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Assessing the Level of Comprehension of Chemical Formulae and Equations Among Secondary School Students in Bo City, Southern Region of Sierra Leone

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Abstract
This study investigates the comprehension of chemical formulae and equations among senior secondary school students (SSS 2 and SSS 3) in Bo City, Southern Sierra Leone. Combining diagnostic pre-tests and questionnaires, the research identifies alarming deficiencies in foundational chemistry competencies: only 3.6% of students correctly formulated lithium trioxosulphate(IV), while 7.3% accurately balanced the sodium-chlorine reaction equation. Qualitative data revealed widespread struggles with IUPAC nomenclature (64.9%) and polyatomic ion valencies (88.3%), compounded by systemic barriers such as overcrowded classrooms, scarce instructional resources, and limited laboratory access. Critical misconceptions included misinterpretations of chemical symbols (23% understood NaCl) and the principle of mass conservation (47.3% failed to connect it to equation balancing). The findings underscore how abstract symbolic representation and inadequate pedagogical strategies hinder learning outcomes.
The study advocates for targeted interventions— strategy remedial drills, mnemonics, and interactive visualization tools—alongside systemic reforms, including enhanced teacher training, curriculum prioritization of foundational topics, and improved resource allocation. These evidence-based recommendations aim to address STEM education disparities in low-resource contexts, offering actionable pathways to bridge learning gaps and align with global efforts to advance equitable science education.

Keywords: Chemistry, chemical formulae, equations, diagnostic pre-tests, IUPAC nomenclature, equation balancing, valency, STEM

1. Introduction

Science education serves as a cornerstone for societal and economic development. For any nation, community and society to experience economic growth there must be a strong stimulation and growth in the teaching and learning of science (Oyovwi, 2012). As a foundational subject in Sierra Leonean and global secondary schools, chemistry is often called the "central science" because of its relevance to disciplines such as biology, physics, medicine, and engineering (Adams & Sewry, 2010). As Orukotan (2007) emphasizes, science education drives transformative advancements globally. Students aiming for science-based higher education must master chemistry, particularly to pass the compulsory West African Senior School Certificate Examination (WASSCE) chemistry exam for university admission.

A pivotal component of the WASSCE chemistry syllabus is the study of chemical formulae and equations, which form the cornerstone for grasping advanced chemical principles. Chemical formulae denote the elemental composition of compounds, while equations model chemical reactions. Mastery of symbols, valences, and stoichiometry is essential, equipping students to predict material properties, quantify reaction outputs, and balance equations—a foundational skill for upholding the law of mass conservation and determining precise mole ratios (Johnstone, 1991). These symbolic systems are vital for scientific discourse, facilitating standardized compound classification and enabling rigorous stoichiometric analysis.

Despite their foundational importance, students worldwide grapple with comprehending chemical formulae and equations, particularly at the symbolic and submicroscopic levels of representation, which demand abstract reasoning (Rachel et al, 2011; Johnstone, 1991). In Sierra Leone, these challenges are compounded by inadequate educational infrastructure and pedagogical shortcomings. For example, the 2018 West African Examination Council (WAEC) Chief Examiners' Report highlighted students' poor performance on tasks such as writing the equation for chlorine's reaction with water ($Cl_2 + H_2O$), underscoring systemic gaps in understanding. Scholars like Calik & Ayas (2005) link such struggles to learners' difficulty in bridging abstract concepts with real-life contexts—a barrier intensified in under-resourced environments such as Bo City.

Misconceptions in these areas hinder students' ability to grasp advanced chemistry topics, often resulting in academic underperformance. For instance, balancing chemical equations—a task requiring proficiency in symbolic representation—is frequently misinterpreted as a mechanical process rather than an application of the law of mass conservation. Likewise, confusion between molecular and empirical formulae stems from insufficient foundational understanding. These challenges highlight the urgency of assessing students' comprehension in chemical formulae and equations, examining recurring errors, and formulating adaptive, situation-aware educational interventions to address these gaps.

