JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

MISCONCEPTIONS ON BASIC STOICHIOMETRY AMONG THE SELECTED ELEVENTH-GRADE STUDENTS IN THE URBAN REGIONS OF THE GAMBIA

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Abstract. *The study complements previous research on a case study of chemistry lesson plans design and teaching. It has been found that chemistry education in The Gambia has been challenged by ineffective lesson plans design and teaching, and laboratory resources. The consequences have been unsatisfactory learning outcomes. However, what could lead to unsatisfactory learning outcomes in chemistry if basic stoichiometry is considered challenging? This has led the present study to develop a survey research method to assess students' misconceptions on basic stoichiometry. Through a systematic random sampling technique, 285-grade eleventh students were selected. The topics covered in the study included interpreting the pH of common substances, balancing basic stoichiometric equations, and inferences of experimental results. Students' responses to misconception survey questions were reviewed and analysed. The results indicated that students could be taught some basic principles of stoichiometry. Students who were challenged to correct inferences from experimental results need to develop their knowledge better. Accordingly, the study concluded that chemistry education can indicate the success of introducing basic stoichiometry, including referencing to the lower grades, rather than secondary grades. Nevertheless, what this study could recommend was to examine the possible source and cause of such misconceptions concerning basic stoichiometry reactions and balancing.*

Keywords: *basic stoichiometry, chemical reactions, pH values interpretation, students' misconceptions*

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Introduction

Chemistry is the branch of science that study the composition, properties, and transformations of matter. It explains the composition of matter to the different components along with their relative proportions. Furthermore, the properties can be used to distinguish one sample of matter from another. Besides, these properties can be classified as physical and chemical. Considering the properties of matter, teaching about and how they interact to form products require content knowledge and appropriate pedagogical strategies. However, one of the challenges that have been found in today's chemistry education is the effective instructional strategies (Can-Kucuk et al., 2022; Gilagu, 2019; Jammeh et al., 2022a; Yitbareh, 2011), and adequate laboratory resources (Igaro et al., 2011). The consequence is learning misconceptions, particularly in balancing basic stoichiometry (Yitbareh, 2011). The content of basic stoichiometry in grade 11 textbook do not seem to engage the students in meaningful thinking. Mergo (2012) described learning objectives and questions in the current textbooks as inappropriate for promoting critical thinking. Particularly, if teachers' chemistry content knowledge and teaching strategies are inappropriate, conceptual understanding of basic stoichiometry will continue to be challenging (Tal et al., 2021). However, inadequate instructional hours could be very challenging too for a teacher to accomplish and eloquently address the demand of learning objectives and questions (Gabel & Stucky, 2006). This may pose difficulties to students' learning, and as they move from one class to another, content also changes from simpler to complex.

Consequently, understanding those complex concepts becomes challenging for students to apply or learn. Accordingly, their interest in the subject may also decline as the content advances (Dillon & Avraamidou, 2021). For example, balancing neutralisation reactions in which all charges and state symbols are expected to be provided and the chemical equation balanced. The condition of providing all variables in the reaction often confuses students as they move to higher grade (Hans-Jurgen & Chemie, 1995; Yitbareh, 2011). Another example is the advance stage of finding conjugates between acid-base reactions using Bronsted-Lowry theory. Due to the weak founda-

https://doi.org/10.33225/jbse/23.22.254

tion, most of the students could not eloquently distinguish conjugate acid and conjugate base (Hans-Jurgen & Chemie, 1995). Therefore, to understand how students learn chemistry at the secondary level, the study focuses on the concept at which acid and base are stoichiometrically assessed by taking note of the pH of the solution and inferences. This is because there are different approaches used by teachers to teach such concepts (Bhise et al., 2014). Some helped students to understand chemical knowledge by first introducing the concepts of the acid and base, as the basis of chemistry foundation (Tunesi, 2020) before introducing neutralisation reactions. That is, the pH scale or values, for example, must be understood by students to better classify common substances within their localities into acid or base (Slessarev et al., 2016). A teacher may introduce the scale with the range of pH between 1 – 14 using pH=-log [H+] and pOH=-log [OH-], and the values describe the nature of the substances. Alternatively, the nature of substances can be determined using pH indicators, which could be in liquid dyes or paper strips. The liquid form of pH indicators (e.g., phenolphthalein, Methil orange, among others) is usually added directly to solutions to observe colour change and hence the determination of the pH strength. In contrast, the paper form is dipped into solutions and removed for comparison against a colour or pH key. Alternatively, the confirmatory test of substances as acid or base can also be locally tested using Akalypha Wilkesiana plants (Bhise et al., 2014) to perform the same function as conventional pH indicators. The proponents of this confirmatory test of acid and base are two renowned scientists, namely Brønsted-Lowry and Gilbert N. Lewis.

Brønsted-Lowry explained acid as a substance that gives out a proton from one of its hydrogen atoms and is usually a positively charged particle (nucleus of the hydrogen atom). These characteristic features explain the 'give' or 'take' of a hydrogen's proton. If this is translated into a pH scale, the acid will have a pH value below 7. In contrast, a base is any substance capable of accepting a proton, which requires a lone pair of electrons to bond to the H+. The pH value is above 7.

On the other hand, Lewis' theory explains an acid as any ion or molecule that can accept a pair of non-bonding valence electrons. While the base is any substance, such as the hydroxide (OH) ion, that can donate a pair of non-bonding electrons. A neutral substance (neither acid nor base) on the pH scale is 7 classified as pure water. Understanding this foundation course at the microscopic level is a challenge for most secondary school students (Kelly et al., 2021; Tunesi, 2020).

