
4.	Ability to name 2 in 2H from H_2SO_4	45 (23.9%)	143 (76.1%)	1.24
5.	Ability to identify atoms of elements in H_2SO_4	39 (20.7%)	149 (79.3%)	1.20
6.	Ability to find the total number of elements in $2H_2SO_4$	39 (20.7%)	149 (79.3%)	1.77
7.	Ability to find how many elements are present in H_2SO_4	145 (77.1%)	43 (22.9%)	1.83
8.	Ability to identify the physical states of SO_2 and H_2O	86 (45.7%)	102 (54.3%)	1.46
9.	Ability to identify a balanced equation	151 (80.3%)	37(19.7%)	1.80
10.	Ability to calculate the valency of elements	39 (20.7%)	149 (79.3%)	1.22
11.	Use of capital and small letters in writing formula	16 (8.5%)	172 (91.5%)	1.08
12.	Ability to calculate based on the information from the chemical equation	7 (3.7%)	181 (96.56%)	1.04
13.	Ability to transform worlds into chemical equations	5 (2.7)	183 (97.3%)	1.02
14.	Ability to find the number of moles in a chemical reaction	45 (23.9%)	143 (76.1%)	1.24

3.1. Analysis of Challenges Faced by Students in Balancing Chemical Equations

Research Question 1: What challenges do students face while balancing a chemical equation?

Table 1 displays the proportion of students who correctly or incorrectly answered the questions on the chemical equation diagnostic test, with percentages in parenthesis.

Table 1, item 1, shows that 96.56% of respondents could not identify the limiting reagent in the reaction, whereas 3.7% were successful. This suggests that many pupils could not identify the chemical reaction's limiting reagent.

Item 2 reveals that 51.6% of the students correctly identified the reactants in the reaction; however, this is still not very excellent, as 48.4% of them could not do so.

Item 3 reveals that only 8.5% of the students could say what 2 in H_2O stands for, while 91.5% could not understand the subscript.

Item 4 shows that 23.9% of students could name 2 in 2H from H2SO4, while 76.1% could not name 2 in 2H from H_2SO_4.

Item 5 on the table shows that 20.7% of the students could identify elements of elements in H2SO4, while 79.3% could not identify atoms of elements in H_2SO_4.

Item 6 on the table shows that 20.7% of the students could find the total number of elements in 2H2SO4, while 79.3% could not find the total number of elements in $2H_2SO_4$.

Item 7 on the table shows that 77.1% could identify the number of elements in H2SO4, while 22.9% of students could not.

Item 8 on the table reveals that 45.7% of the respondents could identify the physical states of SO_2 and H_2O, while 54.3% could not identify the physical states of SO_2 and H_2O.

Item 9 on the table shows that 80.3% of the students could identify a balanced equation, while 19.7% could not identify a balanced chemical equation.

Item 10 on the table shows that 20.7% of the students could calculate the valency of elements, while 79.3% could not.

Item 11 on the table shows that only 8.5% of 91.5% understood using capitals and small letters in formulas.

Item 12 on the table indicates that only 3.7% of students could calculate based on the information from chemical equations, while 96.56% could not.

Item 13 on the table shows that 2.7% of students could transform worlds into chemical equations, while 97.3% could not.

Item 14 on the table shows that 23.9% of students could find the number of moles in the chemical reaction, while 76.1% could not find the number of moles in the reaction.

3.2. Identifying Key Student Difficulties in Understanding Fundamental Chemistry Concepts

Research Question 2: What percentage of students struggle to balance chemical equations?

Based on the percentage of students who provided wrong responses, there is evidence that students could not identify limiting reagents (96.56%); students could not identify reactants in a reaction (48.4%); students could not state what 2 in H_2O stands for (91.5%); students could not name 2 in 2H from H_2SO_4 (76.1%); students could not count

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the number of atoms of elements in H_2SO_4 (79.3%); students could not find the total number of elements in $2H_2SO_4$ (79.3%); students could not find how many elements are present in H_2SO_4 (22.9%); students could not identify the physical states of elements (54.3%); students could not identify a balanced chemical equation (19.7%); students could not calculate the valency of elements (79.3%); students did not understand the use of capital and small letters in writing formula (91.5%); students were unable to transform worlds into chemical equation (97.3%). Students could not handle calculations based on chemical equations (96.56%). Students could not find the number of moles in the reaction (71.6%).