1.1 Problem Statement

A strong foundation in chemical formulas and equations is critical as they form the "building blocks for further understanding in chemistry." However, students often struggle with these concepts, leading to misconceptions and poor academic performance. This is evidenced by "mass failures" in exams like WASSCE, which contribute to low university enrollment in chemistry education, poor achievement, and a decline in qualified chemistry teachers (Khurshid, M. et al., 2017). According to Khurshid et al. (2017), a key challenge is students' lack of proficiency in the "language of chemistry," including writing chemical symbols, formulas, and equations.

In Sierra Leone, Secondry Schools face systemic challenges such as overcrowded classrooms, scarce laboratories, and underqualified teachers—amplify learning disparities. The 2018 WAEC Chief Examiners' Report noted nationwide deficiencies in balancing equations, corroborated by this study's findings (7.3% accuracy in $Na + Cl_2$ balancing). Similar issues are reported in Nigeria (Orukotan, 2007), where students' inability to decode chemical "language" correlates with high exam failure rates.

Most first-year students in Sierra Leone Universities struggle to calculate molecular masses, writing chemical formulas correctly and determining the total number of atoms in a compound. This foundational challenge frequently hinders their ability to grasp subsequent topics, creating obstacles that persist over the course of the semester." These struggles impede progress in mastering advanced chemistry topics, underscoring the urgency of addressing foundational gaps early in education.

While extensive research exists on chemical misconceptions in high-income countries, few studies address Sub-Saharan Africa's unique challenges. Sierra Leone's post-conflict education system, characterized by infrastructural deficits and teacher shortages (Ministry of Education Sierra Leone, 2022), remains understudied.

The research specifically sought to: (1) assess students' proficiency in writing chemical formulas and balancing equations, and (2) identify difficulties and misconceptions in the area of study. This study assessed the level of students' comprehension in chemical formulae and chemical equation in senior secondary schools in the Bo city to identify the difficulties of pupils in comprehending Chemistry and challenges faced by their teachers in teaching Chemistry.

1.2: Aims and Objectives of the Study

The aim of this study is to investigate the level of students' comprehension of chemical formula and chemical equation in senior secondary schools to help improve teaching methodology which could improve on the performances of pupils in chemistry.

To achieve this aim, the following objectives are pertinent to this study: (a) Determine the level of understanding of students in foundational topics such as chemical formula and chemical equation in senior secondary schools in Bo City, (b) Identify any common misconceptions or difficulties faced by students in comprehending chemical formula and chemical equation, (c) Proffer possible strategies that could be advanced to improve on the performances of pupils in chemistry in Bo City.

2. Literature Review

Chemistry, often termed the "central science" (Adams & Sewry, 2010), bridges disciplines like biology, medicine, and engineering, forming a cornerstone of STEM literacy. Mastery of chemical formulae and equations is critical for understanding stoichiometry, reaction dynamics, and material properties (Johnstone, 1991). These symbolic systems underpin scientific communication and problem-solving, enabling students to predict reaction outcomes and adhere to fundamental principles like the law of mass conservation (Zhihui et al, 2013). However, global studies consistently highlight persistent challenges in teaching and learning these abstract concepts, particularly in resource-constrained settings (Calik & Ayas, 2005; Taber, 2020).

Chemical notation demands fluency in three representational levels: macroscopic (observable phenomena), sub-microscopic (particulate interactions), and symbolic (formulae/equations) (Johnstone, 1991). Students often struggle to transition between these levels, leading to fragmented understanding. For instance, balancing equations is frequently misperceived as a mechanical task rather than an application of mass conservation (Nakhleh, 1992). Misinterpretations of subscripts (e.g., NaCl representing atoms vs. ions) and confusion between molecular/empirical formulae are widespread (Taber, 2002, Jack et al 2017), mirroring findings in this study where only 23% of Bo City students correctly interpreted NaCl.

