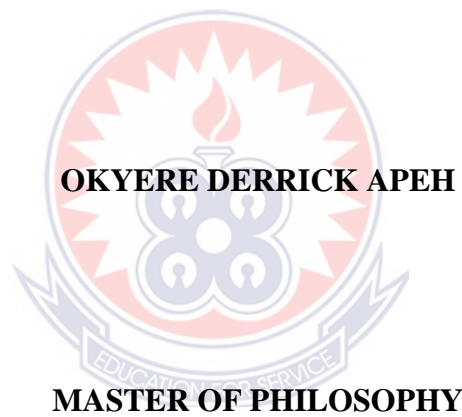


UNIVERSITY OF EDUCATION, WINNEBA

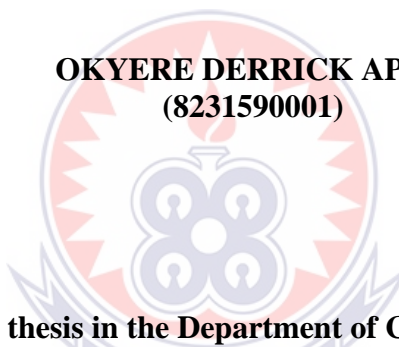
**Senior high students' academic performance in stoichiometry the use of
interactive simulations**



UNIVERSITY OF EDUCATION, WINNEBA

**SENIOR HIGH STUDENTS ACADEMIC PERFORMANCE IN
STOICHIOMETRY: THE USE OF INTERACTIVE SIMULATIONS**

**OKYERE DERRICK APEH
(8231590001)**



**A thesis in the Department of Chemistry
Education, Faculty of Science Education, submitted to the School of
Graduate Studies in partial fulfillment
of the requirements for the award of the degree of
Master of Philosophy
(Chemistry Education)
in the University of Education, Winneba**

AUGUST, 2025

DECLARATION

STUDENT'S DECLARATION

I, Okyere Derrick Apeh, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE.....

DATE.....

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

Supervisor's Name: PROF. RUBY HANSON

Signature.....

Date.....

DEDICATION

To my lovely late father, Mr. Francis Akwasi Okyere



ACKNOWLEDGEMENTS

I wish to express my profound gratitude to the Almighty God for the protection He gave to me through my years of study and the knowledge given to me to finish this work. I also thank Prof. Ruby Hanson and Dr. Esther Nartey for taking the pain and time off their busy schedule to go through this work, and make in-depth and constructive criticisms and suggestions for this work to become a reality. God bless her for a good job.

I am also thankful to the teaching and non-teaching staff of the Department of Chemistry Education for their contribution in diverse ways towards the success of my stay on campus, may the good Lord replenish their losses, and also to all the lecturers of University of Education, Winneba under whose tutelages I sat for all my courses; I say God bless you.

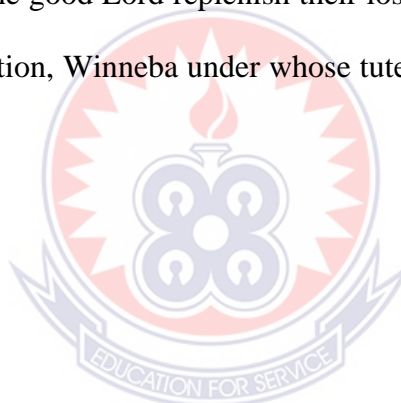


TABLE OF CONTENTS

Content	Page
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	viii
LIST OF FIGURES	ix
ABSTRACT	iv
CHAPTER ONE: INTRODUCTION	1
1.0 Overview	1
1.1 Introduction	1
1.2 Problem Statement	5
1.3 Purpose of the Study	6
1.4 Research Objectives	6
1.5 Research Questions	6
1.6 Null Hypothesis (H ₀)	7
1.7 Significance of the Study	7
1.8 Limitation to the Study	8
1.9 Delimitation to the Study	8
CHAPTER TWO: REVIEW OF RELATED LITERATURE	10
2.0 Overview	10
2.1 Theoretical Framework	10
2.1.1 Activity theory	10
2.1.2 Social constructivism theory	12



2.1.3 Kohler’s field theory of learning	13
2.1.4 Bruner’s theory of learning by discovery	14
2.1.5 Kolb’s theory of learning by doing or experience	15
2.2 Conceptual Framework	17
2.3 Stoichiometric Chemistry: Quantitative Aspects of Chemistry	18
2.3.1 Overview of stoichiometry and the mole concept	19
2.4 Concept of Stoichiometric Chemistry	24
2.5 Students Prior Conceptions Leading to poor Learning Outcomes in Stoichiometric Chemistry	25
2.6 Problem-Solving Skills in Stoichiometric Chemistry	27
2.7 Teaching Stoichiometric Chemistry	28
2.8 Learning Stoichiometric Chemistry	30
2.9 Computer Simulations	30
2.9.1 Using computer simulations with diverse learners	31
2.9.2 Advantages of computer simulations	31
2.9.3 Teaching with computer simulations	32
2.9.4 Using computer simulations to promote inquiry-based teaching	33
2.9.5 Computer simulations in the teaching and learning of chemistry	33
2.9.6 PhET Simulations	34
2.9.7 Positive effect of computer simulations on students’ performance in stoichiometry	35
CHAPTER THREE: METHODOLOGY	38
3.0 Overview	38
3.1 Research Paradigm	38
3.2 Research Approach	39

3.3 Research Design	40
3.4 Population	42
3.5 Sample and Sampling Technique	42
3.6 Instruments for Data Collection	43
3.6.1 Pre-test and Post-test	44
3.6.2 Validity of the Pre-test and Post-test	44
3.6.3 Reliability of the pre-test and post-test	45
3.6.4 Questionnaire design	45
3.6.5 Validity of the questionnaire	46
3.6.6 Reliability of the questionnaire	46
3.6.7 Administration of questionnaires	46
3.6.8 Interview guide	47
3.6.9 Reliability of interviews	47
3.6.10 Administration of interviews	47
3.7 Pre-intervention Activities	47
3.8 Simulation Intervention Activities	48
3.9 Simulations of Reactants, Products, and Leftovers	55
3.10 Post-Intervention Activities	57
3.11 Data Analysis	57
3.12 Content Analysis	58
3.13 Thematic Analysis	58
3.14 Paired Sample t-test	58
3.15 Ethical Considerations	58

CHAPTER FOUR: RESULTS AND DISCUSSIONS	60
4.0 Overview	60
4.1 Research question one	60
4.2 Research question two	65
4.3 Research question three	70
4.4 Research question four (4)	72
CHAPTER FIVE: SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS	78
5.0 Overview	78
5.1 Summary of the main findings of the study	78
5.1.1 Students' prior conceptions about stoichiometry.	78
5.1.2 Factors influencing students' poor performance in stoichiometry.	79
5.1.3 The effect of interactive simulations on students' academic performance is stoichiometry.	79
5.1.4 Students' perceptions regarding the effectiveness of the interactive simulation intervention on students' academic performance in stoichiometry.	79
5.3 Conclusion	80
5.2 Recommendations from the Study	80
5.4 Suggestions	81
REFERENCES	82
APPENDICES	101
APPENDIX A: Pre-test	101
APPENDIX B: Interview guide	102
APPENDIX C: Questionnaire	103

APPENDIX D: Post-test	105
APPENDIX E: Questionnaire	106
APPENDIX F: Marking Scheme (Pre-test)	108
APPENDIX G: Marking Scheme (Post-Test)	110



LIST OF TABLES

Table	Page
1: Total Population of Participants	42
2: Frequency of Students' responses to close-ended questionnaire	66
3: Paired or dependent sample t - test	70
4: Cohen's d categorization table	72
5: Results of the analysis from the questionnaire	73



LIST OF FIGURES

Figure	Page
1: Conceptual Framework	18
2: The moles and other terms that represent quantity of a substance	20
3: Concept map showing relationship of moles with other quantities	21
4: Flow diagram of calculations based on moles	29
5: Simulation changes, misconception changes to scientific conceptions	32
6: Flow chart showing the research approach	41
7: Game screen on building of molecules	50
8: Game screen on Phet simulation: Unbalanced reaction between Nitrogen and Hydrogen to produce ammonia	51
9: Game screen on Phet simulation: Balanced reaction between Nitrogen and Hydrogen to produce ammonia	52
10: Sandwich method to explain the ratio of reactants, products and leftovers	53
11: Phet simulation molecular view	54
12: Sandwich method of excess and limiting reagents of reactions	55
13: Phet simulation molecular view of excess and limiting reagents	56
14: Some students' answers obtained from the pre-test question about balanced chemical equations	61
15: Students' answers obtained from the pre-test question about mole ratio	63
16: Students' answers obtained from the pre-test question about molar mass calculations	64

ABSTRACT

The study investigated the use of interactive simulation intervention on students' academic performance in stoichiometry. The study used action research as the research design. The sample size for the study was 28 students comprising form 2 science students at Keta Senior High Technical School. A pre-test was administered to all the students followed by a semi-structured interview to know their prior conceptions about chemical stoichiometry. A questionnaire was used to determine the factors influencing students' poor stoichiometry performance. The results of students show that a lot of factors contributed to their poor performance in stoichiometry, some of which include low level of interest in the subject of study. After that, the interactive simulation was used to investigate the effect of students' performance before and after incorporating the interactive simulation intervention on students' performance in stoichiometry. To determine whether there was a significant difference in the academic performance of the students, the pre-test and post-test were analyzed using the paired sample t-test. There was a statistically significant difference in the academic performance of the pupils, as indicated by the paired sample t-test, which revealed that the t-statistics (6.42) was higher than the t-critical (2.060). This indicates that the interactive simulation intervention had a bigger impact on the students and that they fared better on the post-test than the pre-test. A questionnaire was again administered to examine student's perceptions about the use of interactive simulation intervention and the results were positive indicating students enjoyed the interactive simulation intervention which had a positive influence on their academic performance.



CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter includes the study's background, which serves as its main source of support, the problem statement, the study's purpose, its objectives, the research questions that guided it, its hypothesis, its significance, its limitations, and its delimitations.

1.1 Introduction

A main objective of chemistry education is to help students in creating mental models of chemical phenomena and ensuring a close harmony to scientifically accepted models as their higher order thinking skills are challenged (Akesela, 2005). Practical lessons form an embedded and indispensable part of any science curriculum at senior secondary schools. This is more so in chemistry as it is an experimental science. One area of physical chemistry where students demonstrate a lot of challenges with respect to building pure mental picture is stoichiometry (Mayer, 2017). Proper understanding of concepts involving stoichiometry is very beneficial to students and lots of professional programs which help in various practical applications like drug formulation, environment analysis and food productions (Gambari et al., 2016).

Simulations allow these individuals to understand and optimize chemical reactions which is crucial for industries such as pharmaceuticals and agriculture (Gambari et al., 2016). The basic idea of chemical stoichiometry is used in many branches of chemistry, particularly analytical chemistry, where a balanced equation illustrates the quantitative correlations between the number of moles of reactants and products. It makes it possible

for students to effectively answer numerical problems involving chemical reactions, concentrations, matter quantities, titrimetry, and chemical equilibrium. The linked stoichiometric ideas discussed above are essential to quantitative chemistry. Students' performance suffers when they are unable to comprehend and relate these ideas. For instance, to assess the outcomes of quantitative analysis such as titration, stoichiometric computations are required.

Reigeluth (2009) stated that chemistry is a branch of science that can be learned most effectively, if it is activity-centered or student-centered rather than the conventional method which is mostly teacher-centered. The teaching and learning of science and mathematics in less developed countries face significant challenges.

According to Qhobela and Moru (2014), a lot of scientific instructors primarily use the chalk-and-talk approach, which has a number of drawbacks and difficulties. Low academic performance, a decline in desire and interest in the subject, and a lack of persistence when faced with difficult concepts are some of the difficulties associated with the chalk-and-talk approaches (Gambari et al., 2016). Teachers find it difficult to use experimentation because of these difficulties, which are partially caused by things like poorly furnished labs and a shortage of supplies (George & Kolobe 2014). Consequently, both teachers and students find chemistry concepts like stoichiometry to be extremely difficult (Makhechane & Qhobela 2019). When teaching and learning strategies do not support conceptual development, the difficulties become more apparent.

Teachers occasionally find it difficult to break down difficult stoichiometry ideas into simpler, more understandable forms for the students (Kanime, 2015). Students have difficulty applying algebra to chemistry at a high level, connecting invisible and visible

constructs, using and interpreting chemical symbols, correctly applying the law of conservation of mass and proportion, balancing and interpreting chemical equations, and identifying limiting reagents (Gupta, 2019). Students must be able to balance equations, convert between quantities like mole and mass, and mentally picture sub-micro processes in order to have a meaningful understanding of stoichiometry. For stoichiometry to be taught and learned effectively, specific teaching techniques are therefore required.

Teaching for conceptual transformation and using 3-D representations is one recommendation (Taha et al., 2014). Furthermore, in order to enable students to concretize notions, the introduction of stoichiometry must begin with sub-microscopic representations (Davidowitz et al., 2010). The potential advantages of information and communication technology (ICT) for chemistry instruction and learning at the secondary school level have been investigated (Devalaki, 2019). Among these efforts is an emphasis on tools like virtual labs and simulations. Through interactive software applications called simulations, students can investigate intricate relationships between dynamic variables that mimic real-world circumstances. Literature documents the benefits of simulations such as responding to economic and safety challenges of real experiments and infrastructure shortage, assisting in the visualization of unobservable phenomena, promotion of critical thinking, enhancement of motivation and improvement of learners' performance (Kotoka, 2013; Nkemakolam et al., 2018; Plass et al., 2012). Studies on multimedia tools draw their theoretical support from theories such as Mayer's cognitive theory of multimedia learning, which proposes that meaningful learning occurs when words and pictures scaffold assimilation and accommodation (Mayer, 2017).

Research published in the literature offers valuable perspectives on attempts to assess how well simulations teach and learn stoichiometry principles. According to Gupta (2019), undergraduate students who took online courses that included simulations fared better than those who merely used text-based content. In balancing and comprehending chemical equations, as well as identifying limiting and surplus reagents, learners who were exposed to simulations performed exceptionally well (Gupta, 2019).

The majority of these research used an online platform and involved undergraduate students. Studies that are now available on scientific education have concentrated on topics including the development of ICT infrastructure and opinions regarding the integration of ICT and its potential to enhance chemistry instruction (Kotoka, 2013; Nkemakolam et al., 2018; Plass et al., 2012). There don't seem to be many research on the practical application and empirical results of simulations in the classroom, especially when it comes to stoichiometry. Thus, the goal of this study was to assess how simulations affected students' academic performance as a measure of how well stoichiometry was taught and learned. Thus, giving pupils the chance to socialize and participate in suitable activities improves their cognitive capacities.

They can then come up with problems, scientific questions, hypotheses, experiments, data collection and analysis, and conclusions regarding chemical phenomena (Aliu, 2011). Students can try to learn something together, ask each other questions, assess each other's ideas, and keep an eye on each other's work thanks to interactive learning. Therefore, each person is dependent upon and answerable to their coworker.

Given the importance of chemistry, it would be wise for teachers to master suitable techniques that will enable them to comprehend concepts and principles for successful learning outcomes, particularly in stoichiometry. According to Chang (2010),

stoichiometry is a branch of chemistry that uses computations to determine the masses or volumes of reactants and products in a chemical reaction. Additionally, stoichiometry indicates how much of each reactant is required to produce a sufficient amount of the desired product. Given this, pupils' learning outcomes would be greatly impacted by active engagement. According to (Akpan et al., 2020), a number of scholars looked into the elements that contributed to students' subpar performance, including Aliu (2011), Olurunyomi (2013), and Olorundare (2014).