If students are challenged to determine the acidic and basic properties of substances through the pH scale, then exploring quantitative calculation of acid-base reactions – the process of titration would be a challenge too (Jimenez-Liso et al., 2020). Stoichiometry, therefore, is a significant component of chemistry, which explains the numerical relationship between reactants and products. According to Drechsler (2007), if students can determine the amounts of substances consumed and produced in chemical reactions, they may predict or produce the end formula of a wide range of unrelated reactions. For example, determination of acid and base conjugate, complex reaction mechanisms, and identification of the nature of the substances may be easier. The determination of the mole ratio to relate the amounts of two or more substances either by pairing substances or coefficients for each substance in the balanced chemical equation is another integral component in stoichiometric reactions. This has been found challenging for students to provide a coefficient for each substance (Lemma, 2013). Similarly, the reaction between [Fe_2O_3(s) + 2Al(s) 2Fe(l) + Al_2O_3(s)], is another challenge for students to explained as 1 mole of Fe_2O_3 with 2 moles of Al to form 2 moles of Fe and 1 mole of Al_2O_3. This procedural step for interpreting the mole ratio in the reactants and products should be clearly explained through lesson activities to give details of core ideas (Qing et al., 2010). The visual representation of reactions has been suggested to be included in the lesson activities (Kelly et al., 2021) than only writing the operations with little explanation of how or why on the blackboard.

Therefore, procedural steps in balancing reactions should be practiced avoiding or minimise learning misconceptions. In other words, core values to balance reactants and products should be emphasised as well as why they exist (Kelly et al., 2021). Explained to students why each reactant should have equal ratio, according to Qing et al. (2010), is a teaching requirement. Further, the reactions between sodium hydroxide and sulphuric acid to produce sodium sulphate and water, for example, heat is released [as 2NaOH + H_2SO_4, reactants and Na_2SO_4 + $2H_2O$ products], a step-by-step operation can be explained to students by arranging according to the mass or volume, on the one hand. On the other hand, a teacher may display reactants on the left side of the equation and the products on the right with a separation of either a single or double arrow to signifies the direction of the reaction (Lorenzo, 2005). This may be followed by indicating an equal number (proportion) of atoms on the left side of the equation as on the right with their states, which also included the elements, molecules, or ions in the reactants and the products. The proportion of how much each particle is relative to one another is learned through the stoichiometric application (Gongden et al., 2011; Lugemwa, 2012), and how such concepts should be reported must

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

be in line with scientific principles. However, in schools nowadays, this suggestion needs to be more effectively practised and considered (Keller, 2018).

Inappropriate inferencing is another concern reported in the Chief Examiner's Report (WAEC, 2019) involving metals and acids. Instead of students giving the appropriate interpretation of the observable features, they described non-observable features. For example, in a reaction between aqueous silver nitrate and aqueous sodium chloride produced a precipitate. Students' observations were based on the description of the colour, not the precipitate. This is because core activities are emphasised more than operational or process skills (Marchak et al., 2021). This has been supported by Kidanemariam et al. (2013), cited that learning macroscopic, microscopic, and symbolic levels can be step-by-step problem-solving. However, teaching of those levels in chemistry is based on assessment outcomes, and if the learning outcome is presumed positive then little effort is applied to the application of core principles (Yitbareh, 2011). These learning challenges continue to occur even though they performed better in the assessment (Dillon & Avraemidou, 2021). Ann-Soffi et al. (2020) have reported similar observations on students' learning concepts and applications during their survey research on a few selected students.

Research Problem

Essentially, chemistry teaching and learning in The Gambia, most of the students concerns about learning are ineffectively addressed. Are they being practised? How was the teaching approach addressing learning misconceptions? The consequence of this problem is unsatisfactory learning outcomes and application (WAEC, 2019), and if these questions are asked during lesson preparation, it might minimise learning misconceptions (Jammeh et al., 2022a). However, Cooper et al. (2016) have argued that even if those questions are asked, learning misconceptions will occur because teachers' pedagogical content knowledge (Jammeh et al., In Press) and teaching strategies are not giving meaningful meaning to learning (Lorenzo, 2005; Rogers et al., 2021). Teachers' collaboration is another concern that may cause learning misconceptions at some point (Gabel & Stucky, 2006), and through their collaboration, their teaching strategy, including content knowledge can be improved (Akyol & Fer, 2010). Therefore, this study was assessed through a survey research method comprising six different basic stoichiometry chemistry misconception test questions to understand and verify the report about The Gambian students' chemistry knowledge and application. This interest focus has never been studied on specific courses where they have been found challenging to demonstrate competence as this study intended.

Research Focus

Confirmatory tests of the common substances using pH values, basic stoichiometric equations, and inferences of experimental findings are the research focus. Through survey questions, the study learned about students' levels of misconceptions concerning the topics and highlighted the recommendations for improvement.

Research Questions

A. What are students' knowledge levels for interpreting pH values on common substances?
B. What are the students' levels of mastery of writing balanced stoichiometric equations?
C. How do students apply basic stoichiometric knowledge to chemical reactions and balancing?
D. What are students' knowledge levels on inferencing experimental findings?

Research Methodology

Research Design

The study used a survey research design comprised of six basic general chemistry tests to assess students' misconceptions. The design can describe students' strengths and weaknesses, particularly basic stoichiometry (Fraenkel et al., 2010), as its importance has been reflected positively in a diagnostic assessment of students' and teachers' basic chemistry concepts (Lemma, 2013). Since the study was a follow-up study, qualitative methods were used to review every response provided by students and quantitative approaches to obtain descriptive statistics for their

https://doi.org/10.33225/jbse/23.22.254

performances on each concept. However, the study only assessed basic stoichiometry in general chemistry courses of grade 11 within one and a half hours but it did not assess the sources and causes of students' misconceptions.