The complexity of IUPAC nomenclature and polyatomic ion valencies poses significant barriers. Studies attribute these difficulties to rote memorization strategies that neglect conceptual foundations (Barke et al., 2021). For example, Calik & Ayas (2005) found that 75% of Turkish students misapplied valency rules to oxoanions, aligning with this study's findings (88.3% struggled with polyatomic valencies). Such gaps are exacerbated in under-resourced contexts, where limited access to molecular models or digital tools hinders visualization (Gilbert & Treagust, 2022).

Effective pedagogy requires contextualized approaches. However, teachers in low-resource settings often lack training in misconception-based instruction (OECD, 2023). Targeted interventions, such as mnemonics for nomenclature (Barke et al., 2021), have proven effective in bridging gaps. OECD (2023) underscores the need for systemic investments in teacher training and laboratory access. In Rwanda, curriculum reforms prioritizing foundational topics in early secondary grades reduced stoichiometry misconceptions by 30% (Ministry of Education Rwanda, 2021). Similarly, Ghana's integration of molecular kits into classrooms enhanced symbolic comprehension.

3. Methodology

3.1 Research Design

The study employed a mixed-method approach, combining descriptive and diagnostic research designs to provide a thorough understanding of both performance gaps (quantitative data) and their root causes (qualitative insights).

3.2: Population and Sampling

The researcher selected six Senior Secondary School in Bo City, Southern Region of Sierra Leone namely Ahmaddiya Muslim Secondary School (A.M.S.S), Christ the King College (C.K.C), United Church of Christ (U.C.C), Queen Rosary School (Q.R.S), S.O.S, and Ark of Hope. A total of 40 sample size was randomly selected from which 120 were pupils from Senior Secondary level 2 (SS2) to Senior Secondary level 3 (SS3), 10 teachers, and 10 parents as presented in Table 1.

Table 1: Sample selection showing sample size

School	**Sample Size**	**Respondents**			
		Pupils		**Teachers**	**Parents**
		Girls	**Boys**		

Ahmaddiya Muslim Secondary School (A.M.S.S)	54	25	25	2	2
Christ the King College (C.K.C)	54		50	2	2
United Church of Christ (U.C.C),	34	15	15	2	2
Queen Rosary School (Q.R.S)	39	35		2	2
S.O.S	32	15	15	1	1
Ark of Hope	27	13	12	1	1
Total		103	117	10	10
	240	220		10	10

3.3: Data Collection Instruments

Both quantitative and qualitative data collection methods were used: The quantitative assessment comprised of a carefully designed questionnaire containing sections which evaluated fundamental chemistry competencies in (a) basic chemical notation proficiency (b) testing equation formulation and balancing skills (c) equation balancing. The qualitative assessment was done by Key Informant Interview (KII) of teachers and parents from the respective six secondary schools investigated,

3.4: Data Collection Procedure

Prior to data collection, a pre-test of the questionnaire was done to validate the tool and also ensure that respondents, especially pupils, clearly understood the chemistry questions presented to them. This involved the researchers having discussions on the questions with pupils selected for the study.

After the pre-test, the reviewed questionnaire was administered to respondents. The data collected was validated to get the relevant data from the study. The validated data was coded for easy classification in order to facilitate tabulation and to generate figures. The tabulated data was then analyzed quantitatively by calculating various percentages where possible. To analyze statistical data.

3.5: Data presentation and analysis techniques

Quantitative data were presented in tabular format and qualitative information in descriptive form. The information was thoroughly recorded first and then analyzed for the established objectives. Quantitative data from the questionnaire were analyzed using Microsoft Excel and the Statistical Package for Social Science (SPSS version 20). Qualitative data obtained, from key informant interviews were analyzed by content and comparative analysis techniques.

4. Discussion Of Results

4.1 Level of Understanding in Chemical Formulas:

Students exhibited significant difficulties in writing correct chemical formulas, particularly for compounds requiring valency exchanges (e.g., beryllium nitride). Many could not recall the correct symbol for nitride, revealing gaps in foundational knowledge. This aligns with prior findings by Smith et al. (2021). For more complex compounds like calcium tetraoxophosphate(V), nearly all responses were incorrect, highlighting widespread struggles with applying valency rules to polyatomic ions.