These factors included inadequate practice, limited problem-solving abilities, trouble picturing chemical reactions, and a lack of comprehension of the fundamental concept. These are well-known factors that have a minor impact on pupils' performance. Structured education that allows students to build their own authentic sequenced ideas under the guidance of a facilitator can unleash students' skills, intelligence, and creative thinking.

1.2 Problem Statement

Reigeluth (2009) explained that active or participatory learning by students fused with a more interactive activities within the classrooms setting has been recognized as an effective, efficient and superior instructional techniques. Few students at Keta Senior High Technical School, namely those in form two, truly comprehend how to solve stoichiometric chemistry issues, according to the researcher's findings. The researcher examined the learners' calculations and found that the primary difficulties were their inability to balance equations, their inability to interpret the mass or mole ratio of the limiting reagent to the product, or their misinterpretation of a limiting reagent. In view of this, the study sought to adopt a simulated interactive learning environment

specifically an interactive computer simulation to assist students in conceptualizing stoichiometric principles to improve their performance.

1.3 Purpose of the Study

The purpose of this study was to use interactive simulations to improve form two (2) chemistry students' academic performance in stoichiometry.

1.4 Research Objectives

The study sought to:

1. unearth students' prior conceptions about stoichiometry.
2. explore the factors that influence students' poor learning outcomes in their study of stoichiometry.
3. determine the effect of using interactive simulations on students' performance in stoichiometry.
4. examine the perceptions of students regarding the effectiveness of interactive simulations on their learning outcomes in their study of stoichiometry.

1.5 Research Questions

1. What are students' prior conceptions about stoichiometry?
2. What factors influence students' poor learning outcomes in their study of stoichiometry?
3. What is the effect of using interactive simulations on students' performance in stoichiometry?
4. What are the perceptions of students regarding the effectiveness of interactive simulations on their learning outcome in their study of stoichiometry?

1.6 Null Hypothesis (H₀)

Based on research question 3, the following null hypothesis was formulated to guide the study. There is no statistically significant difference between students' academic performance in the concept of stoichiometry before and after the intervention.

1.7 Significance of the Study

The results of this study are intended to promote the use of computer simulations in the teaching and learning process in order to improve students' stoichiometry performance. In particular, the results of this study may be useful to curriculum developers, school administrators, chemistry teachers, students, and aspiring researchers. The results of this study may lead school administrators to see the necessity of encouraging and motivating their chemistry professors to use a simulated learning environment with their pupils during class. Similarly, this can give school administrators the chance to assess themselves and make the required changes.

The results of this study may give teachers more confidence that using computer simulations will help kids perform better. It might serve as a reminder to chemistry instructors of the value of these models in the classroom. Teachers would be familiar with how they are conducted and may correct them as necessary, increasing students' enthusiasm for chemistry and independence. Students may also benefit from the study's findings since they may gain a better understanding of how to approach stoichiometric difficulties.

It is believed that the results would give educational administrators information they may use to plan conferences, seminars, and workshops for chemistry teachers on different approaches to teaching stoichiometry. The results of this study could serve as a basis for future research in related chemical or other domains, according to the

researcher. This might provide additional support for the usage of computer simulations, which would give curriculum authors a starting point for their future work. This might result in the creation of books that will help educators understand the usage of simulations and make it more common in Ghanaian classrooms.

1.8 Limitation to the Study

Every single student has his or her unique style of learning, but this study particularly employed an interactive computer simulation which may not be the ideal method of instruction for all students to learn concepts. Additionally, some students never benefited from the intervention due to illness which affected their performance in the end. Also, some did not participate fully in the intervention because of absenteeism which affected the results obtained.

1.9 Delimitation to the Study

This study investigated the use of an interactive simulation on students' performance in stoichiometry at Keta senior high technical school at the Keta municipality. Specifically, the study focused on only form two chemistry students. The study covered four sub-topics under stoichiometry selected from the form two scheme of work. These topics are; balancing of chemical equations, limiting and excess reagents, stoichiometric ratio, and percentage yields. The sub-topics were selected with the aim of helping students address the challenges they face in stoichiometry, a topic identified by the researcher as a significant problem area for the chemistry students in this study.

1.10 Organisation of the Study

The impact of interactive simulations on students' academic achievement in stoichiometry was investigated in this study. Five chapters comprised the study's structure. The problem's background is presented in Chapter One. It includes the study's relevance, limitations, and delimitations, as well as its aim, objectives, questions, and hypothesis. The literature that is pertinent to the topic is reviewed in Chapter 2. The methodologies that are suitable for the study are highlighted in Chapter Three. Target population, sampling strategies, research instrument development, data collection methods, validity and reliability of the data, and research design are some examples of these approaches.



CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.0 Overview

This chapter examines the relevant research in the domains of science, psychology, and education. The following topics are covered in this chapter: conceptual framework, theoretical framework that incorporates activity theory, social constructivism theory, Kohler's Field Theory of Learning, Bruner's theory of learning by discovery, Kolb's theory of learning of experience, stoichiometric chemistry: quantitative aspects of chemistry, overview of the mole concept, concept of stoichiometry, misconceptions and difficulties related to learning stoichiometry, alternative concepts in stoichiometry, problem solving in stoichiometry, teaching and learning of stoichiometry, computer simulations, the advantages of computer simulations, using computer simulations to promote inquiry-based teaching, computer simulations in chemistry education, and Phet simulations. There has also been discussion of the empirical framework.

2.1 Theoretical Framework

2.1.1 Activity theory

Activity theory, which provides a thorough theoretical framework for a setting of computer-supported activities, served as the basis for this investigation (Hardman, 2005; Karanasios, 2014). Activity theory describes the organization and development of computer-assisted activities. In the current study, students engaged in simulation-based activities to accomplish a goal while learning stoichiometric chemistry. Thus, activity theory serves as a good theoretical basis for the study. Visual representations can be used to create a learning environment where students can interact with abstract concepts (Naidoo, 2017).

Therefore, the intentional design of the learning activities employing simulations for the current study, carried out through interaction, can result in conceptual comprehension. Activity theory was created in 1920 by Russian psychologists Vygotsky, Rubinshtein, Leont'ev, and others as a theoretical perspective on human-computer interaction. Engeström later added to it in 1987. Activity theory has been applied to human-computer interaction studies since the late 1980s and early 1990s.

Scholars note that understanding how technology benefits people is facilitated by framing human-computer interaction with intentional behaviors (Kaptelinin & Nardi, 2018). Activities that are more teacher-centered should give way to ones where students are in charge of their own education, according to activity theory (Froyd & Simpson, 2010). In order to account for the systems that connect stoichiometric chemistry, learning, and various social milieus which comprise the human, physical, and social conditions of the environment in which activities take place activity theory was employed as the theoretical framework for the current study.

This theory is predicated on the idea that all human acts are mediated by tools and are inextricably linked to the social context in which they are performed (Naidoo, 2017). Activity theory is closely related to Lev Vygotsky's (1978) constructivist theory of learning, which holds that students build their own knowledge through a variety of activities. By building their own knowledge, students are able to construct a meaningful experience through the activities and interactions with one another (Kotoka, 2013).

The social component of constructivism, which places emphasis on the social cognitive components of learning, is highlighted in Vygotsky's work. A learner's social and cultural background has an impact on their cognitive development. Although social engagement is how students learn, it is the teacher's responsibility to create an

atmosphere that supports social interaction. Accordingly, culture and community serve as a mediator for learning (Amineh & Asl, 2015; Malia & Kambleb, 2020). Activity theory has been a prominent topic in research on human-computer interaction since the early 1990s. A hierarchical structure of activity, object-orientedness, internalization/externalization, tool mediation, and evolution are the fundamental tenets of activity theory (Kaptelinin & Nardi, 2018).

Activity and learning are interrelated and interactive, according to the tenets of activity theory. The activity is aimed at an object in the hierarchical structure, and it is guided by particular objectives. Achieving the target, which entails doing many deliberate acts, is the aim. According to Kaptelinin and Nardi (2018), object-orientedness has socially or culturally defined characteristics even if humans live in an objective reality. They contend that in activity theory, the subject internalizes the item by using imagination and mental simulations. A subject converts external activities into internal ones in this way. Externalization is the process by which internal operations are changed into external ones.

Activity theory emphasizes how human activities are mediated by tools and how the use of tools leads to the creation and sharing of social knowledge. Lastly, the subject's active participation in monitoring developmental changes is also included in activity theory.

2.1.2 Social constructivism theory

Lev Vygotsky introduced the social constructivism learning theory in 1968. Vygotsky (1978) asserted that a person's language and culture have a significant impact on both their intellectual development and worldview. This suggests that concepts are expressed through language and then comprehended through social interaction and

individual experience within a specific cultural setting (Akpan et al., 2020). Social constructivists contend that humans learn from their interactions with other people in addition to creating meaning for themselves in a vacuum.

Hein (as stated in Akpan et al., 2020) asserts that the degree of development that a student can achieve with the help of teachers or in collaboration with peers is the level of potential prospects (academic performance). Education is therefore a social activity that involves interacting with family, friends, and even complete strangers.

It could be done through group discussions, teamwork, or any kind of educational interaction in a setting for education or training, on social media, in houses of worship, or in the market place. All of these need coordination and collaboration between those who wish to accomplish a shared goal. Social constructivism also highlights the collaborative nature of education (Western Governor University, 2020). As they collaborate to achieve a common objective, students' interactions with one another form the basis of their knowledge and allow them to gain knowledge from their peers. Social constructivism demands social cooperation and interdependence before goals can be achieved.

2.1.3 Kohler's field theory of learning

In order to test the theory of learning that supports Gestalt psychology, Kohler conducted an experiment. According to the theory, rather than being viewed as a collection of distinct elements, the entire learning scenario, including the surroundings, must be viewed as a single unit or pattern. According to the hypothesis, people see things as a single, cohesive whole rather than as a collection of disparate feelings. The theory focuses on what goes on inside of man and his capacity to recognize his surroundings and alter them in order to gain understanding and accomplish his

objectives. Here, structure, problem-solving, creativity, organization, significance, and complete comprehension are prioritized.

This was illustrated by Kohler (1929) in an experiment with a banana and a caged ape named Sultan. There were two sticks one short and one long between the sultan and the banana. The sticks were positioned so that the long stick could reach the banana, but the sultan's hands could only reach the short sticks and not the long one. Following an analysis of the issue, the Sultan gained a clear understanding of how to resolve it without resorting to a trial-and-error approach. The ape Sultan saw a connection between himself, the banana, the long staff, and the little stick.

According to the experiment, the ape solves its dilemma by first selects the short stick and pulls the long stick, which it then uses to draw the banana. This hypothesis suggests that learning is comprehensive and systematic rather than the result of trial and error. According to this hypothesis, perception plays a significant role in learning, including gaining insight. The approach also highlights how crucial learning is through exploration. Through investigation and experimentation, the student solves an issue using this learning approach.

Since hands-on learning entails problem-solving, experimentation, and research as a result of exercises or activities students participate in to find solutions to the problems, the theory is pertinent to the current study. After presenting the problem to the students, the study's teacher lets them use tools to solve the problem utilizing activities.

2.1.4 Bruner's theory of learning by discovery

The significance of the discovery learning approach to teaching is emphasized by Bruner's theory of discovery learning (Bruner, 1961). According to him, learning is

best supported when an individual can make their own decisions. According to this notion, when teaching science, teachers should design activities for their students that will help them learn the fundamentals while they are working on the lesson. In a learner-centered activity known as a "discovery activity," a student applies his newly acquired cognitive abilities to solve a problem. When used in science instruction, this method fosters self-assurance, intellectual curiosity, motivation, retention, and critical thinking, all of which improve student performance and retention.

2.1.5 Kolb's theory of learning by doing or experience

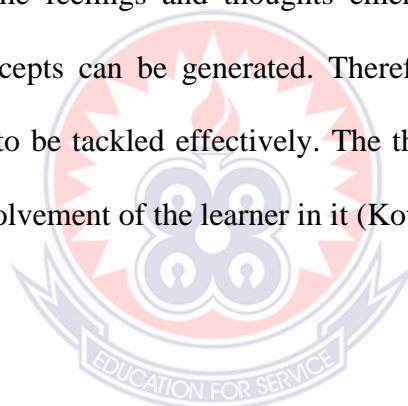
According to Kolb's theory, learning is the process by which experience or activity is transformed into knowledge. With four stages, the theory offers a cyclical model of learning. Although they must follow the order, one can start at any point. The learner actively participates in an activity, such as a lab session or fieldwork, during the first stage, known as the concrete experience (or "Activity"). The learner intentionally reflects on that activity in the second stage, which is known as reflective observation (or "Observe").

The third stage is called 'abstract conceptualization (for "Think")' is where the learner attempts to conceptualize a theory or model of what is observed. The final stage, active experimentation (for "Plan") this is where the learner is trying to plan how to test a model or theory or plan for a forthcoming activity. Kolb identified four learning styles which correspond to these stages. The styles highlight conditions under which learners learn better.

The styles are: assimilators, who learn better when presented with sound logical theories to consider. Convergers, who learn better when provided with practical application of concepts and theories. Accommodators, who learn better when provided

with “hands-on” activities. Diverges, who learn better when allowed to observe and collect a wide range of information. Kolb’s theory of learning by doing is relevant to this present study because, it emphasizes the important of active involvement of the learner in concrete experience or activity using concrete materials. It gives an insight on the manner as well as procedural steps involved in learning by activity through a series of sequential arrangement of those activities for effective learning.

It also emphasized that learning from experience or activity must involve links between the doing and the thinking. By implication, learning stoichiometry by doing may enhance reflection towards such activities, therefore, enhancing retaining ability of such activities. It is from the feelings and thoughts emerging from this reflection that generalizations or concepts can be generated. Therefore, its generalizations would enable new situations to be tackled effectively. The theory supports this study as its emphasis on direct involvement of the learner in it (Kotoka, 2013).

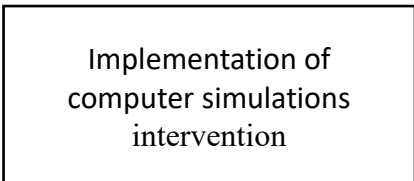


2.2 Conceptual Framework

A conceptual framework shows how variables are related to one another (Bas & Tega, 2023). The framework underlying this study is mainly concerned with computer simulations towards students' academic performance in stoichiometry. The conceptual framework of this study is rooted in the following representation of activities:

1. Students interacting with group members- This is where students have conversations with one another about stoichiometry.
2. Class objectives- This is where the teacher spells out what needs to be taught under stoichiometry.
3. Students' involvement- This is where students actively participate during the intervention.

When the computer simulations (the independent variable) are manipulated, it affects the academic performances of the students (the dependent variable). The study's conceptual framework is derived from the relationship between the independent variable (computer simulations) and the dependent variable (students' academic achievement). Figure 1 illustrates how the factors involved relate to one another.