Participants

A consent form was prepared for study participants to promote confidence, trust, and reliability of the research findings as they were over 16 years of age. The participants were grade eleven chemistry students who consented and signed up for their participation. They were drawn from 12 secondary schools (Government/Public and Private) located in two out of the six administrative regions of The Gambia. Schools in regions 1 and 2 were selected because of the high chemistry student population compared to other regions in the country. This sampling characteristics were consistent with the current studies (Muralidharan, 2015) about how a sample could be selected from the population.

Systematic random sampling methods were used to select 285 students who were matched for equivalence using their academic records. That is, according to education statistics, the population from which the sample was selected were 1420 students (Directorate of Planning and Budgeting, 2018) and during the sampling, every 5th student from the beginning of the list of students was included, which gave a total sample of 285 students. This sampling frame was in line with the current practice for the selection of a sample from the population (Boru, 2018). Thus, the study was able to generate important data on the strengths and weaknesses of students' conceptual understanding of general chemistry courses (Boru, 2018).

Instrument

The misconceptions test items were developed using the grade eleventh secondary school syllabus and a typical textbook in the country (Aki-ola series). In total, ten (10) main questions were developed to assess students' misconceptions. Each of the question had sub-items of two to five (Table 1). The following learning area included interpreting common substances into acid and base using pH values, basic stoichiometric reactions and balancing equations, including states, ionic equation reaction, inferencing experimental findings, and observation and reporting skills. These topics were central to this study as they determined a lot about chemistry teaching and learning in secondary education (WAEC, 2019). The chemistry courses under study outlined students' understanding, competence, and challenges in solving problems.

Validity and Reliability

Content validity was provided by experts who were knowledgeable in chemistry education from the Gambia College School of Education, University of The Gambia School of Education and Science and Technology Directorate ministry of education. They checked language, clarity, ambiguity, and appropriateness, including the marking scheme for the level. Interrater reliability was used and the questions that did not meet the set criteria were revised by the researchers and returned to the raters for re-scoring. Items that failed to meet the criteria after three rounds were excluded from the study. Then, the pilot testing took place using 40 eleventh graders to determine the test's reliability and discriminant level. Each response was graded for item analysis and items with the highest points were mentioned first. Then, a sub-group was developed using the exact number of the lowest-scoring values through the difficulty index and the discrimination index concept on all items. Consequently, the number of items was reduced to six (6), see Table 2, and the resulting data was found with a reliability coefficient of .84 Cronbach's Alpha, which revealed to what extent the questions measure according to the difference among the questions and the variance of these questions (Hinton et al., 2004).

Data Collection and Procedures

This was a follow-up study from the previous one about a case study of a chemistry lesson plans design and teaching. General chemistry courses were developed to assess students' misconceptions and review after enlisting support from knowledgeable individuals for content validation.

Achievement test items were drawn to determine the specific characteristics of a group. These include learning the stoichiometry of chemical reactions, titration to quantitatively analysed solutions for acid or base

https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

concentrations and determining the nature of substances using a pH scale. Then the follow up questions were: what area was a challenge for them? why? And how were they inferencing experimental results? The descriptive survey technique was used through written items to test a representative set of students (Fraenkel et al., 2010). Each response provided by the students in a questions booklet was reviewed according to scientific principles and practice. Responses were tabulated and reported in the form of frequencies and percentages of those who answered in a particular way for each question. While ensuring representative results, data were collected in a way that items were clear and not misleading, and students were encouraged to respond thoughtfully and honestly within the sufficient number of assessment time (1hr30 min). In addition, each student was provided with a pen, calculator, eraser, pencil, and extra A4 papers for rough work. For every attempt, a mark (point) was allocated and entered as in Table 1.

Table 1
Items Preparation on Learning Areas for Assessment

Item	Sub-items	Learning area
1	3	pH Values & Scale
2	3	Stoichiometry
3	5	Symbolic equation
4	2	Ionic equation
5	5	Inferences
6	2	Observation

Table 2
Description of Items on Each Course

Item Number	Description of assessment parameters
1	Since it was a prerequisite course for stoichiometry chemical reactions, students were assessed on the identification or interpretation of common substances using pH values and scales as strong acids or bases. Weak acid or base, or neutral substances.
2	This was followed by stoichiometry chemical reactions and balancing. Examples, naming a gas formed between sodium hydroxide and dilute sulphuric acid, a description of colour that can be observed after adding copper (II) oxide onto the dilute sulphuric acid, and balanced reactions between sodium hydroxide and dilute sulphuric acid.
3	This measured students' ability to complete a symbolic equation by showing all physical states of reactants and products between copper (II) carbonate and dilute sulphuric acid.
4	Balancing the ionic equation of a reaction between ammonia and hydrochloric acid.
5	This assessed students' conceptual understanding of inferences on experimental results. For example, the reaction or addition of 5 cm3 of a weak acid (dilute hydrochloric acid) to sodium bicarbonate.
6	Students were expected to give correct scientific observations and reporting on reactions of three different substances (A, B, and C) at different temperatures (see Table 4).

Data Analysis

Scores were analysed based on points generated from 285 students on each item. These points were divided with a class interval of one (1). That is, 1 was the lowest point and 10 was the highest as in Table 3. Based on this approach, frequencies of students obtained at any point within a class interval, and percentages were calculated (Statistics Canada, 2021). The pivotal power table in the Excel data analysis tool was used to determine the frequency (*f*), and percentages (%) of points. The total frequency of students scored on each interval, divided by the total number of students (285) who took the assessment, multiplied by the result by a hundred per cent (100%).

https://doi.org/10.33225/jbse/23.22.254

For example, if 86 students (*f*) were between class intervals 1 to 2 on item one (1), the frequency per cent would be between 20 less than 40 or mathematically represented as 86/285 X 100= 30.2%. On this basis, the misconceptions were determined. Researchers used this interpretation to define the strengths and weaknesses of students' misconceptions.