Figure 1 presents results of students' competency levels in writing basic chemical notations, particularly chemical formulas and equations.

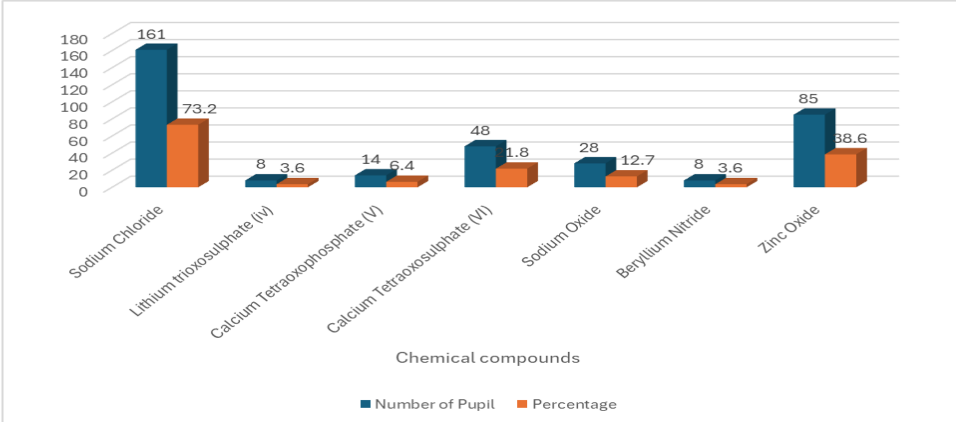

Figure 1: pupils' performance in writing chemical formulae

Sodium Chloride:

73.2% of pupils correctly identified the chemical formula for Sodium Chloride, indicating a strong understanding of this basic compound. However, 25.9% of students provided incorrect answers, and 0.9% did not attempt the question.

Lithium Trioxosulphate (IV):

Few students (3.6%) correctly identified the chemical formula, while 93.6% provided incorrect answers, and 2.7% of students did not attempt the question.

Calcium Tetraoxophosphate (V):

Only 6.4% of students correctly identified the chemical formula, and 90% providing incorrect answers, it reveals a lack of comprehension of polyatomic ions.

Calcium Tetraoxosulphate (VI):

21.8% of students correctly identified the chemical formula, while 75.5% provided incorrect answers, indicating moderate comprehension but significant gaps.

Sodium Oxide:

12.7% of students correctly identified the chemical formula, while 85.5% provided incorrect answers, and 1.8% did not attempt the question, showing a moderate understanding of this compound.

Beryllium Nitride:

3.6% of students correctly identified the chemical formula while 88.2% provided incorrect answers, indicating lack of comprehension due to complex exchange of valencies.

Zinc Oxide:

38.6% of students correctly identified the chemical formula, while 50.5% provided incorrect answers, and 10.9% did not attempt the question indicating moderate comprehension but significant gaps

An assessment was also done on pupils' performance in writing chemical formulae by gender. The results presented in Figure 2 revealed no significant difference between male and female pupils' performance in writing chemical formulae, especially for common compounds like sodium chloride and zinc oxide