Implementation of
computer simulations
intervention

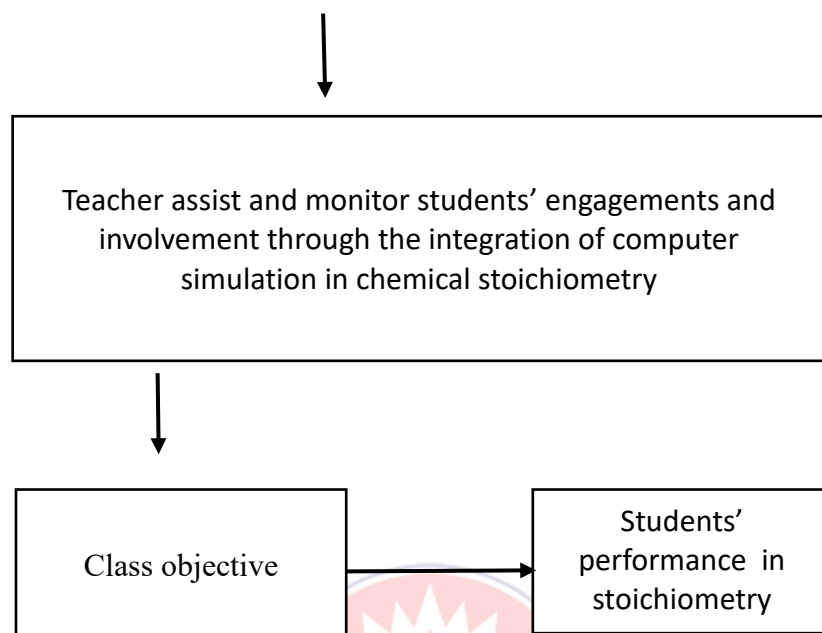


Figure 1: Conceptual Framework

Source: Researcher's construct

From Figure 1, when computer simulations are manipulated, it affects the academic performance of students. This means for the academic performance (dependent variable) of a student in stoichiometry to increase or decrease it depends on the effectiveness of the computer simulations (independent variable).

2.3 Stoichiometric Chemistry: Quantitative Aspects of Chemistry

Stoichiometric chemistry is divided into three parts: chemical systems, matter and materials, and chemical change. This study's primary focus, stoichiometry, has to do with chemical transformation. Stoichiometry is an important subject in Ghanaian high school curricula since it deals with the quantitative aspects of chemistry (Malcolm et al., 2018). Conservation of matter and chemical change are two fundamental concepts in stoichiometric chemistry. The conservation of matter is the cornerstone of any

investigation into chemical change. The law of conservation of matter, which asserts that matter is never created nor destroyed, was discovered by Antoine Lavoisier.

It is crucial to understand that the amount of any reactant involved in a chemical transformation will be preserved as a result. This concept, which will be covered in detail in the following sections, provides the basis for both the stoichiometry of the reaction and the balancing of the equation.

2.3.1 Overview of stoichiometry and the mole concept

In order to calculate ratios by the mass of chemical elements as they mix, German chemist Jeremias Richter coined the term "stoichiometry" in 1792. The Greek terms *stoicheion*, which means element, and *metron*, which means measure, are the origin of the phrase stoichiometry. According to Upahi and Olorundae (2012), the term "mole" in chemistry refers to the quantity of a chemical that is essential to beginning chemistry. Ostwald was the first to introduce it at the start of the twentieth century. Mole is represented by the letter *n*. Adding the suffix "cula" to the Latin word "mole," which means "big mass," changes it to "molecula," which implies "small" or "tiny."

The German chemist coined the term "molar," which comes from the word "mole," which meaning "large mass" and is the reverse of "molecular mass." The phrases microscopic and macroscopic are replaced by molar and molecular. Since then, the term "mole" has been used extensively without any explanation of the type of number it refers to (Pekdağ & Azizoğlu, 2013). The International Organization for Standardization, the International Union of Pure and Applied Chemistry, and the International Union of Pure and Applied Physics suggested in 1971 that the mole be added to the International System of Units (SI) as the fundamental unit of substance amount.

According to Pekdağ and Azizoglu (2013), a mole is defined as the quantity of a system's material that has as many elementary entities as there are atoms in 0.012 kg of carbon-12. Figure 2 illustrates the key concepts that must be understood when applying the mole idea and is based on a study on stoichiometric chemistry conducted by Malcom et al. (2014).

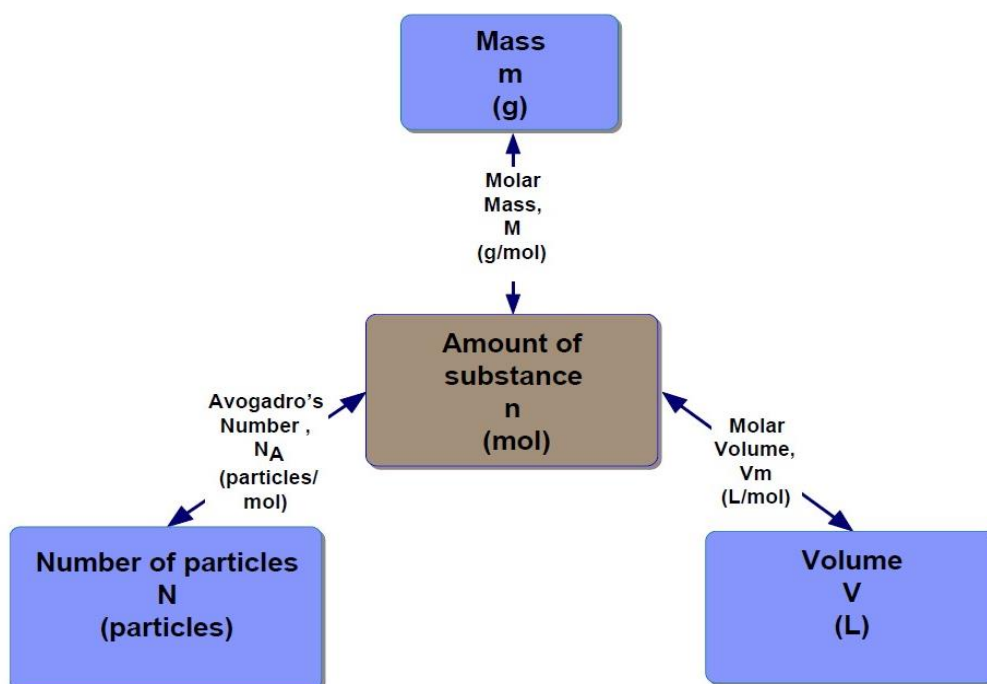


Figure 2: The moles and other terms that represent quantity of a substance

The various quantities in which compounds are expressed while working with stoichiometric calculations are explained in Figure 2. There is a connection between each of them and the quantity of chemicals, mol. Certain fundamental formulas are used in calculations based on the mole idea. These formulas relate the substance's mass (m), molar mass (M), or atomic mass, number of particles (N), and volume (V) with gases included to the mol (n), which is the central block in Figure 2. When converting the amount of a substance from mol to other values, like mass, volume, or particle count, these equations must be used in the computations.

Stoichiometric calculations rely on these interconversions, which allow one mole of a material to be equivalent to a specific mass of each substance in grams, number of particles, and volume. The mole's relationship to mass, molar mass, number of particles, and volume is depicted in Figure 3 (Fang et al., 2016).

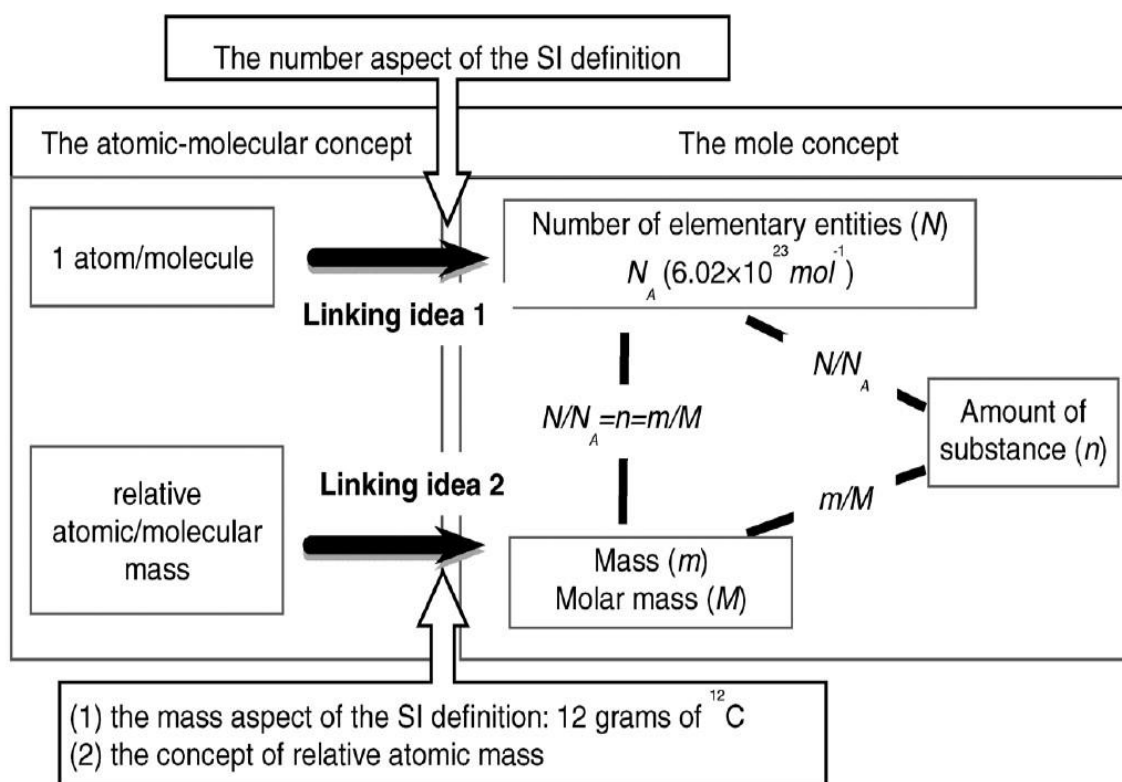


Figure 3: Concept map showing relationship of moles with other quantities

The concept map illustrates how the mole is incorporated with the atomic molecular concept and linked by the two linking ideas. The meaning of the mole can be comprehended from two perspectives: the mass aspect and the numerical aspect. An example can be used to better illustrate the numerical aspect: if two moles of Ne-20 are present, the substance will have two $\times 6.02 \times 10^{23}$ Ne-20 atoms (Ne-20 is the element neon with atomic mass 20). This is due to the fact that 6.02×10^{23} elementary entities make up one mole of any substance.

The relationship between the associated mass in grams and the atomic mass/molar mass can be used to explain the mass idea, which is given in grams. A material's molar mass, measured in grams per mole (gmol^{-1}), is the mass of one mole of that substance equal to its atomic mass, molecular mass, or formula mass. The total mass of two moles of Ne-20 is equivalent to two times twenty, or forty grams. Regarding the atomic-molecular idea, these two points are relevant. This explanation brings us to the crucial point that the mass component deals with relative atomic mass, molecular mass, or formula unit mass, whereas the number component deals with the material made up of atoms or molecules.

The following three formulas relate the mass (m) or molar mass (M), the number of elementary entities (N), and the amount of material (n): Idea 1: $n = N / N_A$ Idea 2: $n = m / M$

The numerical component of the SI-accepted definition of the mole is the first connecting notion. In order to explain the numerical equality between molar mass and relative atomic mass, linking idea 2 demonstrates the relationship between the two. Teachers can teach students to compute moles and their interconversions with mass, number of particles, volume for gases, and concentration for solutions using a problem-solving technique that can be summed up as follows (Arya & Kumar, 2018):

- Put the given data in writing and determine what has to be calculated.
- Choose the right formula that relates moles to the necessary computations.
- If the molecular mass (M) is not provided, compute it if necessary.
- Change the formula's subject after substituting what is provided to determine the unknown.

The area of science known as stoichiometric chemistry examines the quantitative features of chemical processes, including the correlations between the number of moles of reactants and products. This is because students need to determine the amount of a reactant or product in a chemical reaction in order to gain a deeper understanding of the subject. In chemistry, this is categorized under the quantitative aspects (Hanson, 2016; Okanlawon, 2010). By understanding stoichiometric chemistry, students may solve numerical problems related to chemical reactions, concentrations, amounts of substances, titrations, and chemical equilibrium (Hanson, 2016).

These concepts form the foundation of quantitative chemistry. When students are unable to understand and connect these concepts, they encounter conceptual challenges. To solve stoichiometry problems, the student must utilize ratios in balanced equations, write balanced chemical equations, apply the mole concept, calculate the molar mass of compounds, identify the limiting reagent, mass percentage, and yield percentage, and determine the empirical and molecular formula (Gulacar, 2007). When analyzing a balanced equation, the coefficients that appear before the chemical formula indicate the quantity of reactants that reacted and the products that were produced in accordance with particular proportions or ratios. These coefficients show the ratio of reactants to products.

When doing calculations, the coefficients can be thought of as the mole ratio of the reactants and products. As the quantitative aspects of chemical transformation, stoichiometry is covered in Ghana beginning in year 2 and focuses on balancing chemical equations, calculating molar mass, mole concept, discovering empirical formulae, mole formula, and mass-mole ratio computations. More complex calculations utilizing limiting reagent/reactant, yield, and purity percentages are covered in Year 2.

Since a thorough understanding of stoichiometry requires an understanding of limiting reagents and excess reactants in a chemical reaction, it is especially important that students understand what a limiting reagent is and how it affects the amount of the product formed (Gauchon and Méheut 2007). The number of products generated in a reaction is determined by the amount of the limiting reagent, which is the substance that is consumed completely first. The ratio of the limiting reactant to the product must be considered in order to calculate the amount of product that is produced. Furthermore, reaction stoichiometry includes solving theoretical and practical yield concerns.

The theoretical yield is the maximum amount of product that can be generated once every limiting reagent has reacted in line with the balanced equation without causing any loss. However, most reactions are not perfect in reality. As a result, the actual yield—the quantity of product produced during a chemical reaction experiment—will be less than the theoretically anticipated amount. Calculations using a sample's percentage purity are also part of reaction stoichiometry. This calculation is important when an impure sample is used in a reaction. The percentage purity of the impure sample can be determined by reacting with a pure chemical, such as in an acid-base titration.

2.4 Concept of Stoichiometric Chemistry

Stoichiometric chemistry, according to Upahi and Olorundare (2012), essentially entails connecting a substance's mass to atoms, molecules, or formula units; transforming the composition analysis result into a chemical formula; and utilizing the quantitative information contained inside. Students' comprehension of the more complex ideas that build upon the foundational principles in chemistry will suffer if

they do not fully grasp the basic ideas (Osman & Sukor, 2013; Woldeamanuel et al., 2014).

Understanding the different obstacles that stoichiometric chemistry faces in both teaching and learning is crucial. These obstacles include teaching stoichiometric chemistry, misconceptions about how to interpret and comprehend stoichiometric chemistry, and the challenges that students face when trying to grasp the concept.