Table 3
Frequency of Points on Class Interval Width with Interpretations

Class interval		Frequency per cent	Interpretation
Lower	Upper		
1	2	0 less than 20	Poor conception
3	4	20 less than 40	Weak conception
5	6	40 less than 60	Moderate conception
7	8	60 less than 80	adequate conception
9	10	80 less than 100	Strong conception

Research Results

The interpretation and understanding of the pH scale and values on some common local substances was a common introductory lesson or prerequisite knowledge about acidic, basic, and neutral substances. As shown in the rectangular box below, the diagnostic assessment results show that 30.2% (*N*=86) of students scored from 7 to 8 points, 30.9% (*N*=88) scored 5 to 6 points, 25.3% (*N* = 72) scored 3 to 4 points, and 13.7% (*N* = 39) scored from 1 to 2 points (Figure 1). This has indicated that 38.9% (*N* = 111) of students fell below moderate conception, meaning they were unable to correctly interpret the common substances into either strong acidic, basic, or weak acidic. However, 61.1% (*N* = 174) of students were above moderate conception, which indicated that common identification of substances was relatively easy as determined by their points.

Further on individual conception, the following were the students' interpretation of conventional pH values for some common substances: for example, soap (*pH = 9*) and baking soda (*pH = 8*), as the acidic solution, clearly showed that they may not understand pH scales or were not given a proper foundation of basic rules on pH scale to classify substances as acidic, basic, or neutral. Similar observations were found on vinegar (*pH = 3*), salt (*pH = 6*), dish wash detergent (*pH = 12*), sodium hydroxide 0.1M (*pH = 12*), well water (*pH = 6*) and distilled water (*pH = 6*), interpreted as weak alkaline, while distilled water (pH = 6), white sugar (*pH = 6*), and salt (*pH = 6*) as neutral substances were a bunch of misconceptions.

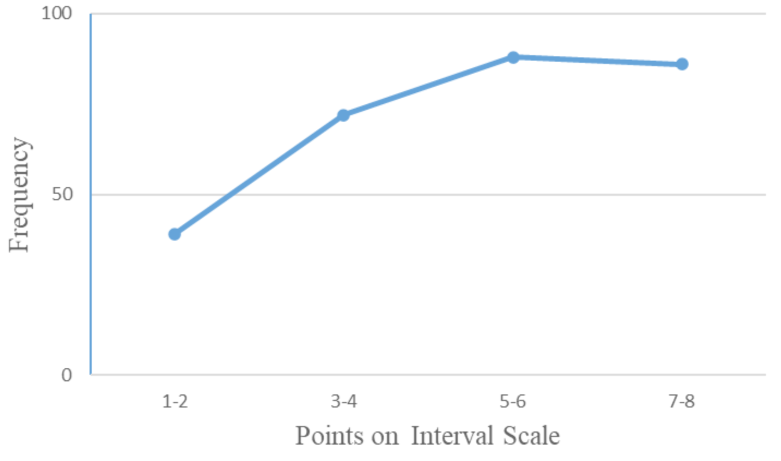
Use the table and answer the following questions:

i. *First, name at least three substances that can be regarded as strongly acidic.*
ii. *Next, name at least two substances that can be regarded as weakly alkaline.*
iii. *Finally, name two neutral substances, if any.*

https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1
Students' Interpretation of Common Substance-Using pH Values



Item two of the assessment (The stoichiometric balancing of chemical equations), as shown in the rectangular box below, had lower intervals than item 1. The results have indicated that 3.2% (*N* = 9) of students scored from 5 to 6 points, 12.6% (*N* = 36) from 3 to 4 points, and 84.2% (*N* = 240) from 1 to 2 points. Accordingly, the description has shown that 96.8% (*N* = 276) of students were below moderate conception, while 3.2% (*N* = 9) were within moderate conception (Figure 2).

In response to the items regarding products formed after adding magnesium ribbon to the dilute sulphuric acid. Students stated different products such as *[Water-$H_2O_{(l)}$, Hydrochloric acid-$HCl_{(aq)}$, Sodium hydroxide-$NaOH_{(aq)}$,* among others, instead of magnesium sulphate and hydrogen gas [$MgSO_{4(aq)}$ and $H_{2(g)}$] as two products formed. Similarly, when sulphuric acid was added to copper (II) carbonate, the products formed were supposed to be copper (II) sulphate, carbon dioxide gas and water. However, students wrote *Sulphur gas-$SO_2(g)$, copper (II) carbonate-$CuCO_{3(s)}$, sulphuric acid, water, and magnesium.*

Another example was balancing and naming the reaction between dilute sulphuric acid and sodium hydroxide. Only a few students had balanced and named the type of reaction, including their physical states. However, most of them were unable to correctly *balance the chemical equations, as well as indicate the state symbols for each molecule (Sodium hydroxide and dilute sulphuric acids)* or infer the colour correctly *(reaction between sulphuric acid and copper (II) carbonate).* A similar observation was found in observed colour change upon the addition of sulphuric acid to copper (II) carbonate. A few of them stated cyan-blue colour, and the rest could not.

Name **two products** formed when magnesium ribbon is added to dilute sulphuric acid.

i. Name the g**as** formed when dilute sulphuric acid is added to copper (II) carbonate.
ii. Balance and name the type of reaction between Sodium hydroxide and dilute sulphuric acid. Indicates their physical states.