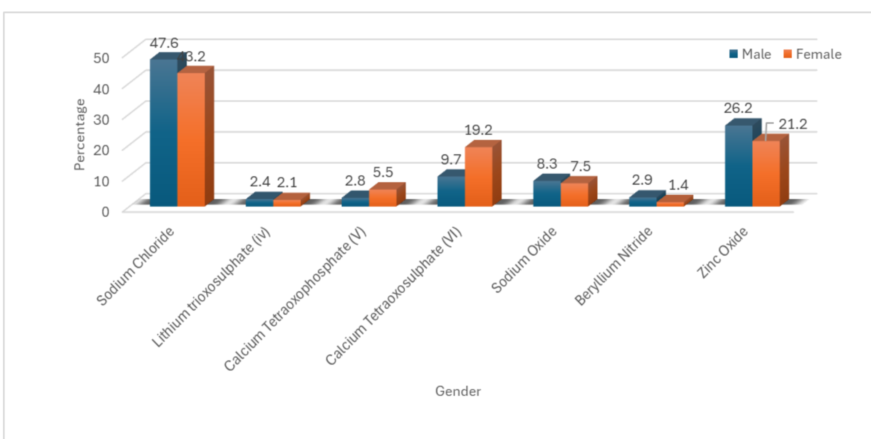

Figure 2: Pupils' performance in writing chemical formulae by gender

4.2 Common Misconceptions and Difficulties

Naming and writing formulas for polyatomic radicals (oxoanions), such as trioxosulphate(IV) and tetraoxophosphate(V), proved particularly difficult for students. Many provided incorrect formulas, highlighting gaps in their understanding of IUPAC nomenclature and ionic compound formation. This issue was further emphasized in pupils feedback, where 64.9% cited challenges with IUPAC naming conventions.

The recurring mistakes suggest that students struggle with remembering the valencies of these complex ions and elements. This was supported by survey responses, where 88.3% of students admitted to misconceptions regarding the valencies of polyatomic ions when asked about difficulties in writing chemical formulas. In identifying misconceptions, major gaps were linked to complex nomenclature and valency application.

Furthermore, the study assessed pupils' comprehension of chemical equations as shown in Figure3.

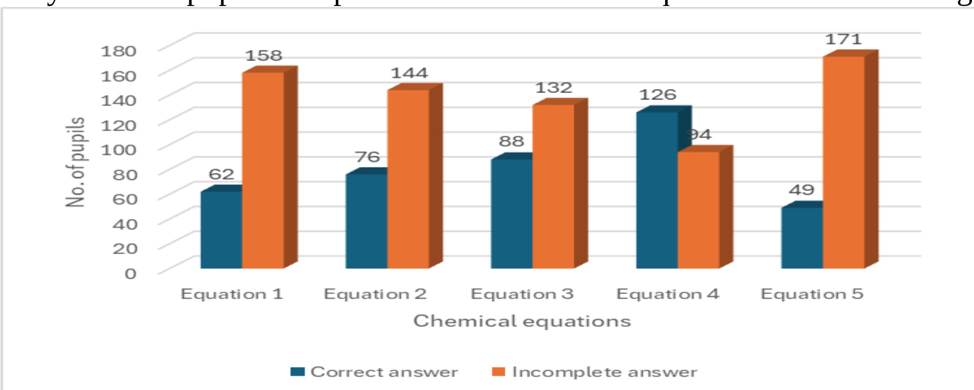

Figure 3: Pupils' performance in writing chemical equations

Table 2: Key to equations presented in Figure 4

Equation No.	Chemical reaction	*Chemical equations*
Equation 1	*Sodium and Chlorine*	($Na + Cl_2$)
Equation 2	*Calcium and Tetraoxophosphate(V)*	($Ca + H_2PO_4$)
Equation 3	*Zinc Hydroxide and Tetraoxosulphate(VI) Acid*	($Zn(OH)_2 + H_2SO_4$)
Equation 4	*Methane and Oxygen Reaction*	($CH4 + O2 \rightarrow CO2 + H2O$)
Equation 5	*Hydrochloric Acid and Calcium Carbonate*	($HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$)

Reaction 1: Sodium and Chlorine Reaction ($Na + Cl_2$)

89.1% (196) of pupils failed to correctly write the product and balance the equation, indicating a fundamental misunderstanding of basic reaction principles.This aligns with Smith et al. (2023), who identified similar challenges in balancing simple reactions among secondary students.