2.5 Students Prior Conceptions Leading to poor Learning Outcomes in Stoichiometric Chemistry

Several studies (Bridges, 2015; Fach et al., 2007; Gauchon & Meheut, 2007; Opara, 2014; Upahi & Olorundare, 2012) have shown that many learners struggle to understand stoichiometric concepts in chemistry. Despite this, limited research has focused on strategies to improve learners' conceptual grasp of the subject. According to Malcolm et al. (2018), students often underperform in stoichiometric calculations because they lack a sound understanding of the mole concept, fail to write and balance chemical equations, struggle with mathematical skills, and cannot systematically interpret word problems into solvable steps. Misconceptions are also common: some believe "mole" is simply an abbreviation of "molecule," while others confuse the terms atom, molecule, element, and compound (Ndlovu, 2017). Yaayin and Ayoberd (2018) further note that students inconsistently link the mole either with particle number or mass, despite its clear international definition. Even at university level, confusion persists, with learners mixing up related concepts such as mass, molar mass, molar volume, and the mole (Hanson, 2016). For instance, students sometimes apply the gas molar volume relationship when calculating quantities of solids and liquids, reflecting gaps in their conceptual knowledge (Ndlovu, 2017).

Learners also struggle to see the role of coefficients in balanced equations as mole ratios that guide reaction proportions (Opara, 2014). This difficulty undermines their ability to apply the law of conservation of mass, which requires correct use of mole ratios to connect reactants and products (Chandrasegaran et al., 2009). As Ndlovu (2017) points out, many cannot balance equations, apply algebraic reasoning, or translate word problems into procedural steps, relying instead on rote algorithms. Such methods may yield answers but do not strengthen comprehension or critical thinking (Van der Westhuizen, 2015). Weak conceptual foundations at school level further hinder students when faced with advanced chemistry at university.

For example, in the reaction between hydrochloric acid and sodium carbonate: $2\text{HCl} + \text{Na}_2\text{CO}_3 \rightarrow 2\text{NaCl} + \text{CO}_2 + \text{H}_2\text{O}$ the coefficients indicate that two moles of HCl react with one mole of Na_2CO_3 . Learners often fail to grasp this relationship and apply it consistently in problem-solving, a skill central to mastering stoichiometry (Okanlawon, 2010; Omwirhiren, 2015). Misunderstandings extend to concepts such as limiting and excess reactants. Many students assume both reactants are fully consumed, or that the limiting reagent is simply the one with the smallest mass or lowest mole ratio, which leads to incorrect solutions (Chandrasegaran et al., 2009; Gauchon & Méheut, 2007; Marais & Combrinck, 2009; Malcolm et al., 2014). Even when they can identify the limiting reagent, they often fail to use it to calculate remaining reactants or the products formed (Hanson, 2016).

Additional misconceptions include misunderstanding dilution failing to recognize that while concentration and volume change, the number of moles remains constant (Malcolm et al., 2014). The challenge of moving between the macroscopic and

microscopic levels of matter compounds these difficulties, especially when foundational ideas are poorly understood (Marais & Combrinck, 2009).

Because students often lack conceptual grounding, both learners and teachers rely heavily on algorithmic approaches. While formulas and substitutions may work for direct calculations (e.g., determining moles from a given mass), such methods fail with multi-step or unfamiliar problems that require reasoning (Schmidt & Jignéus, 2003; Fach et al., 2007; Arasasingham et al., 2004; BouJaoude & Barakat, 2000). Research suggests that solving stoichiometric problems successfully requires an integration of scientific understanding, mathematical skills, and language competence. Rote strategies may help in basic tasks, but genuine mastery of stoichiometry demands conceptual understanding particularly of mole ratios, proportional reasoning, and the interconnection between macro and micro perspectives. Without this, learners are restricted to solving familiar problems, while complex problem-solving remains a challenge (Marais & Combrinck, 2009).

2.6 Problem-Solving Skills in Stoichiometric Chemistry

Problem-solving in stoichiometric chemistry relies heavily on learners' understanding of moles, chemical equations, and formulae. According to Gulacar (2007), students' ability to carry out stoichiometric calculations is influenced by cognitive factors such as prior knowledge, reasoning ability, and problem-solving skills. Without these foundations, learners struggle with concepts like limiting reagents, percentage purity, and acid-base stoichiometry. Developing these skills not only supports success in basic stoichiometric problems but also prepares learners for more advanced topics such as reaction rates, equilibrium, and acid-base chemistry. However, many students, both at school and university level, find mole calculations and stoichiometric problem-solving

particularly challenging, which discourages them from pursuing chemistry further (Lerman, 2014; Ross, 2016).

From the literature, the essential skills needed for mastering stoichiometric problem-solving can be summarized as follows:

- Identifying and balancing unbalanced equations;
- Interpreting mass–mole relationships of reactants and products;
- Classifying and understanding types of chemical reactions;
- Explaining and identifying limiting and excess reagents;
- Calculating theoretical and actual yield; and
- Determining the percentage purity of compounds.

2.7 Teaching Stoichiometric Chemistry

Given its complexity, stoichiometric chemistry requires learners to build on both conceptual understanding and mathematical competence. Mastery of reaction stoichiometry depends on connecting fundamental concepts, such as moles, mass, and molar mass, to calculations. Since many of these terms sound similar, teachers should first ensure that learners review and fully understand their definitions before applying them in problem-solving (Fach et al., 2007). Misunderstandings often arise when definitions and conceptual links are unclear.

Hanson (2016) highlights three core ideas essential for effective teaching of stoichiometry: the mole concept, limiting reagents, and solution concentration. Instruction should therefore focus on these concepts until learners can apply them with confidence. The goal is not simply to solve problems mechanically but to help learners conceptualize stoichiometry so that they can use it to explain and predict chemical processes. To achieve this, learners must be guided in translating abstract ideas into

concrete representations (Hanson, 2016; Malcolm et al., 2018; Pekdağ & Azizoglu, 2013).

Teachers' instructional strategies play a crucial role in developing both scientific and procedural knowledge. Research emphasizes the importance of teaching for conceptual understanding rather than relying solely on traditional lecture-based methods (Malcolm et al., 2018). By adopting diverse instructional approaches, teachers can help students overcome misconceptions and engage more meaningfully with stoichiometric chemistry.

A common pattern that is used to teach stoichiometric calculations, suggested by Gulacur (2007), is shown in Figure 4.

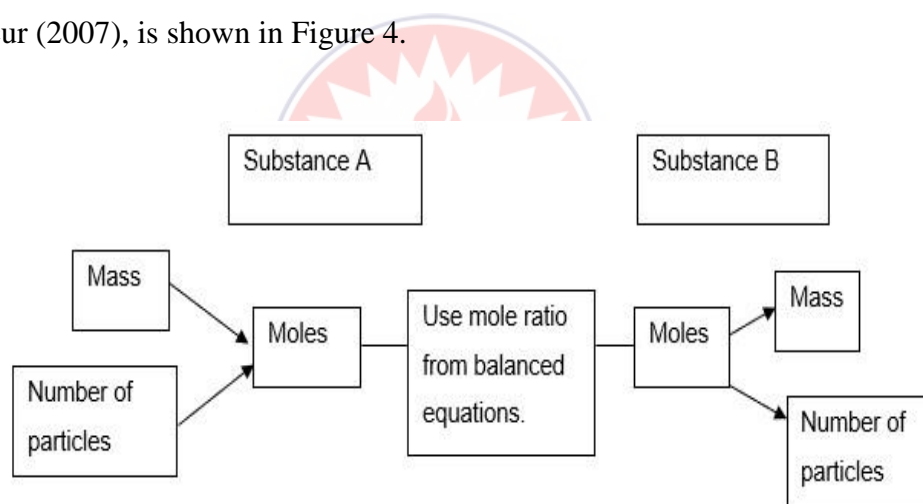


Figure 4: Flow diagram of calculations based on moles

2.8 Learning Stoichiometric Chemistry

Research on students' understanding of stoichiometry suggests that successful learning requires conceptualization, visualization, mathematical competence, and problem-solving skills. A strong foundation in balancing equations and applying mole ratios to identify limiting and excess reagents is essential. Teachers can support this learning by using innovative strategies that expose learners to macroscopic, microscopic, and symbolic representations (Jaranilla et al., 2017).

Students frequently make errors in problem-solving because they fail to approach problems conceptually. To minimize such comprehension errors, teachers are encouraged to emphasize clear explanations, simplify concepts, and discourage reliance on purely algorithmic methods. Stepwise approaches, group work, and activity-based demonstrations have been recommended to improve learners' understanding (Omwirhiren, 2015).

Different perspectives exist on how best to teach the mole concept. Fang et al. (2016) suggest identifying key components of the topic to strengthen classroom instruction, while Omwirhiren (2015) advocates for structured, logical progression in teaching complex calculations. Malcolm et al. (2018) recommend teaching stoichiometry across a series of lessons to consolidate understanding. Other approaches include the use of multiple representations (Sunyono et al., 2015) and collaborative learning (Opara, 2014), both of which have shown promise in enhancing student performance.

2.9 Computer Simulations

Technological advances have made computer simulations valuable tools for teaching and learning. Simulations provide interactive, dynamic representations of natural and artificial systems, unlike the static illustrations found in textbooks (Eckhard et al., 2013;

Clark et al., 2009; Plass et al., 2009). They allow learners to explore abstract or inaccessible concepts in authentic contexts, offering practice, feedback, and motivation without physical risks (Nkemakolam et al., 2018; Julius, 2018).

2.9.1 Using computer simulations with diverse learners

Classrooms typically include learners with a range of abilities, from slow to gifted, which can make teaching challenging. Simulations are particularly useful here, as they allow students to repeat experiments at their own pace, visualize abstract ideas, and learn in a more accessible way (Hennessy et al., 2007). Each simulation typically focuses on one concept, reducing distractions and allowing students to construct knowledge actively by testing variables and hypotheses (Ceberio et al., 2016; Widiyatmoko, 2018). Furthermore, simulations support collaborative learning, enabling students of different abilities to interact and share knowledge in a constructivist manner (Bindu, 2016; Nkemakolam et al., 2018).

2.9.2 Advantages of computer simulations

Studies show that simulations improve student outcomes by fostering deeper understanding, addressing misconceptions, and enhancing engagement (Jimoyiannis & Komis, 2001; Correia et al., 2019). They enable learners to:

- Test ideas and hypotheses;
- Explore relationships between variables;
- Express their mental models of phenomena; and
- Investigate processes difficult to replicate in traditional labs.

Simulations are particularly effective in visualizing microscopic processes such as stoichiometry, where mole ratios and molecular interactions are otherwise abstract (Widiyatmoko, 2018). Additional benefits include authentic learning environments,

individualized feedback, enhanced motivation, and active participation (Tareef, 2014; Hursen & Asikoy, 2015). Research consistently finds that learners taught with simulations outperform those taught through traditional methods (Bozkurt & Ilik, 2010; Rutten et al., 2012).

2.9.3 Teaching with computer simulations

Effective teaching requires addressing misconceptions and supporting conceptual change. Simulations have been shown to help bridge the gap between learners' prior knowledge and new scientific concepts, offering opportunities for students to reformulate incorrect ideas (Jimoyiannis & Komis, 2001; Ulukök & Sari, 2016). The Reformed Teaching Observation Protocol (RTOP) emphasizes the importance of creating such learner-centered environments (Sawada et al., 2002). By using simulations strategically, teachers can gradually guide students toward deeper, more accurate scientific understanding.

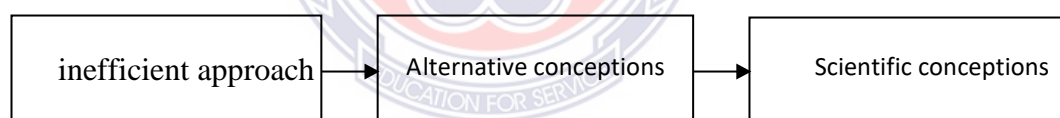


Figure 5: Simulation changes, misconception changes to scientific conceptions

When ineffective methods are used to teach stoichiometric chemistry, learners often develop misconceptions. To address this, alternative approaches such as experiments and simulations are recommended. Appropriate teaching strategies support conceptual change, allowing students to transition from alternative conceptions to scientifically accurate ones. Integrating computer simulations with hands-on activities not only helps learners test and refine their understanding but also allows them to articulate ideas and explore problem-solving strategies (Kunnath & Kriek, 2018; Koedinger, 2020). These

aims align with the Reformed Teaching Observation Protocol (RTOP), which was used in this study to evaluate whether the use of simulations reflected reformed teaching practices.

2.9.4 Using computer simulations to promote inquiry-based teaching

Research highlights that simulations enhance inquiry-based learning by enabling students to construct their own knowledge. When combined with guided inquiry, simulations encourage exploration, critical thinking, and a positive attitude towards science (Potane & Bayeta, 2018; Rutten et al., 2012). Teacher-led discussions supplemented with simulations guide learners through the stages of scientific inquiry while fostering authentic engagement (Kunnath, 2017). Thus, simulations not only enhance student learning but also scaffold authentic science inquiry by mirroring real-world scientific practices.

2.9.5 Computer simulations in the teaching and learning of chemistry

Information and communication technology (ICT) has proven to be an effective way to improve the quality of education (Alkahtani, 2016). Multiple studies have demonstrated the benefits of computer simulations in chemistry instruction. For example, Udo and Etiubon (2011) compared simulation-based instruction with guided discovery and traditional methods, finding that simulations significantly improved achievement compared to traditional teaching and were as effective as guided discovery. Other studies have shown positive effects of simulations in conceptualizing gas behavior (Correia et al., 2019), teaching acids and bases (Bayrak & Bayram, 2010), chemical equilibrium (Sarıçayır et al., 2006), chemical bonding (Özmen, 2008), and connecting chemical reactions to equations (Liu, 2005).

Simulations enhance inquiry skills, foster positive attitudes, and allow visualization of processes at microscopic and macroscopic levels (Bailey, 2007; Develaki, 2019). They also help prevent misconceptions and provide opportunities for professional growth in teacher education. The American Chemical Society recommends a range of online resources, such as PhET Interactive Simulations, Chem Collective, CK-12 chemistry simulations, and virtual labs, to support chemistry teaching and learning. Of these, PhET simulations are widely recognized for their accessibility and effectiveness in enabling students to construct knowledge through interactive exploration (Paulson et al., 2009).

2.9.6 PhET Simulations

Developed by the University of Colorado in 2002, PhET provides free, research-based interactive simulations across disciplines including chemistry, physics, biology, and mathematics. These simulations use intuitive controls and visual aids to make abstract concepts accessible and engaging (Podolefsky et al., 2009; Kunnath, 2017). Studies report that PhET promotes inquiry skills, conceptual change, problem-solving, and student motivation by encouraging prediction, experimentation, and reflection (Tavares et al., 2019; Potane & Bayeta, 2018; Wieman et al., 2015).

Research also shows that PhET simulations enhance long-term memory (Sari et al., 2018), improve process skills (Bell & Smetana, 2008), and foster creativity when combined with collaborative learning models (Astutik & Prahani, 2018). Students often describe their experience with PhET as enjoyable and engaging, which increases academic achievement and interest in science (Bandoy et al., 2015). By integrating PhET into classroom instruction, teachers can create activity-based, student-centered

learning environments aligned with activity theory, where learners actively construct knowledge and develop scientific thinking.

2.9.7 Positive effect of computer simulations on students' performance in stoichiometry

Between 2014 and 2022 many studies have been conducted on interactive simulation in science education. Gupta (2019) examined the effect of university students' achievements in physics by using interactive simulation teaching method which adopted a quasi- experimental design. With respect to the pretest scores, students in the treatment and control group had quite the same level of basic knowledge of the subject. The distribution scores were indifferent, however, after a 15-week intervention strategy, it was found that the treatment group had higher achievement scores than the control group with a statistically significant difference. The findings agreed that phet simulations enhanced students' conceptual understanding, hence, enhanced performance.