3.3. Discussion

Table 1 shows the frequency distribution based on students' difficulties balancing chemical equations. The findings from this study reveal the difficulties of students in balancing chemical equation, the students' difficulties in balancing chemical equations are as follows: inability to identify limiting reagents in a reaction, inability to identify reactants in a chemical reaction, inability to interrogate with H_2O to make sense of subscript in a chemical reaction, by implication students do not understand atomicity. This finding is consistent with the WAEC report [15], which identified students writing trivial names instead of chemical formulae, having inadequate knowledge of chemical concepts, inability to write the correct formula of a compound, having poor knowledge of the mole concept, and using wrong symbols to represent ions. Also, the result agrees with the WAEC report [15], which linked students' poor performance in balancing chemicals to inadequate knowledge of students about fundamental concepts in chemistry. By identifying the specific areas where students struggle, such as identifying reactants and products or interpreting chemical formulas, teachers can tailor their instruction to meet students' needs and enhance their proficiency in balancing chemical equations. The study also revealed students' inability of students to make sense of the stoichiometric coefficient from $2H_2SO_4$, inability to identify atoms of elements in H_2SO_4, inability to find the total numbers of elements in $2H_2SO_4$, inability to find how many elements are present in H_2SO_4; inability to identify the physical states of SO_2 and H_2O; inability to calculate the valency of elements in a compound. Inability to identify a balanced chemical equation; inability to calculate the valency of elements; wrong use of capital and small letters in writing formula; inability to handle calculations based on chemical equation; inability to find the number of moles in the reaction. The results of this study resonate with the claim that students have various difficulties in balancing chemical equations. These findings are consistent with Deleña & Marasigan [3], who revealed the nature of students' misconceptions about chemical formula writing and naming ionic compounds.

The findings of this study established that students have various difficulties in balancing chemical equations. The results corroborate Johnstone [14], who argued that balancing chemical equations is among the chemistry concepts that are abstract and difficult to teach. The findings are consistent with Olatunde [9], who established that students cannot balance chemical equations, identify reactants and products in a chemical reaction, make sense of subscripts, and lack accuracy in balancing chemical equations.

This finding was also reported by Ekere [11], who acknowledged that students have difficulties in balancing chemical equations and broadly supports [12], who asserted that students usually have persistent difficulties in topics related to balancing chemical equations.

Inferentially, if the problem of students' inability to balance chemical equations is not addressed, students will have various misconceptions about other concepts in chemistry; they will have poor quantitative and qualitative skills; students will find it challenging to understand stoichiometry of reactions; they will find it difficult in communicating their ideas especially their experimental findings to others, students' inability to balance chemical equation stands a chance to hurt their achievement.

Inevitably, the practical implication of identifying such difficulties in balancing chemical equations can bring about improved learning outcomes in chemistry; it can help the teachers refine their teaching strategies and resources; it can help teachers create resources addressing specific challenges; and even it can help students to resolve among themselves specific challenges; it can bring about regular monitoring of student progress and reduce students' frustration and anxiety. It can also boost students' confidence in chemistry, help them retain information, and be better equipped to handle advanced chemistry topics.

4. CONCLUSION

This study has established that students have a series of difficulties in balancing chemical equations, which aligns with the posited that balancing chemical equations is among chemistry concepts that are difficult to teach. Hence, the new trajectory of teaching and learning chemistry, especially in balancing chemical equations, should identify various students' difficulties in balancing chemical equations among the students. Therefore, The teacher should assume the role of a doctor who will diagnose students' difficulties in balancing chemicals and apply the proper method to cure students' difficulties in balancing chemical equations to improve students' achievement in balancing chemical equations. Also, teachers can leverage technology such as MATLAB, MAPLE, INP, ILP, or online tools to facilitate students learning and practices in balancing chemical equations.

Teachers can design targeted interventions to address common difficulties, improving students understanding and skill development by understanding common difficulties. Identifying such difficulties can inform curriculum developers, ensuring that topics are presented logically and progressively, building on students' existing knowledge. Similarly, teachers can create a more supportive and effective learning environment, leading to improved student learning outcomes and a stronger foundation in chemistry. In conclusion, teachers can adjust their instructional strategy using alternative teaching methods or emphasizing key concepts to support better student learning. In the same vein, further study on this subject can also look for alternative methods of teaching the balancing of chemical equations, which could reduce students' difficulties and misconceptions.

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