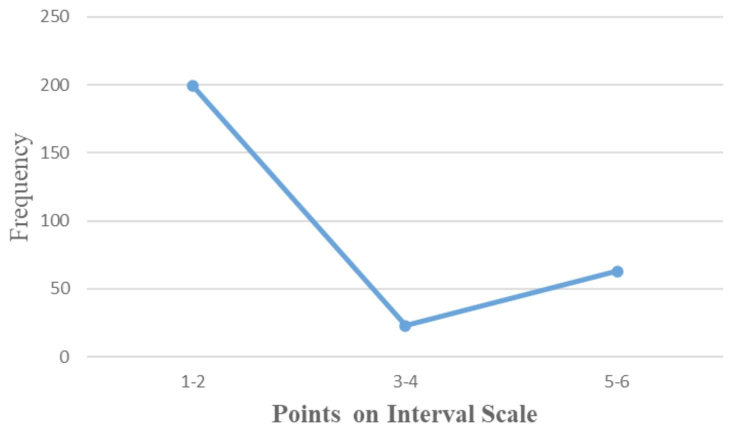
$$H_2SO_4 + NaOH \longrightarrow Na_2SO_4 + H_2O.$$

iii. What colour may be observed if sulphuric acid is added to copper (II) carbonate?

https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 2
Responses to the Reaction Between Common Metals and Acid Solution



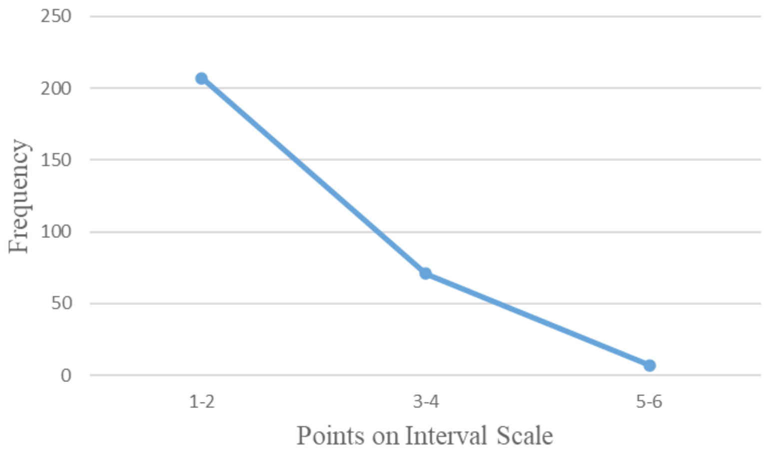
Another conceptual understanding was assessed for students to change the word equation to molecular, as shown in the rectangular box below. According to the results, 22.1% (*N* = 63) of students scored from 5 to 6 points, 8.1% (*N* = 23) from 3 to 4 points and 69.8% (*N* = 199) from 1 to 2 points (Figure 3). These values have indicated that only 22.1% (*N* = 63) fell within the moderate conception as this equation

$$[CuCO_{3(s)} + H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(l)} + CO_{2(g)}],$$

but with minor errors in physical states and the mole ratio of reactants and the products, while 78 % (*N* = 222) were outside the moderate competences (Figure 3), significant errors on application and understanding.

Balance symbolic with their state's chemical reaction between copper (II) carbonate and dilute sulphuric acid: ------------+ ----------------- $\longrightarrow$ --------------- + -----------+ ------------------------.

Figure 3
Responses to the Reaction between Copper (II) Carbonate and Dilute Sulphuric Acid



https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

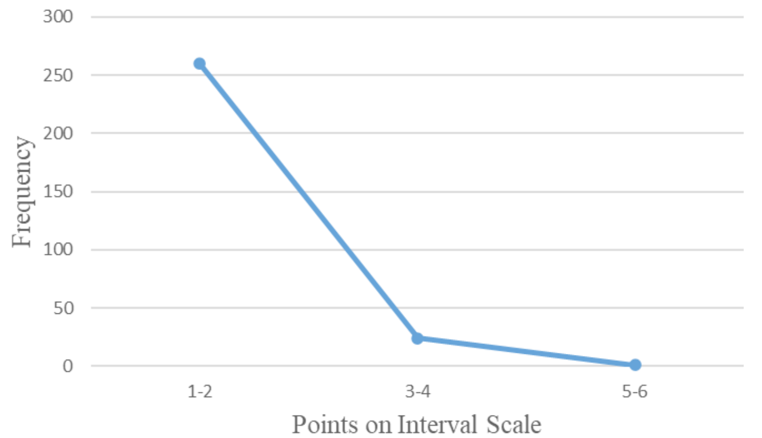
Stoichiometric balance reaction between ammonia and hydrochloric acid, including ionic equation as shown in the box below [$NH_{3(g)} + HCl_{(aq)} \longrightarrow NH_4Cl_{(g)}$] and [$NH_{3(g)} + H^+_{(g)} \longrightarrow NH_4^+ + Cl^-$]. According to the results, 2.5% (*N = 7*) of students scored from 5 to 6 points, 24.9% (*N = 71*) from 3 to 4 points and 72.6% (*N = 207*) from 1 to 2 points (Figure 4). By analysis, this has indicated that 2.5% (*N* = *7*) of students were within moderate conceptions because they had missed the physical states or needed help to complete the net ionic equation. While 97.5% (*N* = *278*) of students were below the moderate conceptions (Figure 4) with major areas for improvement, especially on the formula of ammonia (NH_3), which many wrote *as*

[NaOH + HCl? $\longrightarrow$ NaCl + H_2O?], without the state symbols. Similarly, forming complete net ionic equations of NH_3 and HCl as *[$NH_3(g)$? + HCl(ag)? $\longrightarrow$ NH_4Cl?].*

i. --------------- + --------------- $\longrightarrow$ -------------------.
ii. The net ionic equation between ammonia and hydrochloric acid.