Develaki (2019) conducted a quasi-experimental study using Solomon's four-group pre- and post-test design to examine the impact of interactive simulations on students' achievement in stoichiometry. The sample consisted of two Grade 12 classes (N = 83), with one class of 42 learners assigned as the control group and another of 41 learners as the experimental group. Purposive sampling was employed due to ICT accessibility, time constraints, and costs. Pre-tests confirmed that both groups had comparable prior knowledge in stoichiometry, ensuring valid comparisons. Following the intervention, post-test results revealed that the experimental group significantly outperformed the control group, both immediately after instruction and three weeks later. This improvement was attributed to the positive effects of simulations, which enhanced both

performance and retention of concepts. Learners were assessed not only on final answers but also on each correct concept and step in problem-solving, meaning higher mean scores reflected deeper conceptual understanding. Simulations acted as scaffolding tools by making invisible entities and interactions visible, enabling learners to visualize equations in three dimensions and better understand coefficients and subscripts. They also reduced the cognitive challenges caused by unfamiliar scientific language, allowing learners to make meaning by manipulating simulation parameters.

Similarly, Dichev (2022) found that simulations supported undergraduates in balancing chemical equations by overcoming language barriers, which improved comprehension and performance. Retention was particularly strong in the experimental groups, aligning with temporal and spatial principles, which suggest that learning is enhanced when texts and visuals are presented simultaneously. This dual-channel processing reduces cognitive load and allows new information to be assimilated and stored in long-term memory, from which it can be retrieved later. In contrast, control groups, limited to text-based instruction, lacked opportunities for deep conceptualization. These findings are consistent with the cognitive theory of multimedia learning (CTML), which emphasizes that meaningful learning occurs when verbal and visual representations complement each other. By stimulating both auditory and visual channels, simulations foster stronger conceptual grasp and retention.

The results resonate with previous research, which has shown that simulations improve performance in stoichiometry-related tasks such as solving conceptual problems, balancing chemical equations, identifying limiting reagents, and carrying out stoichiometric calculations. Studies on online-based laboratory exercises have similarly demonstrated gains in problem-solving skills. Gupta (2019), while focusing on

chemical equilibrium rather than stoichiometry, reported comparable outcomes. His study showed that simulations combined with conceptual change texts significantly boosted university students' understanding, with experimental groups achieving higher mean scores in both immediate and delayed post-tests. These differences were attributed to the scaffolding role of simulations, which provide additional support for conceptual development.



CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter outlines the research methodology and procedures employed in the study. It covers the research paradigm, design and approach, target population, sampling and sampling techniques, and the instruments used for data collection. It further addresses the validity and reliability of these instruments, followed by a description of the data collection process and the intervention strategies applied. The chapter concludes with an explanation of the analytical techniques—content analysis, thematic analysis, and paired sample t-test—together with the ethical considerations observed in the study.

3.1 Research Paradigm

All scientific inquiry operates within a particular paradigm, which provides a framework shaped by researchers' philosophical assumptions about reality and knowledge (De Vos et al., 2011). This study adopted **pragmatism** as its guiding paradigm, widely regarded as an appropriate foundation for justifying the use of mixed methods (Brierley, 2017). The term “pragma,” derived from the Greek word for action, reflects the search for practical and workable solutions to complex real-world problems (Parvaiz et al., 2016). From a pragmatic perspective, researchers address authentic issues and generate knowledge by employing a mixed methods approach (Maree, 2016).

Pragmatism prioritizes addressing the research questions by selecting strategies best suited to the problem at hand, thus allowing for the integration of multiple methods rather than adherence to a single approach (Creswell & Garrett, 2008). According to Parvaiz et al. (2016), pragmatism positions the research problem at the center, drawing

on both qualitative and quantitative techniques—such as interviews, questionnaires, observations, and analysis—to provide comprehensive insights. Unlike paradigms committed to one philosophical stance, pragmatism values flexibility, enabling researchers to apply the most practical and useful methods for their inquiry (Creamer, 2017).

In mixed methods research, pragmatism gives equal weight to qualitative and quantitative dimensions, ultimately working toward a unified response to the research question (Schoonenboom & Johnson, 2017). In this study, both methods were combined to capture objective and subjective dimensions of knowledge (Wong & Cooper, 2016). Pragmatism also accommodates both inductive and deductive reasoning; here, an inductive approach was adopted, enabling the identification of patterns, consistencies, and meanings in learners' behavior from data collected through pre-tests, post-tests, questionnaires, and interviews. Consequently, pragmatism supported the integration of varied methods of data collection and analysis, freeing the researcher from the constraints of a single paradigm and allowing for methodological flexibility (Feilzer, 2010).

3.2 Research Approach

The study combined both qualitative and quantitative methods which involved analyzing both numerical data from pre-test, post-test scores, closed-ended questionnaires and non-numerical data from the interviews and open-ended questionnaire which extracted or contributed to immense rich data collection procedures (Bhandari, 2023).

3.3 Research Design

The study employed a case study research design integrated with in-class action research, aimed at addressing and improving a situation that affected the entire class in an interactive and dynamic way. Action research provides opportunities for continuous improvement in teaching and learning (Creamer, 2017). It follows a cyclical process, enabling both researchers and participants to learn from one another through ongoing reflection. This approach deepens understanding of a situation by encouraging conceptualization, iterative interventions, and evaluation. In addition to enhancing classroom practice and student learning, action research also contributes to tutors' professional growth and development.

In order to better understand and enhance the efficacy of the teaching and learning process, action research in education entails examining the school environment, as Julius (2018) says. There were five stages to this investigation. Creating the study tools, such as the interview guide, questionnaires, and assessments, was the initial stage. Students from different schools participated in a test-retest pilot study of these assessments, and the findings were utilized to improve them. The second phase included pre-intervention activities, which included educating participants about the study's objectives before the pre-test, questionnaire, and interviews were conducted. A post-intervention exam was given and interactive simulations were incorporated during the third step, which was the implementation stage.

While the fifth phase concentrated on coming to conclusions and offering suggestions, the fourth phase involved the analysis of the data that had been gathered. Figure 6 provides an overview of this study procedure.

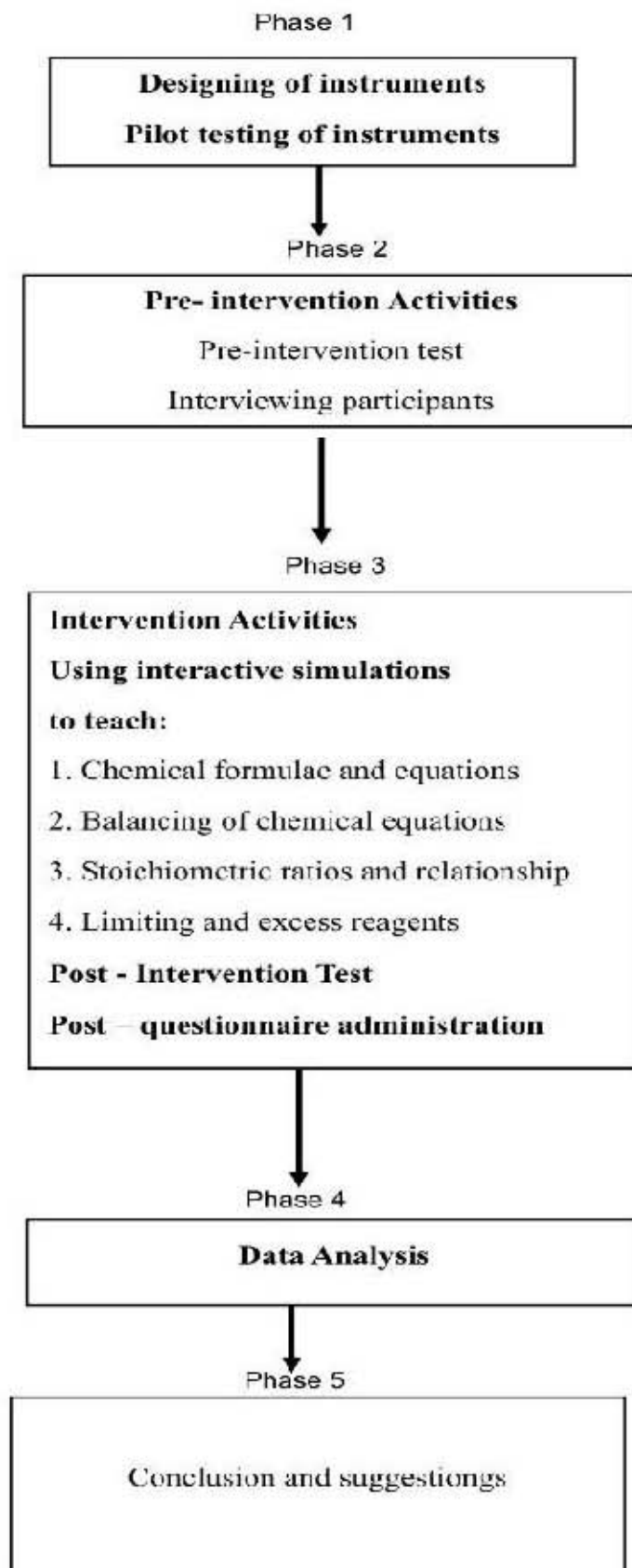


Figure 6: Flow chart showing the research approach

3.4 Population

Finding the people from whom the data will be gathered is crucial in any mixed methods study (Edmonds & Kennedy, 2016). A population is the complete group about which a study is intended to be conducted (Bhandari, 2023). Stated differently, the researcher is interested in the group as a whole. The target demographic is another name for this. 78 students, all chemistry majors at Keta Senior High Technical School for the 2023–2024 school year, were the study's target group. The targeted population's breakdown is displayed in Table 1.

Table 1: Total Population of Participants

Class	Number of students
Form 1	24
Form 2	28
Form 3	22
Total	74



3.5 Sample and Sampling Technique

For the study, purposive sampling was employed. The researcher selects the sample in purposive sampling with a specific goal in mind. The most representative members of the population that can support the study's objectives make up this sample (De Vos et al., 2011; Edmonds & Kennedy, 2016; Maree, 2016).

Accordingly, the study's accessible population consisted of Keta Senior High School's form two general science students. The researcher chose the school since it was close by. Thus, there were 28 students in the sample, with 13 girls accounting for 46% and 15 men for 54%. The pupils were between the ages of sixteen and nineteen.

A pre-test was administered to 28 students to gather preliminary data and identify potential trends (Liu, 2005). Following the pre-test, an interview was scheduled to gather more in-depth insights from a subset of participants. A purposive sampling strategy was employed, where six students were selected based on their pre-test scores (Kunnath, 2017). Specifically, two students with the highest scores, two students with medium scores, and two students with the lowest scores were chosen for the interview and questionnaire administration.

This sampling strategy allowed for a more nuanced understanding of the issue under investigation, as it captured the perspectives of students with varying levels of knowledge and understanding (Kunnath, 2017). In a study by Hursen and Asisoy (2015) on small-scale qualitative research, Hursen and Asisoy (2015) selected 6 participants from a larger pool based on their pre-test scores, to explore their experiences and perspectives during an interview schedule to represent the whole sample. Julius (2018) used a similar approach in their pilot study, where they selected 5 participants with varying levels of knowledge and understanding, based on their pre-test scores to represent the whole sample during a questionnaire administration. By selecting participants with diverse scores, the researcher aimed to increase the validity and reliability of the findings (Samuels, 2017). Furthermore, this approach enabled the researcher to explore potential patterns and themes in the data, which might have been overlooked with a larger, more homogeneous sample (Julius (2018).

3.6 Instruments for Data Collection

This section discusses the instruments used for data collection in the study and their validity and reliability. Tests, questionnaires, and an interview guide served as the instruments. Data triangulation, in which the results of the pre-test, post-test, and

closed-ended questionnaires (quantitative) were compared and contrasted with the results of the qualitative questionnaires and interviews, was employed by the researcher to determine the degree to which the findings from the quantitative data support the findings from the qualitative data.

By contrasting the quantitative pre-test and post-test results with the qualitative interview and questionnaire data, triangulation can also be used to support internal validity. By comparing and seeking convergence and complementarity between the results from the quantitative and qualitative phases, triangulation can be accomplished (Wong & Cooper, 2016).

3.6.1 Pre-test and Post-test

Quantitative data were collected first through the administration of a **Stoichiometry Performance Test (SPT)**, designed to measure students' conceptual understanding of stoichiometry. The pre-test helped to uncover students' existing ideas and misconceptions, addressing research question one. These findings were further supported with interviews for deeper insight. Following the intervention, a post-test was conducted to address research question three, focusing on the intervention's impact on student performance. The test items were drawn from the course content and structured according to the stated lesson objectives. The SPT covered six cognitive levels—knowledge, comprehension, application, analysis, synthesis, and evaluation—and carried a total of 30 marks. Two versions were used: the pre-test and the post-test (Appendices A and D).

3.6.2 Validity of the Pre-test and Post-test

The study accounted for both **internal and external validity**. Internal validity ensures that the test measures what it intends to measure, while external validity relates to the

generalizability of findings (Maree, 2016; Alshenqeeti, 2014; Ary et al., 2010). Internal validity was strengthened by keeping conditions uniform for all students to ensure sample homogeneity, controlling external factors, and spacing the pre- and post-tests to minimize carryover effects (Creswell & Creswell, 2018). The SPT was further validated through supervisor review and subsequent revisions. Although external validity was limited by the small sample size, inferential statistics from the pre- and post-tests allowed for cautious inferences to broader populations (Kabir, 2016; Maree, 2016; Wong & Cooper, 2016).

3.6.3 Reliability of the pre-test and post-test

Reliability, referring to the consistency of results across conditions (Maree, 2016), was evaluated using **Cronbach's alpha**. This measure assesses internal consistency of test items (Creswell & Creswell, 2018; Kunnath, 2017). Accepted reliability thresholds are 0.70 (low acceptable), 0.80 (good), and 0.90 (excellent) (Samuels, 2017). The SPT achieved a reliability coefficient of 0.778 for the pre-test and 0.788 for the post-test, both indicating good internal consistency.

3.6.4 Questionnaire design

A questionnaire was also used to collect both qualitative and quantitative data. Adapted from Kotoka (2013) and Kunnath (2017), the instrument was modified to fit the study. At the pre-intervention stage, it explored factors influencing poor performance, while post-intervention, it captured students' views on the intervention. Following Kabir's (2016) guidelines, the questionnaire avoided ambiguity, bias, and double negatives. It was pilot-tested with students from another school to ensure clarity and reliability. The qualitative section contained open-ended items, while the quantitative section used a

six-point Likert scale. Responses from the questionnaire addressed research questions two and four.

3.6.5 Validity of the questionnaire

The questionnaire's validity was evaluated on three levels: **face validity**, ensured by supervisor review; **content validity**, achieved by aligning items with the study constructs; and **construct validity**, tested through pilot administration in another school (Leedy & Ormrod, 2014). Feedback led to simplification of items to ensure accurate measurement (Killen, 2015).

3.6.6 Reliability of the questionnaire

Reliability, understood as the consistency of results over time (Maree, 2016), was confirmed for the questionnaire. For qualitative data, **trustworthiness** was emphasized through credibility, transferability, dependability, and confirmability (Golafshani, 2003; Nowell et al., 2017). Triangulation of data sources and detailed documentation enhanced reliability. For quantitative items, Cronbach's alpha was applied, yielding a coefficient of **0.870**, which is highly acceptable (Samuels, 2017).