Reaction 2: Calcium and Tetraoxophosphate(V) Reaction ($Ca + H_2PO_4$)

Only 1.8% (4) of pupils correctly balanced this reaction, highlighting severe difficulties with polyatomic ions and metal-acid reactions. Consistent with Johnson and Lee (2022), who noted the complexity of reactions involving polyatomic ions.

Reaction 3: Zinc Hydroxide and Tetraoxosulphate(VI) Acid Reaction ($Zn(OH)_2 + H_2SO_4$)

Only 7.3% of students answered correctly, indicating notable difficulties in acid-base reactions and stoichiometry. This aligns with Brown et al. (2021), who reported similar struggles with acid-base mechanisms among learners.

Reaction 4: Methane and Oxygen Reaction ($CH4 + O2 \rightarrow CO2 + H2O$)

Only 28.2% of students correctly balanced the reaction between methane and oxygen, indicating a moderate understanding of combustion reactions. This aligns with findings by Smith et al. (2023), who noted similar challenges in balancing combustion reactions among secondary school students.

Reaction 5: Hydrochloric Acid and Calcium Carbonate Reaction:

$(HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2)$

A slightly higher percentage of students (34.5%) correctly balanced this reaction, suggesting a better understanding of acid-carbonate reactions. According to Johnson and Lee (2022), such reactions are often easier for students to grasp due to their straightforward stoichiometry.

4.3 Test of Pupils' Competency on Basic Principles in Chemistry

The Researchers conducted a test covering some basic principles in chemistry to know the level of pupils knowledge. Table 3 presents results obtained from the data analysis of the questionnaire.

Table 3: Test on pupils' performance on the principles and concept of chemical formulae and equations

Question	Correct response		Incorrect response		No answer		Total
	Pupil	%	Pupil	%	Pupil	%	
1. In the chemical formula NaCl, what do the letters represent	51	23.0	146	66.5	23	10.5	220
2. How many oxygen atoms are present in the formula $C_6H_{12}O_6$?	166	75.5	43	18.5	11	5.0	220
3. What is the primary reason for balancing a chemical equation?	98	44.5	104	47.3	18	8,2	220
4. In a balanced chemical equation, what does the coefficient in front of a compound represent?	86	39.1	114	51,8	20	9.1	220
5. If a compound is represented as X_2 and Y_3, what is the valency of X and Y	41	18.6	80	36.4	99	40.0	220
6. When balancing chemical equation, the total number of --------- on the reactant side must equal the total number on the product side	104	47.3	77	35	39	17.7	220
7. + on the right-hand side + on the left of the equation	4 4	1.8 1.8	156 160	70.9 72.5	60 56	27.3 25.2	220 220
8. In the chemical formula for Aluminium tetraoxosulhpate (VI), represented as $Al_2(SO_4)$	44	20.0	113	51.4	63	28.6	220
9. Chemical Formula Chemical Symbol Chemical Equation	34 79 4	15.5 35.9 1,8	111 64 112	50.5 29.1 50.9	75 77 104	34.0 35 47.3	220 220 220

Table 4 shows pupils' performance on the principles and concept of chemical formula and equation.

Understanding Chemical formula (NaCl):

Only 23% of pupils correctly identified the representation of elements in NaCl. 66.5% provided incorrect answers, indicating poor grasp of basic chemical symbols to represent atoms of the element.

Interpreting Molecular Composition ($C_6H_{12}O_6$):

75.5% correctly counted oxygen atoms, showing better understanding of subscripts. However, 18.5% still struggled, suggesting some students lack confidence in formula interpretation.

Concept of balancing chemical equations:

Only 44.5% understood the law of conservation of mass as the reason for balancing equations. 47.3% held misconceptions, possibly viewing balancing as arbitrary rather than based on mass conservation.

Role of coefficients in equations:

Just 39.1% correctly explained coefficients' significance. 51.8% had incorrect interpretations, indicating confusion about stoichiometric relationships.

Valency and subscript interpretation (X_2 and Y_3):

Only 18.6% correctly identified valency from subscripts. 36.4% answered incorrectly, while 40% skipped the question, reflecting weak foundational knowledge.