Figure 4

Students' Responses to the Reaction between Ammonia and Hydrochloric Acid



The demonstration and understanding of inferencing (observation skills) on experimental results were also assessed. Students observed and explained the reaction between sodium bicarbonate and dilute hydrochloric acid, as shown in the rectangular box below. It was found that only .4% (*N* = *1*) scored from 5 to 6 points, 8.4% (*N* = *24*) from 3 to 4 points and 91.2% (*N* = *260*) from 1 to 2 points (Figure 5).

This has shown that 99.6% (*N* = *284*) of students were below moderate conception (Figure 5), indicating that most of them were challenged with observation skills. The experiment read as follows: what will be observed after adding dilute hydrochloric acid to a small portion of sodium bicarbonate solution? *Most of their descriptions were blue, with no observable change or neutral.* Further, they described the product formed as *sodium bicarbonate ($NaCO_3$) with a complete reaction as follows:*

Suppose a student put a teaspoon of sodium bicarbonate in a test tube, added about 5 cm³ of hydrochloric acid, and shook it thoroughly. The solution was tested with red litmus paper. What would a student observe after adding 5cm³ of weak acid to the teaspoon of sodium bicarbonate?
[$HCl_{(aq)} + NaHCO_{3(aq)} \longrightarrow NaCl_{(aq)} + CO_{2(g)} + H_2O_{(l)}$].

i. What would a man **observe** if he added dilute hydrochloric acid to the small portion of sodium bicarbonate solution?
ii. Name the **products** formed after adding HCl to $NaHCO_3$

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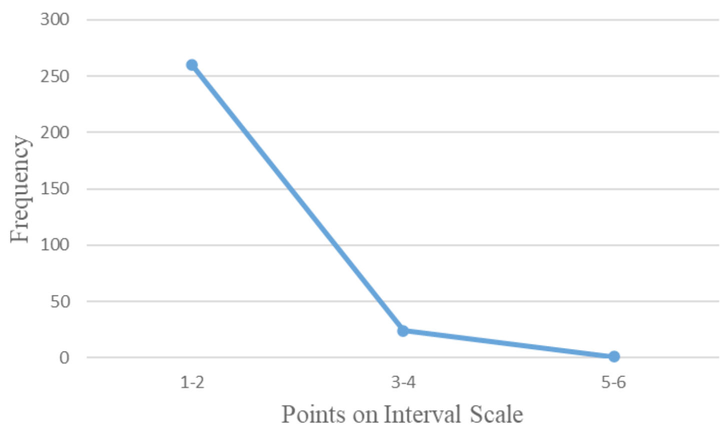
Figure 5
Responses to the Reaction between Sodium Bicarbonate and Dilute Hydrochloric Acid



Similar to item 5, students are expected to follow the instruction, state their observations, and balance a reaction between hydrochloric acid and iron (II) sulphate, as shown in the rectangular box below and in Table 4. While reviewing students' work, it was found that only 1.1% (*N* = *3*) scored from 7 to 8 points, 6.7% (*N* = *19*) from 5 to 6 points, 23.9% (*N* = *68*) from 3 to 4 points, and 68.4% (*N* = *195*) were 1 to 2 points (Figure 6). The results have shown that 1.1% (*N* = *3*) of students had adequate conceptions, 6.7% (*N* = *19*) were within moderate conceptions, and 92.3% (*N* = *263*) were below moderate conceptions.

It also means that few students gave the correct identification of **A**, **B**, and **C** (as *copper carbonate, copper oxide, and sodium chloride, respectively*), and they were able to balance the equation correctly [($FeS_{(s)}$+ $2HCL_{(aq)}$ $FeCl_{2(g)}$+ $H_2S_{(g)}$)]. However, most of them needed support in inferences and balancing correct chemical equations. For example, some students identified '**A'** *as sodium hydroxide, sodium chloride, magnesium, and copper (II) oxide.* '**B'** is *sodium hydroxide, sodium chloride,* and *copper (II) carbonate*, while '**C'** was *magnesium, copper (II) carbonate,* and *copper oxide*.

Similar misconceptions were found between a balanced reaction of hydrochloric acid and iron (II) sulphate, as highlighted in the equations below:

$$HCl? + FeS? \longrightarrow H_2S? + FeCl?$$
$$2HCl? + 2feS? \longrightarrow 2FeCl? + H_2S?$$
$$FeS + 2HCl \longrightarrow 2FeCL? + H_2S?$$
$$4HCl? + Fe_4SO_2? \longrightarrow 4FeCl? + 2H_2O?$$

Int: [*A chemistry student studied acid reactions with three different substances,* **A**, **B**, *and* **C**. *He recorded his observations and temperature change] as shown in Table 4 and the observations.* i. Identify **A**, **B**, and **C** from the substances in the table below. ii. Balance the reaction between hydrochloric acid and iron (II) sulphate