3.6.7 Administration of questionnaires

The questionnaire, administered after the pre- and post-tests, comprised two sections. **Section A** contained five open-ended questions on causes of poor performance, teaching methods, and stoichiometry-related challenges. **Section B** featured close-ended questions using a six-point Likert scale, enabling respondents to express degrees of agreement or disagreement. Learners had 45 minutes to complete the questionnaire.

3.6.8 Interview guide

Semi-structured interviews were conducted to collect qualitative narrative data, providing deeper insight into learners' perceptions (Alshenqeeti, 2014; De Vos et al., 2011). This format allowed for predetermined open-ended questions, with flexibility for follow-up probes (Griffiee, 2005). The approach ensured in-depth, reliable data while giving students freedom to express their ideas and experiences in their own words.

3.6.9 Reliability of interviews

Interview reliability was enhanced by standardizing the interview process: all participants received the same questions in the same sequence. Reliability was further strengthened through **dual coding**, with two coders analyzing and interpreting transcripts to minimize bias.

3.6.10 Administration of interviews

Six students, representing high, medium, and low performance levels in both pre- and post-tests, were selected for interviews. The guide included open-ended questions to explore prior conceptions of stoichiometry. Interviews were recorded (with consent) to ensure accuracy and later transcribed for analysis. Recording minimized data loss and allowed the interviewer to focus on interaction. Confidentiality and anonymity were strictly maintained throughout the process (Maree, 2016; Kabir, 2016).

3.7 Pre-intervention Activities

This section explains all of the initial stages of the study before the intervention activities were implemented. The researcher met all the students constituting the sample and briefed them on the purpose and intent of the study, how long the study would take and the need for them to remain in the study till the end. The students were given 14

days to read on chemical stoichiometry at the end of the 14 days, the pre-intervention test was administered to students to answer within a period of 45 minutes. The responses were collected and marked using the pre-intervention test marking scheme (see Appendix F).

3.8 Simulation Intervention Activities

The University of Colorado Boulder granted permission for the simulations used as the intervention in this study.

These tools were designed to begin with introductory tasks, such as building molecules from a set of atoms or making sandwiches, to help students construct chemical formulas and understand basic concepts. In the sandwich-making activity, ingredients like bread, cheese, and ham represented reactants, while the sandwiches represented products. Students might observe the number of possible sandwiches (products), leftovers, or extra items by selecting varying amounts of ingredients. At a macro level, this exercise helped introduce stoichiometric concepts and the law of conservation of mass. It was anticipated that students would apply these concepts to later parts that used symbolic representations and space-filling models.

Since active learning builds on prior knowledge, using molecule-building and sandwich-making as starting points helped provide the foundation necessary for conceptual change. The simulations also included explanatory text and guiding pointers to direct learners' attention to important features and link new concepts with prior knowledge. Additional supports, such as graphs and seesaw models for balancing equations, acted as scaffolds to aid understanding. Moreover, the simulations featured simple navigation controls that allowed learners to mute, adjust, or add parameters for

clarification, ensuring they remained engaged and actively in charge of their learning process.

Summary of lessons

The lessons during the intervention activities were categorized under three lesson deliveries which lasted for three (3) weeks. The key Stoichiometry concepts covered with the students include:

1. chemical formula
2. balancing chemical equations
3. determination of limiting and excess reagents with application to solving problems

In lesson 1, a game screen for building of molecules was used which was downloaded from phet simulation. On the screen at the bottom, there are some bowls of atoms. On the right, you will see a list of molecules you must take then you use the atoms in the bowls to make the molecules and fill out the chart. Figure 7 shows an example of how the simulation appears on the game screen for building of molecules to help learners understand the structure and composition of substances which is essential for making accurate predictions in stoichiometry. Building of molecules help learners to visualize how individual pieces of atoms fit together to create a final product. Figure 7 is about how atoms combine to form molecules purposely to enable learners know the right makeup of certain compounds

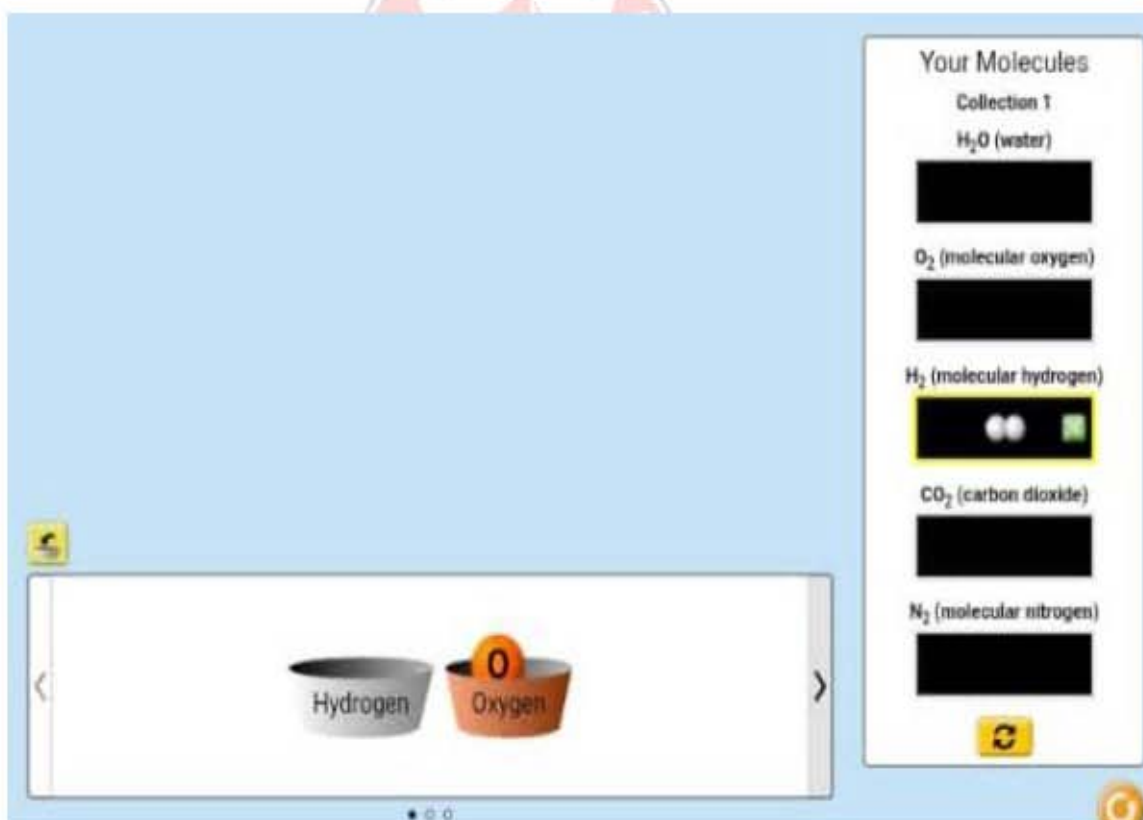
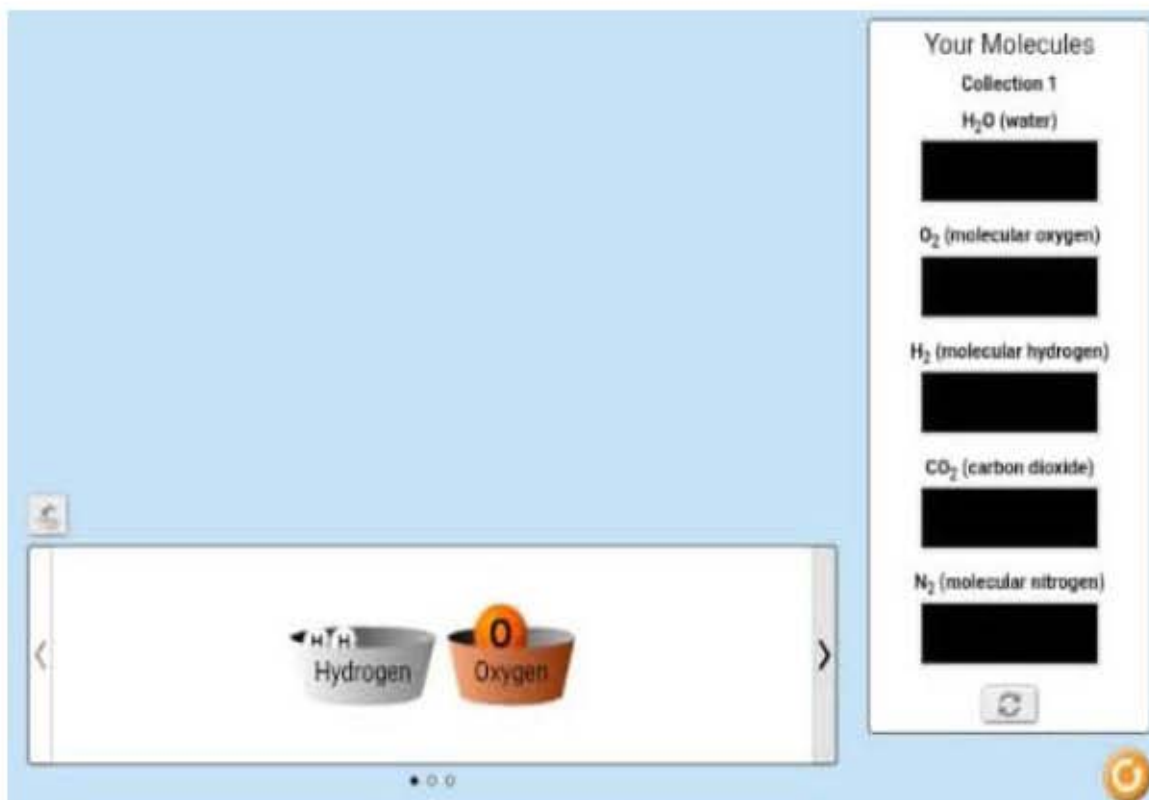


Figure 7: Game screen on building of molecules

The game screen has bowls of atoms of hydrogen and oxygen, specifically to build water molecule from its constituent atoms (2 atoms of hydrogen and 1 atom of oxygen).

The second session focused on utilizing a game screen to balance chemical equations. An example of how the simulation for the reaction between nitrogen and hydrogen to form ammonia, which was retrieved from the PhET simulations, appears on the game screen is shown in Figure 8.

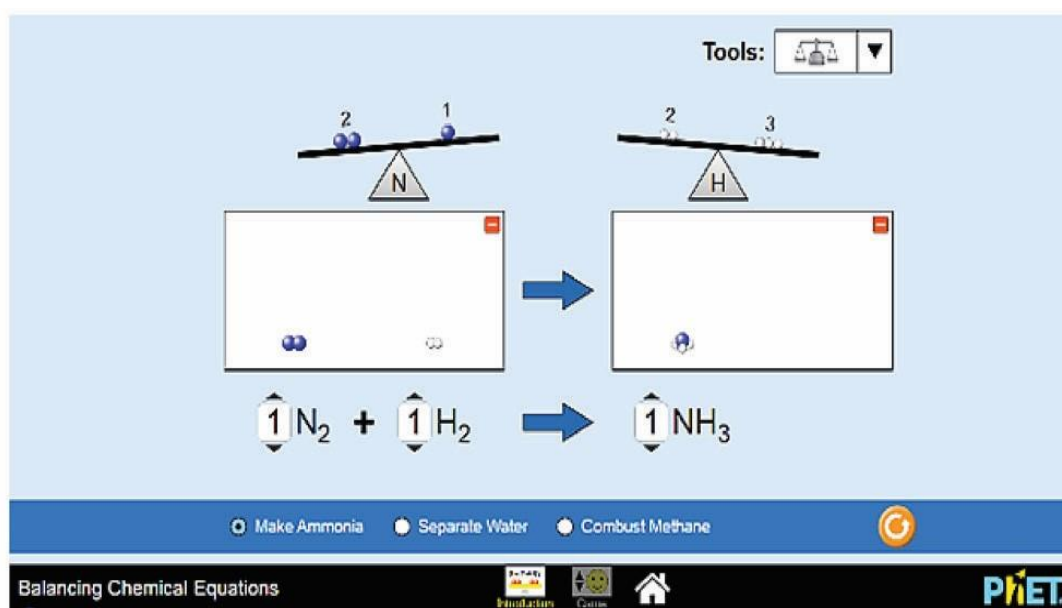


Figure 8: Game screen on Phet simulation: Unbalanced reaction between Nitrogen and Hydrogen to produce ammonia

The equation with the provided coefficients is not balanced, as seen in Figure 8. By examining the chemical representations on both sides, students can adjust the coefficients until the equation is balanced. Students can determine how many atoms of each element are required to balance the element on either side by examining the amount of atoms of each element on either side. Two nitrogen atoms and two hydrogen atoms are shown in Figure 8 on the left-hand side of the equation with the corresponding

coefficients. On the other hand, there is one nitrogen atom and three hydrogen atoms on the right.

This indicates that there is an imbalance in the number of atoms for each element on either side. The simulation's molecular scale representation aids students in adjusting reactant and product coefficients and properly balancing the equation. The result of adjusting the coefficients and achieving balance is displayed in Figure 9.

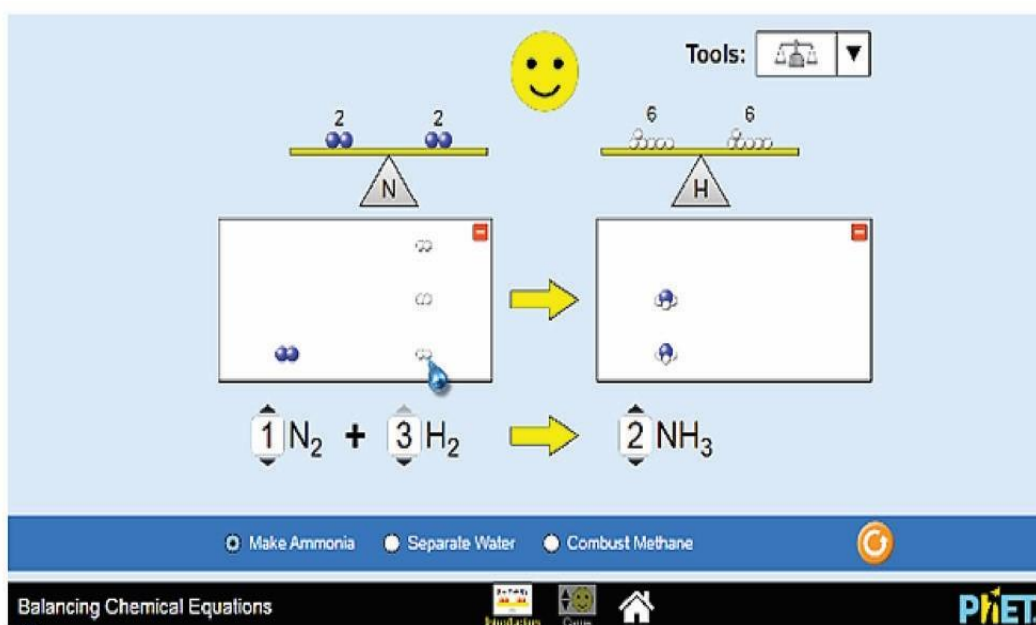


Figure 9: Game screen on Phet simulation: Balanced reaction between Nitrogen and Hydrogen to produce ammonia

A different kind of game for studying balancing equations in the PhET simulations employs various ingredients to create a sandwich in the most recent lesson delivery. Students make their own sandwiches using bread, cheese, and ham in the first section of the simulation. They can see how much of each component is needed to make a variety of sandwiches and how many sandwiches can be constructed with the specified amount of ingredients. Later, they draw a comparison between the process of making sandwiches and the process of resolving chemical equations. A sandwich requires two

slices of bread, one slice of ham, and two slices of cheese, per the game screen in Figure 10 below.