Placement of '+' Signs in Equations:

Merely 1.8% answered correctly, suggesting students struggle with the symbolic language of chemistry.

4.4 Institutional and Contextual Factors

Inadequate trained and qualified chemistry teachers in schools, severe overcrowding of classrooms, inadequate and poorly equipped laboratory facilities, and insufficient teaching materials significantly constrained practical learning opportunities. 68% of the teachers teaching chemistry do not have a degree in chemistry rather in other areas like agriculture, environmental science, public health and other related science fields. Hence, the study found Teachers, to a very large extent, not effective.

Pupils themselves identified difficulties understanding the concepts due to teaching presentation/pedagogy as majority of the Teachers did not study education in addition to time constraints (34.4%) and large class sizes (19.5%) as major obstacles. These systemic issues directly contribute to fundamental knowledge gaps, particularly in IUPAC nomenclature (64.9% struggling) and polyatomic ion valencies (88.3% misconceptions), areas that receive insufficient attention in the current curriculum. While similar challenges exist throughout Sub-Saharan Africa, Sierra Leone's unique combination of infrastructural deficiencies and pedagogical limitations creates particularly formidable barriers to chemistry education.

The study's findings corroborate international research (Taber, 2020; Calik & Ayas, 2005) on the inherent challenges of chemical symbolism, while importantly extending this understanding to resource-limited educational contexts.

4.5 Summary of Key Challenges of Pupils in Chemistry

Major gaps in predicting reaction products from reactants, particularly in reactions involving polyatomic ions (e.g., Reaction 2); acid-base interactions (e.g., Reaction 3). This was supported by student feedback in the questionnaire where 49.0% of pupils found formulas change during reaction and balancing of equation (28.7%) as persistent challenges.

Other key challenges identified during the study were notably:

a) Failure to apply basic reaction rules (Reaction 1).
b) Limited understanding of polyatomic ion behavior (Reaction 2).
c) Deficiencies in stoichiometry and fundamental reaction principles, such as acid-metal and Acid- base reactions (Reaction 3).
d) Misinterpretation of Symbols and Subscripts: Many students failed to recognize basic element symbols (e.g., Na and Cl in NaCl) and struggled with subscript meanings (e.g., valency in X_2 and Y_3). This suggests inadequate emphasis on foundational concepts in teaching.
e) Difficulties in Balancing Equations: Nearly half of the students did not grasp the conservation of mass principle, leading to incorrect balancing approaches. Misunderstandings about coefficients further indicate rote learning rather than conceptual understanding.
f) Language and Notation Barriers: The extremely low performance on '+' sign placement highlights that students struggle with the symbolic representation of reactions, possibly due to weak integration of language and chemistry instruction.
g) Inconsistent Performance: While students performed better in counting atoms ($C_6H_{12}O_6$), they struggled with more abstract concepts (balancing, valency), indicating a need for more visual and hands-on learning strategies.

5. Conclusions

1) *Evaluation of Basic Understanding:*

Students demonstrated limited proficiency in writing chemical formulas, particularly for compounds involving polyatomic ions (e.g., only 3.6% correctly wrote the formula for lithium trioxosulphate(IV). Balancing chemical equations was a major challenge, with only 7.3% correctly balancing the equation for the reaction between sodium and chlorine. Foundational knowledge gaps were evident, such as misinterpretation of chemical symbols (e.g., only 23% understood the representation of NaCl) and subscripts (e.g., 36.4% could not interpret valency from subscripts like X_2 and Y_3).

This study systematically examined two core objectives: first, to assess students' comprehension of fundamental chemical concepts including formulae and equations; second, to identify prevalent misconceptions and learning obstacles. The investigation yielded significant findings about the depth of students' understanding and the institutional factors contributing to these educational challenges, while situating these observations within both global pedagogical discourse and Sierra Leone's specific educational constraints.