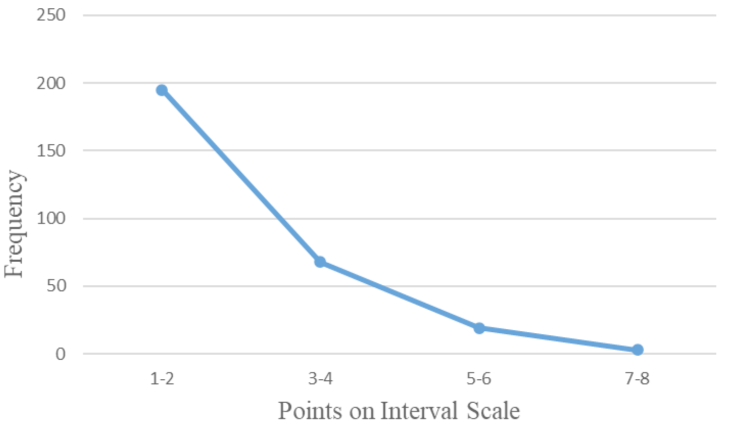
https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 4
Experimental Reports for the Reactions of Acids

A substance added to acid.	Observations	Temperature change (0C)
A	Bubbles of Gas are produced, gas collected turns limewater to milky, and the substance reacts to produce a blue solution.	+4
B	No gas is produced; the substance reacts to produce a blue solution	0
C	No visible change	+8

Figure 6
Students' Responses to the Experimental Experiences and Inferences



Discussion

The identification and interpretation of common substances into acidic, basic, or neutral was an introductory curriculum course for secondary schools in The Gambia. As a result, most of the students through a mathematical scale were able to correctly identify and interpret many common substances as acidic, basic, or neutral. The current study has similarly provided appropriate examples of the mathematical influence on scientific understanding of pH value and scale (Park & Choi, 2010). In addition, in terms of strength, there was adequate conception for students to determine the concentration, strength, and weakness of acid or base relating to their values. However, some of the students had different directions, which were further clarified while describing the pH value on the pH scale. This was similarly found, indicated that some of the students had misconceptions concerning pH identification in terms of strength and weakness (Kala et al., 2013). In this study, there were different contradictions and misconceptions in students' responses in terms of the identification and interpretation of the following substances: Baking soda (with $pH = 8$), vinegar (with $pH = 6$), dish wash detergent (with $pH = 12$), sodium hydroxide (with $pH = 12$), and well water (with $pH = 6$) as strong acid solutions. Further, they identified distilled water (with $pH = 6$) as a weak alkaline solution, while others stated distilled water (with $pH = 6$), white sugar (with $pH = 6$), and salt (with $pH = 6$) as neutral substances. These misconceptions of pH values contravene scientific principles on substance interpretation (Tunesi, 2020). Similar misconceptions were found in other studies (Bhise et al., 2014; Jimenez-Liso et al., 2020), and were not in line with scientific understanding. Cooper et al. (2016); and Dillon and Avraamidou, (2021) have attributed such misconception to a poor foundation. While Ann-Soffi et al. (2020) and Lemma, (2013) related to poor teaching strategies, which could have led students to develop misconceptions, especially defining the pH value as strength of acidity or basicity (Kala et al., 2013). These learning misconceptions might continue from one grade to another if appropriate measures are not taken (Dillon & Avraamidou, 2021; Nicoll, 2001). It is therefore suggested in the cur-

https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

rent study that teachers should be ready to take responsibility for improving students' conceptual understanding of chemical concepts (Qing et al., 2010).

Basic stoichiometry was another parameter assessed. Students were required to write coefficients in a bid to balance the chemical equations, as well as indicate the state symbols. Unfortunately, the results from their attitudes test were sometimes unscientific (Tal et al., 2021). For example, to determine coefficients in the stoichiometric equation, students thought each reactant was a liquid, and each product was aqueous at the sub-microscopic level. Furthermore, students thought ions of opposite charges attract and continue paring without putting the formula correctly. Similar studies found similar learning misconceptions (Kelly et al., 2021; Kidanemariam et al.,2013), and Tal et al. (2021) described such misconceptions as unscientific conceptions. In addition to unscientific reasoning, most of the students needed help in writing and balancing chemical equations, including the justification of coefficients in the reactions. In addition, they were tested to balance the reaction between magnesium ribbon and sulphuric acids [$Mg_{(s)} + H_2SO_{4(aq)} \longrightarrow MgSO_{4(aq)} + H_{2(g)}$]. Instead of producing the correct product, such as [$MgSO_{4(aq)}$], different unscientific products were formed. Examples *[$MgSO_{4(aq)} + H_{2(g)}$], [$NaOH_{(aq)}$]*. The reaction between [$CuCO_{3(s)} + H_2SO_{4(aq)}$ $CuSO_{4(aq)} + H_2O_{(l)} + CO_{2(g),}$] was another learning misconception. Some of the students needed help balancing correctly with physical states. Similar learning misconceptions have been found in students' learning at post-secondary education (Qing et al., 2010; Yitbareh, 2011), but teachers' lesson plans design and teaching (Jammeh et al., 2022a) and chemical knowledge (Keller, 2018; Usak et al., 2011) were the main concerns. Through correlational studies, teachers' misconceptions were positively correlated with the students (Usak et al., 2011). Lemma (2013) conducted a diagnostic assessment of teachers' and students' conceptions of a reaction between hydrochloric acid and iron (II) sulphate. The study found that students' misconceptions about the products and physical states, including balancing chemical equations, were positively correlated with their teachers. This was similarly observed during face-to-face interaction with pre-service teachers' understanding of balancing a reaction, including determining net ionic charges (Lorenza, 2005). WAEC (2019) also found positive correlation of students' misconceptions about learning quantitative calculation of acid-base reactions with their teachers.