In the simulation, students are provided with six slices of bread, five slices of ham, and four slices of cheese. They are tasked with making sandwiches that require all three ingredients. By identifying the quantity of each ingredient needed for a single sandwich, learners determine how many complete sandwiches can be made with the available items. This activity allows them to draw parallels between sandwich-making and the process of balancing chemical equations. Engaging with the simulation enables students to calculate the amounts of ingredients required for different numbers of sandwiches, test their answers, and reattempt the task if mistakes are made. The students can return to using molecular representations for balancing problems after they have had sufficient practice preparing sandwiches. This will enable them to draw comparisons between the process of making sandwiches and the balancing of chemical reaction equations. The game for balancing chemical equations with molecule representation in PhET simulations is depicted in Figure 10.

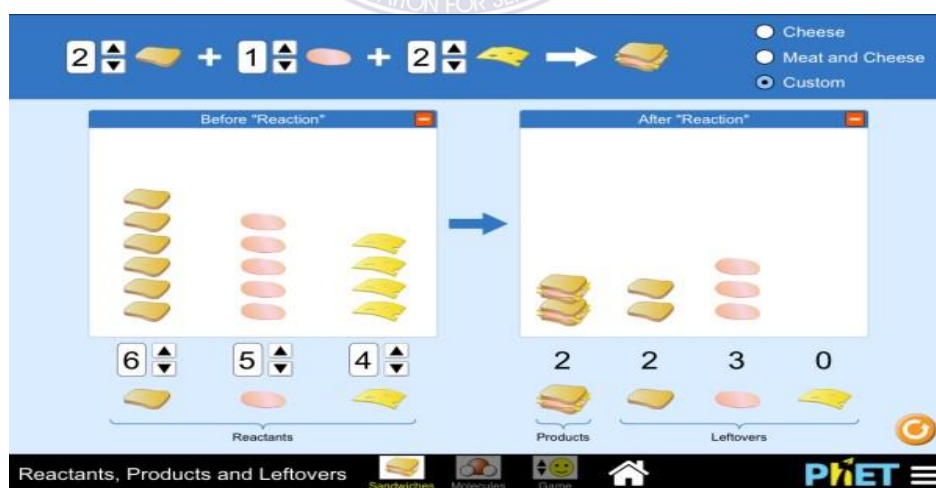


Figure 10: Sandwich method to explain the ratio of reactants, products and leftovers

The game used to balance chemical equations utilizing molecular representation in the PhET simulations that the researcher used to carry out the research with students is seen

in Figure 10. The reaction of hydrogen and oxygen to generate water is seen in Figure 11.

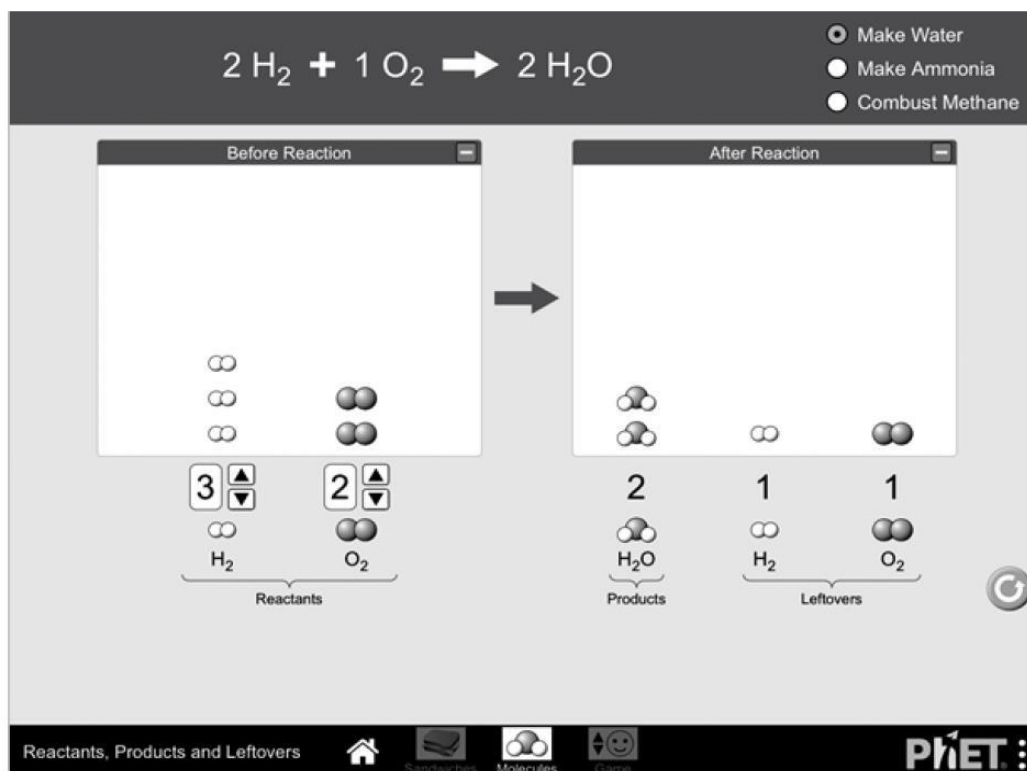


Figure 11: Phet simulation molecular view

Figure 11 illustrates the reaction between hydrogen and oxygen to form water, where two molecules of hydrogen gas combine with one molecule of oxygen gas to yield two molecules of water. The balanced chemical equation, shown at the top of the simulation screen, reflects the simplest whole-number ratio of reactants and products in accordance with the law of conservation of mass. In the game, learners are given three molecules of hydrogen and two of oxygen and are tasked with determining how many water molecules can be produced, as well as identifying any remaining (leftover) hydrogen or oxygen molecules after the reaction.

3.9 Simulations of Reactants, Products, and Leftovers

The simulations first use the sandwich analogy, where bread, ham, and cheese represent reactants and sandwiches represent products. This approach helps learners grasp the concept of ratios in chemical reactions and how equations are balanced. For example, to make one sandwich, two slices of bread, one slice of cheese, and one slice of ham are required. Within the game, learners can adjust the number of ingredients to determine how many sandwiches can be made and identify any leftover items. This hands-on activity provides a concrete and familiar context for understanding stoichiometric ratios (Perkins et al., 2010). Teachers can then extend this analogy to demonstrate that, just as ingredients combine in fixed proportions to make sandwiches, chemical reactants also combine in specific ratios to form products.

The simulation interface displays the following components:

- Reaction Equation:** $2 \text{ Bread} + 1 \text{ Ham} + 2 \text{ Cheese} \rightarrow 1 \text{ Sandwich}$
- Legend:**
 - Cheese
 - Meat and Cheese
 - Custom
- Before "Reaction" Panel:**
 - 6 Bread slices
 - 5 Ham slices
 - 4 Cheese slices
 - Reactants
- After "Reaction" Panel:**
 - 2 Sandwiches
 - 2 Bread slices
 - 3 Ham slices
 - 0 Cheese slices
 - Products
 - Leftovers
- Navigation Bar:**
 - Reactants, Products and Leftovers
 - Sandwiches
 - Molecules
 - Game
 - PIET

Figure 12: Sandwich method of excess and limiting reagents of reactions

Figure 12 illustrates the sandwich-making activity in the PhET simulation, designed to teach the concepts of reactants, products, and leftovers. Using the sandwich analogy, slices of bread, ham, and cheese represent reactants, while the sandwich itself represents the product. This approach enables learners to grasp the ratio in which reactants combine to form products, as well as to identify any excess ingredients that remain as leftovers. The simulation allows both teachers and learners to adjust the quantities of each ingredient, treating them much like variables in a chemical equation. By engaging with a familiar, real-world example, learners can better understand chemical reactions while addressing common misconceptions (Bílek et al., 2018).

Figure 13 provides a screenshot of the molecular view within the PhET simulation, where learners explore the same concepts of reactants, products, and leftovers at a microscopic level.

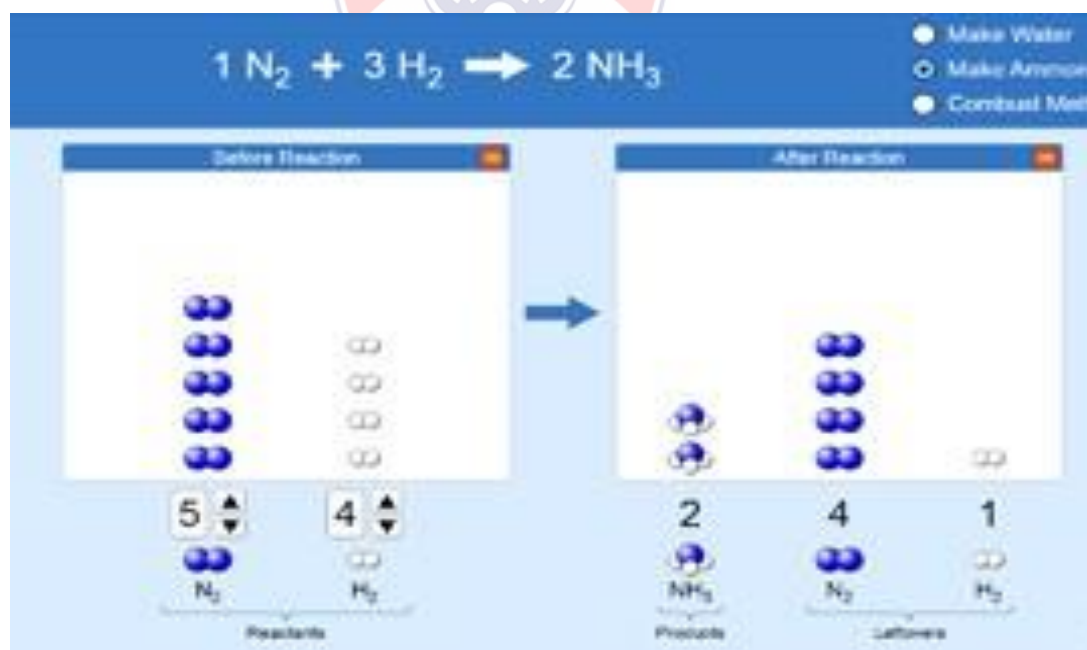


Figure 13: Phet simulation molecular view of excess and limiting reagents

A game depicting each molecule of the reactant that was accessible for a reaction, the products that were produced, and the leftovers is shown in Figure 13. At the top of the gaming screen is the reaction's balanced equation.

Students can utilize the balanced equation at the top of the game screen to check how many molecules of the products and leftovers there are by modifying the coefficients that show how many molecules of each reactant could be used in a reaction. By using the concepts of limiting reagents to predict the amounts of products and leftovers following a reaction, predicting the initial amounts of reactants given the amount of products and leftovers using the same concept, and translating from symbolic to molecular representations of matter, this aids students in learning how to solve limiting reagent problems.

3.10 Post-Intervention Activities

The post-intervention stage occurs after the implementation of the intervention and focuses on evaluating its outcomes. This phase enables the researcher to measure the effectiveness of the intervention and determine whether it directly influenced students' performance. A post-intervention test was administered to the entire class to assess conceptual development and possible improvement in performance following the simulation activities. This was complemented by both open- and closed-ended questionnaires, which captured students' perceptions of the intervention. Their responses were then collected and analyzed.

3.11 Data Analysis

Data analysis involves applying statistical methods to interpret data and extract meaningful insights (Grant, 2023). Since this study adopted a mixed methods approach, both qualitative and quantitative techniques were employed. Specifically, descriptive

analyses (content and thematic) and inferential analyses (paired sample t-test) were used to evaluate the data.

3.12 Content Analysis

To identify students' scientific knowledge and the extent of their prior conceptions, qualitative content analysis (QCA) was applied to their interview responses. In addition, quantitative content analysis was used to determine the effect of the interactive simulations on students' academic performance. A deductive approach was systematically followed throughout the analysis.

3.13 Thematic Analysis

Thematic analysis required repeatedly reviewing the collected data to identify emerging patterns, themes, and sub-themes (Anuradha, 2023). For this study, students' interview responses were examined in detail, categorized into themes, and interpreted. This process provided insights into learners' prior understanding of stoichiometry and their perceptions of the simulation intervention.

3.14 Paired Sample t-test

A paired sample t-test, with an alpha level of 0.05 and a 95% confidence interval, was conducted to determine the impact of the simulation on students' academic performance in stoichiometry. The analysis compared students' scores from the pre-intervention and post-intervention tests. Inferential statistics were performed using SPSS (Statistical Package for the Social Sciences).

3.15 Ethical Considerations

Ethical principles guided the entire research process. Participants' rights were safeguarded through informed consent, ensuring they were fully aware of the study

procedures, assured anonymity, guaranteed confidentiality, and granted the freedom to withdraw at any stage (Creswell, 2009). Only data relevant to the study were collected. During analysis, participants' identities were protected by assigning codes in place of names.



CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Overview

The results and comments of the study's findings are presented in this chapter. The results revealed students' preconceived notions and the elements influencing their subpar stoichiometry learning outcomes. Additionally, it showed how students' academic performance was affected by using the interactive simulation. It concluded by presenting the students' opinions about how well the interactive simulation affected their academic achievement. In accordance with the study questions, the findings and discussions are provided.

4.1 Research question one

What are students' prior conceptions about stoichiometry?

Research question one was aimed at unearthing student's prior conceptions about the concept of chemical stoichiometry. For the researcher to know the prior conceptions students hold, a pre-intervention test was administered to diagnose students' preconceived ideas that would turn into an alternative conception. The test was followed by an interview session to get more rich and detailed information in the form of narratives for analysis. From the diagnostic test administered, students were asked to write a balanced chemical equation for the reaction between magnesium ribbons and dilute tetraoxosulphate (VI) acid. Figure 14 shows students' answers obtained from the pre-test question about balanced chemical equations.