2) Objective 1: Determining the Level of Understanding

The evaluation of students' mastery of chemical fundamentals uncovered substantial limitations in their knowledge. While demonstrating basic competence in simple formulations like sodium chloride (73.2% accuracy), learners exhibited severe difficulties with more complex applications. The extremely low success rates in formulating lithium trioxosulphate(IV) (3.6%) and calcium tetraoxophosphate(V) (6.4%) revealed critical deficiencies in applying valency principles, particularly concerning polyatomic ions and metal valencies. Similar challenges emerged in equation balancing, where only 7.3% could correctly balance the sodium-chlorine reaction, and attempts involving polyatomic ions showed near-total failure (1.8% success). These findings demonstrate that students' understanding remains largely superficial, restricted to memorization of basic concepts while lacking the analytical skills required for more advanced chemical applications.

3) Objective 2: Identifying Misconceptions and Difficulties

The research uncovered persistent conceptual misunderstandings that hinder students' chemical literacy. A striking 47.3% failed to recognize the connection between equation balancing and the fundamental law of mass conservation, approaching the task as rote procedure rather than conceptual exercise. Difficulties writing chemical symbols were equally prevalent, with only 23% comprehending elemental notation in NaCl and 18.6% able to deduce valencies from subscripts. The poorest performance emerged in interpreting the '+' sign in equations (1.8% correct), highlighting students' struggles with chemistry's abstract language.

6. Recommendations

Based on the results of this study, the follow recommendations could me made:

1) Restructuring the curriculum to emphasize foundational topics—such as elements, valency, symbols, chemical formulas, and chemical equations—in the first term of early senior secondary (SSS 1) is crucial for moving beyond memorization and promoting deeper conceptual understanding.
2) *Targeted Interventions*

Recruitment of trained and qualified chemistry Teachers, who should be encouraged to give remedial classes to pupils on symbols, valencies, and polyatomic ions (addressing 33.1% valency challenges). Futhermore, Teachers should implement regular exercises on symbol memorization and valency rules (Mnemonics for IUPAC names).

3) *Enhanced Pedagogy*

Teachers to use Interactive tools (molecular kits, PhET simulations) to visualize abstract concepts (pre-test: 1.8% understood '+' signs). Foundational topics (elements, symbols, formulas, equations) are prerequisites for understanding advanced chemistry concepts, teaching them as early as first term in SSS 1 is necessary. Teachers to use structured scaffolding for balancing (e.g., step-by-step templates for 28.7% struggling students). Peer-led problem-solving sessions could boost confidence among less-prepared students.

4) Systemic Support

School authorities should allocate more time and resources to chemistry instruction (e.g., increased lesson hours, lab access, and funding for molecular kits/digital tools).

-Principals should reform schedules to prioritize laboratory experiments (Pre-test: only 7.3% balanced acid-base reactions correctly).

-Provide teacher training on misconception-based instruction (Questionnaire: 34.4% cited time constraints as a barrier).

5) Continuous Assessment

Teachers to conduct Pre-tests to monitor progress in equation balancing (linked to pre-test gaps). Peer-led sessions to boost confidence (Questionnaire: 19% "Not Confident at all").

6) Further Studies

This research not only fills a gap in chemistry education literature for Sierra Leone but also offers a blueprint for similar contexts. Future studies could explore longitudinal impacts of the proposed interventions or expand into excluded areas like redox reactions. Ultimately, the study advocates for a dual focus: targeted remediation to address immediate knowledge gaps and systemic investment in infrastructure and teacher capacity to sustain long-term improvement. By equipping students with symbolic literacy and critical thinking skills, this work contributes to global efforts to democratize STEM education, ensuring that learners in resource-constrained settings are empowered to engage meaningfully with science in the 21st century.

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Contributions

Dauda Morie Fortune: Design and administration of questionnaire, data analysis and preliminary write up of the manuscript.

Mohamed Syed Fofanah : Data analysis, interpretation of results, review and final write up of the manuscript. (Main contact)

Isharka Mahmoud Conteh: Data analysis and interpretation of results.