Inferencing of experimental phenomena was another challenge revealed in the study. Most of the students responses were inappropriate, example, when substance A (hydrochloric acid) was added to substance B (iron (II) sulphate). In their responses, there was no theory stating that a compound or substance could be observed in the reaction. Similarly, students were asked to; 1, describe bubbles of gas produced or collected and turned limewater to milky, and 2. State observation when substances react to produce a blue solution when the temperature changes to $+4^{0C}$. The bubble of gas formed was stated as sodium hydroxide, instead of copper (II) carbonate. On the other hand, observable features were described more (sodium chloride, carbon dioxide, hydrogen) than non-observable features (effervescence, precipitate, or cyan blue) during and after the reaction. Instead of describing effervescence, some of the students described sodium chloride or hydrogen gas.

Therefore, the study of basic stoichiometry was for students to demonstrate the proportional nature of chemical equations in terms of the reactant needed to produce a given product. These core operations are essential in chemistry education, but how much of this rationale was taught at schools? Or how many of these concepts were investigated through physical experimentations? when laboratory resources continue to be inadequate at secondary schools (Igaro et al., 2011) Besides, most of the things considered challenging in today's chemistry are teaching experiences and strategies (Bayram-Jacobs et al., 2019), and attitude towards chemistry, particularly in Africa (Musengimana et al., 2020). Teachers are therefore encouraged to be innovative, for example, teach students the principles of the law of conservation of matter (Mergo, 2012). This may help them to effectively balance basic stoichiometry equations, including inferences of experimental results. Law of conservation of matter may encourage students to deduce that the atoms that were involved in chemical reaction ultimately remain unchanged, even if in another form.

Consequently, an appropriate reform process is needed, particularly regarding generic competence in chemistry education (Roger et al., 2021). Farheen and Lewis (2021) have suggested teaching reform by starting with what students already know to the unknown and starting with a single reaction to double in a stepwise direction than combining different concepts in a single equation. This was in line with other current studies about reform in chemistry education (Drechsler, 2007; Kelly et al., 2021; Marchak et al., 2021; Yitbareh, 2011). For example, with respect to reaction mechanism, the explanation of chemical reactions may be accompanied by a written formula explaining why it happens and the need for inserting arrows to show the direction of the reaction. In other words, students may be encouraged to articulate the meaning of arrows and physical states and emphases on why they must be provided in the chemical equation. However, if students are not asked to explain why they may continue identifying a product with an arrow, which may affect their understanding, and hence performance (Lemma, 2013).

https://doi.org/10.33225/jbse/23.22.254

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Conclusions and Implications

The study was a follow-up on a case study of a chemistry lesson plan design and teaching by teachers. It examined how each concept in the general chemistry course was understood and applied by the same students was the focus of the present study. While on assessment, six general chemistry courses were prepared to assess students without intervention but to understand the generic competence of students in chemistry education in The Gambia. As students work towards the survey questions, what, why and how students need support was understood. Essentially, the study assessed how students were faring with those courses related to what happened, how it happened, and why it happened. Through this critical thinking, the nature of questions about pH values on common substances, basic stoichiometry reactions and balancing thereof, inferencing and observation skills were the centre of the study, which ultimately reflected the types of responses students provided. This explicitly asked what the nature of the substances (Acidic or basic) was. It also explicitly explained what happened on the molecular level during a reaction and why the reaction occurred. Students who provided mechanistic reactions (based on Lewis or Bronsted theory) could construct appropriate basic stoichiometry chemical equations and balance. However, students who provide observational reasons need help constructing or solving basic stoichiometry reactions.

Therefore, to avoid recurrence of unsatisfactory learning outcome in basic stoichiometry reactions and balancing, the principles of law of conservation of matter may be encouraged as most of the students were challenged to understand basic stoichiometric. Several authors have suggested that helping students develop a better understanding of basic stoichiometric reactions, is by balancing single bond acid-base materials. This may enhance their ability to construct correct reaction mechanisms. Further, their interpretation of properties and prediction of many organic and inorganic reactions would be enhanced than just memorising reactions' paths with arrows, which may stay in mind for only a short period.

In this study, however, the evidence found, students' mastery of basic stoichiometry equations and balancing was a challenge, and they need support from teachers and education management. Interestingly, teachers nowadays do not have time to support students effectively because of their multiple roles in the school. Nevertheless, what this study could not exactly find was the possible source and cause of such misconceptions. It is suggested that further studies may examine the source and cause of students' misconceptions, particularly on basic stoichiometry chemical equations and balancing. The study further recommended that future researchers use standard assessment benchmarks to assess students' knowledge and mastery level, rather than the internal measurement scale.

In addition, chemistry teachers may encourage extra instructional hours to teach students basic stoichiometry rules in relation to the Lewis and Bronsted theory at the beginning of lower grades before moving to secondary school in The Gambia. Because through a deep discussion with students, this process is essential to improve their weak foundation than waiting to be taught at the intermediate grade 11. The study is concluded by emphasizing the importance of continuous professional development for teachers and the reorganisation of the chemistry curriculum from lower secondary to upper level.

Acknowledgements

The authors appreciate the financial support and moral contribution of the African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science- University of Rwanda College of Education (ACEITLMS, UR CE), the Ministry of Basic and Secondary Education (MoBSE), under whose schools the study was conducted for their support and encouragement. We were also indebted to validators from the MoBSE, Gambia College, the University of The Gambia, and colleagues at UR-CE for their valuable contributions.

Declaration of Interest

The authors declare no competing interest.

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Received: *November 10, 2022* Revised: *January 26, 2023* Accepted: *March 10, 2023*

Cite as: Jammeh, A. L. J., Keregeya, C., & Ladage, S. (2023). Misconceptions on basic stoichiometry among the selected eleventh-grade students in the urban regions of the Gambia. *Journal of Baltic Science Education*, *22*(2), 254-268. https://doi.org/10.33225/jbse/23.22.254

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