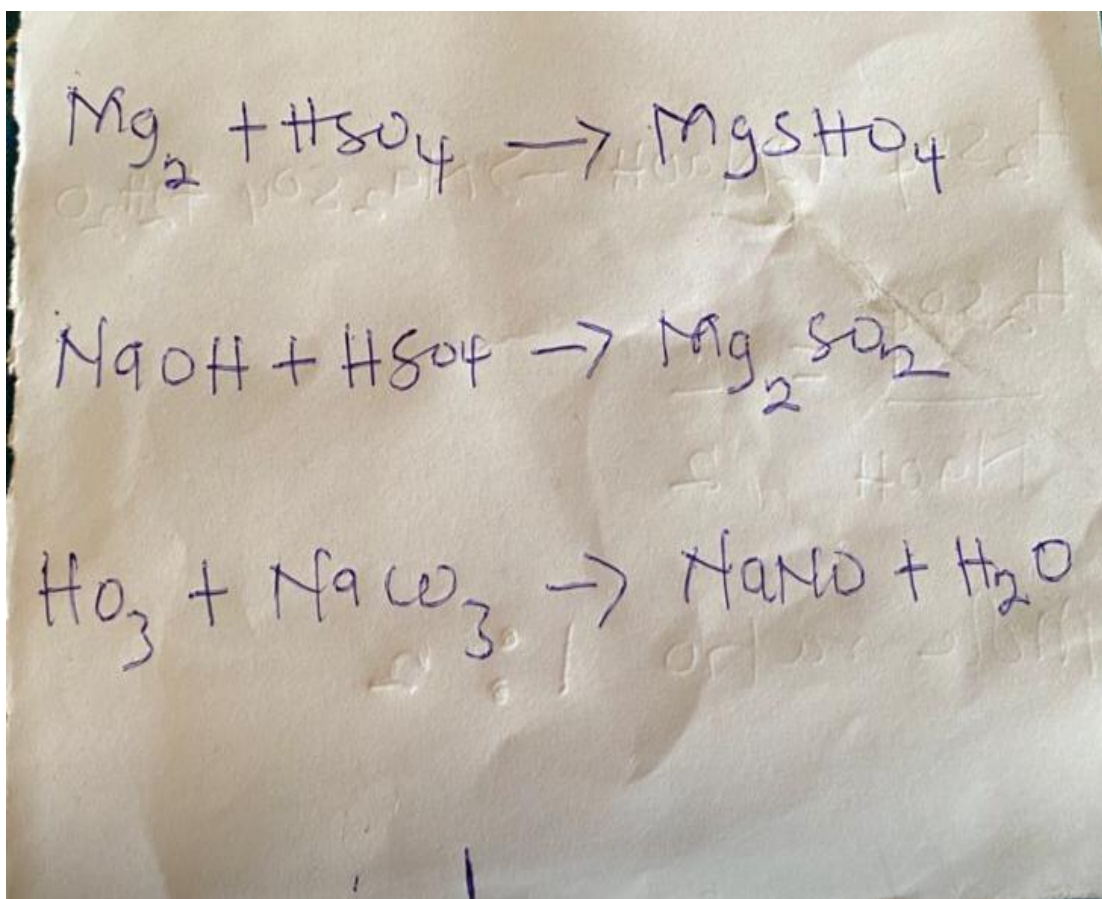


Figure 14: Some students' answers obtained from the pre-test question about balanced chemical equations

As shown in Figure 14, students wrote wrong formula of molecules which resulted in incorrect chemical equations and hence wrong products. A study by Liu and McNeil (2022) found that students who struggled with chemical formulae were more likely to make error when balancing equations. A similar study was done by Cooper et al. (2022) on the role of chemical formulae in balancing chemical equation. In Cooper et al.'s study, students who had a strong understanding of chemical formulae were likely to give correct chemical equations. The students from the current study believed that the numbers in a chemical formula only represent the actual number of atoms present in a molecule, rather than the ratio of the atoms. For example, in the formula of water (H_2O), students thought the formula of water contains exactly 2 molecules of hydrogen and 1 molecule of oxygen.

Again, students believed that a chemical equation can be balanced by simply adding or removing atoms, rather than adjusting the coefficients. For example, some of the students' responses to the interview questions (see Appendix B) included;” *I just added numbers until it looked balanced*”.

All these suggest that students often rely heavily on procedural knowledge rather than conceptual understanding when balancing equations (Liu & Mcneill, 2022). Other students may believe that knowing the reactants and products is enough to balance an equation. However, students need to understand the underlying stoichiometry in order to balance equations correctly (Orgill, 2022).

Again, students from the current study believed that balancing equations is simply a matter of counting atoms even though counting atoms is an important part of balancing equations, it is not the only consideration. Students need to understand the chemical properties of reactants and products as well as the law of conservation of matter (Chandrasegaran *et al.*, 2022).

From Figure 14, it can be seen that students' inability to give a correct formula resulted in wrong products. When students are unable to write correct chemical formulae; it can lead to a cascade of errors in balancing equations and identifying products (Liu & Mcneill, 2022). When students struggle with chemical formulae, they commit mistakes such as:

- Writing incorrect formula for reactants or products (Liu & Mcneill, 2022).
- Failing to account for polyatomic ions (Sutherland, 2022).
- Incorrect balancing of equations (Talanquer, 2022).

Figure 15 shows some students' answers obtained from the pre-test question about mole ratio.

Students were asked to give a mole ratio between the acid and the base.

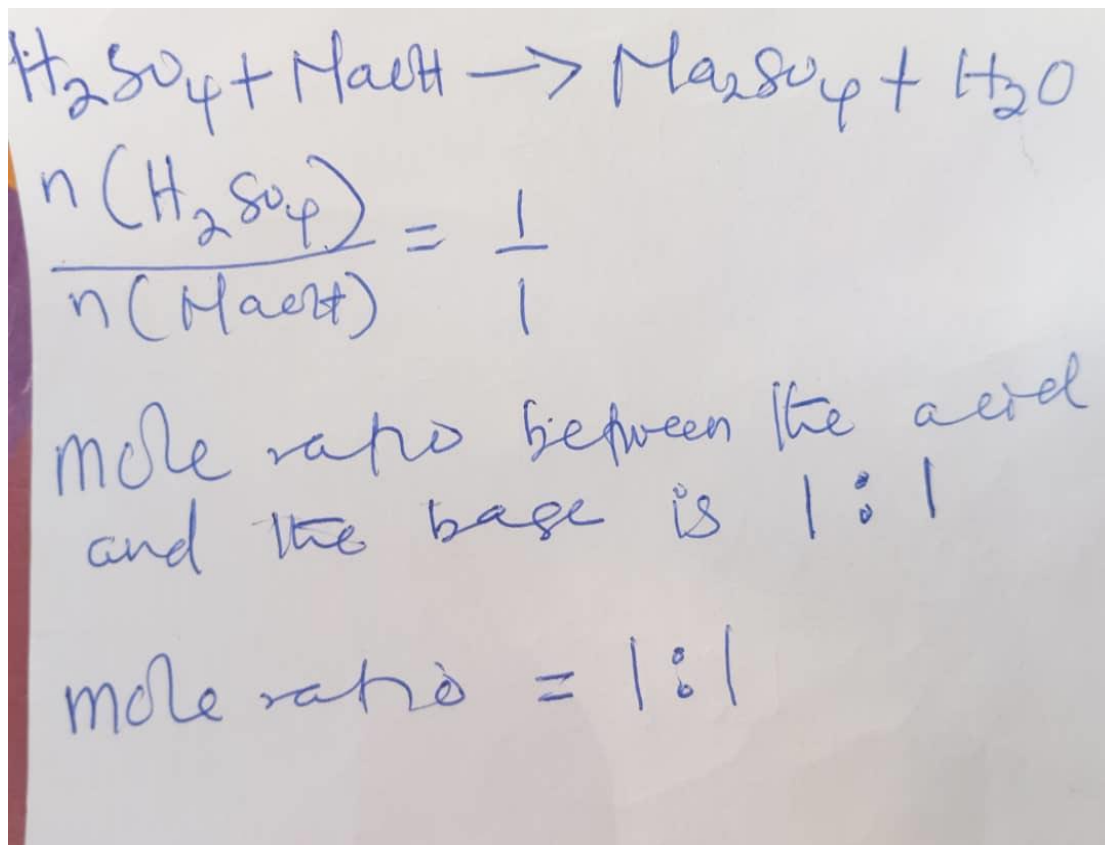


Figure 15: Students' answers obtained from the pre-test question about mole ratio

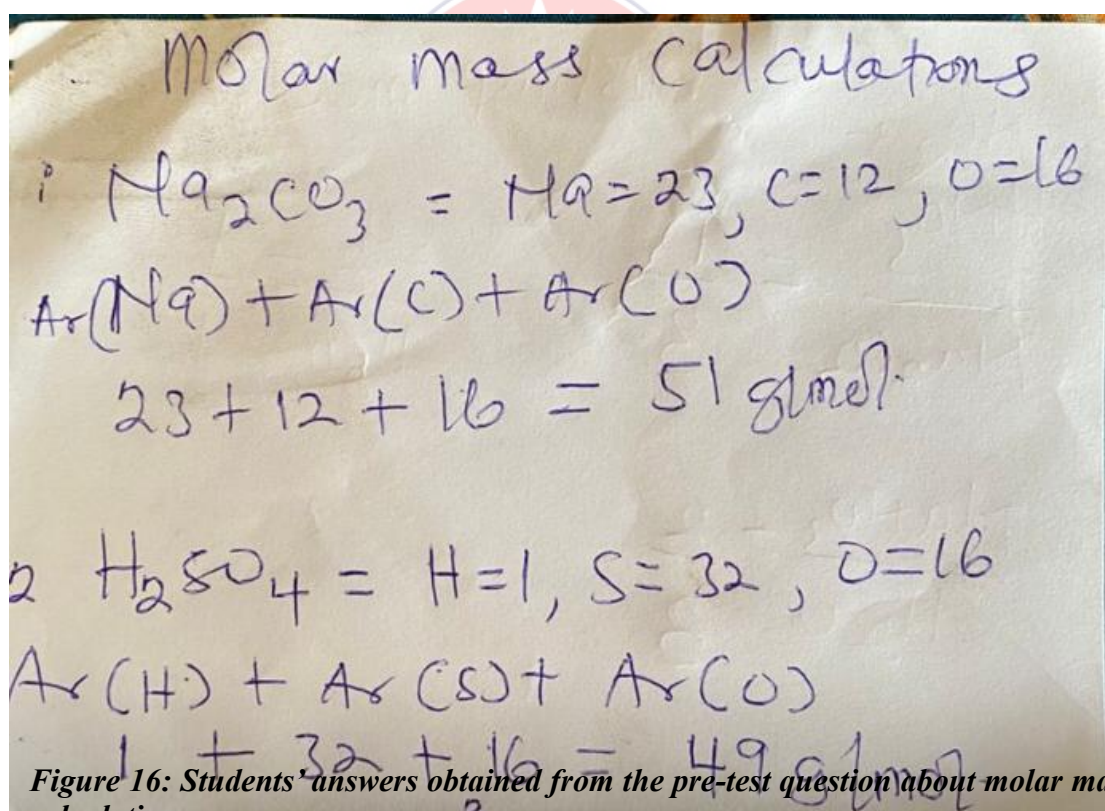
From Figure 15, students believed that acids and bases always react in a 1:1 ratio, so any reaction between an acid and base with different mole ratios are not classified as acid-base reactions.

These ideas from students can lead to errors in balancing acid-base reactions (Sutherland, 2022).

In a study by Orgill (2022) it was found that students believed that mole ratio of reactants and products is the same as the ratio of coefficients in the balanced equation. Similarly, students from the current study believed the mole ratio between the two

reactants are 1:1, that is each of the reactants have one (1) as their coefficient, but rather one needs to balance the equation before bringing out the stoichiometric ratios.

Students asserted that the mole ratio is not necessary for stoichiometric calculations, so they can simply use the coefficients of the unbalanced equation for the calculations. This is consistent with the findings of Chandrasegaran *et al.* (2022) who reported that students often believe that mole ratios are not necessary for solving stoichiometry problems. Figure 16 shows Students' answers obtained from the pre-test question about molar mass calculations. In stoichiometric problems, correct formulae in a balanced equation are important in molar masses calculations (Talanquer, 2022).



From Figure 16, it can be seen that students did not really check the number of atoms in a molecule, they rely heavily on atomic masses and forget to check the number of atoms in a molecule (Orgill, 2022).

In the diagnostic test, students claimed $CaCO_3$ happens to be the reagent that is in excess all because of its larger mass. This was further corroborated in the interview when a student asserted that HCl will run out first during the reaction all because it has a smaller mass compared to the other reactant. This assertion of students about limiting reagents is consistent with findings from Sutherland (2022) where students identified a reactant with a larger mass as the excess reagent.

Findings from research question one

The findings from research question one are as follows:

1. students believed that numbers in a chemical formula represents the number of molecules of each element.
2. students believed numbers in a chemical formula only represents actual number of atoms not the ratio of atoms.
3. students thought that reactants with the smaller mass is always the limiting reagent or the reactant with bigger mass is the excess reagent.
4. students thought limiting reagent is one with a small number coefficient.
5. students thought excess reagent is one with a big number coefficient.
6. students presumed increasing concentration of reactants affected the mole ratios.
7. students presumed that increasing concentration of reactants affected the mole ratios, and
8. students presumed acids and bases always react in a 1: 1 ratio.

4.2 Research question two (2)

What factors influence students' poor learning outcomes in their study of stoichiometry?

After the pre-test administration, all learners were given a questionnaire to answer so that the researcher could get more qualitative data and to a lesser extent quantitative data. All 28 learners completed the questionnaire. The questionnaire consisted of qualitative and quantitative sections (Appendix C). The results from students' responses to the questionnaire are presented in Table 2.

Table 2: Frequency of Students' responses to close-ended questionnaire

S/N	Statement	SA	A	S/A	S/D	DA	SDA
1	My prior chemistry knowledge affected my performance in stoichiometry	8 (28.57%)	8 (28.57%)	1 (3.57%)	3 (10.7%)	5 (17.85%)	3 (10.71%)
2	I feel motivated and engaged during stoichiometry lessons	2 (7.14%)	2 (7.14%)	3 (10.7%)	1 (3.57%)	8 (28.57%)	12 (42.85%)
3	I lack problem solving skills in stoichiometry	10 (35.71%)	9 (32.14%)	2 (7.14%)	4 (14.28%)	3 (10.71%)	0 (0.00%)
4	Difficulty in visualizing chemistry reactions affected my performance in stoichiometry	8 (28.57%)	12 (42.85%)	3 (10.71%)	2 (7.14%)	1 (3.57%)	2 (7.14%)

The analysis in Table 2 shows that 57.1% strongly agreed or agreed that their prior chemistry knowledge affected their performance in stoichiometry due to pre-existing knowledge they had possessed before new information was given out. The amount of prior knowledge strongly influences the process of conceptual change (Stern, 2015).

Prior knowledge has a profound impact on students' performance in stoichiometry, a fundamental concept in chemistry that deals with the quantitative relationship between reactants and products. When students bring prior knowledge to the learning process which is in contrast with the new information given, it hinders their learning process. For example, students who have previously learned about stoichiometry in a simplistic or inaccurate way may struggle to understand more complex concepts, such as limiting reactants or percent yield. This is because their prior knowledge can create a cognitive bias, making it difficult for them to reconcile new information with their existing understanding (Kalyuga, 2020).

Moreover, prior knowledge can also lead to misconceptions and misunderstandings in stoichiometry among students. For example, students who have previously learned that stoichiometry is only about balancing chemical equations may struggle to understand the concept of mole ratios and how they relate to the quantities of reactants and products.

This can lead to errors in calculations and a lack of understanding of the underlying principles (Koedingier, 2020). Additionally, research has shown that prior knowledge influences students' ability to transfer learning to new situations, with students who have a strong foundation in stoichiometry being more likely to struggle with applying their knowledge to novel problems (Wylie, 2020).

The analysis in Table 2 shows that 57% strongly agreed or agreed that their lack of problem-solving skills in stoichiometry affected their performance negatively in stoichiometry lessons. Lack of problem-solving skills in stoichiometry significantly hinders students' ability to apply mathematical concepts to real-world problems. Stoichiometry problems often require students to think critically and make connections

between different concepts such as mole ratios, limiting reactants, and percentage yield (Khan, 2023). Without a strong problem-solving skill, students struggle to identify the problem type which is their inability to recognize the type of stoichiometry problem they are dealing with, which leads to incorrect application of formulae and concepts (Naidoo, 2017).

Students responses to the open-ended questionnaire showed that they get frustrated whenever they struggle to apply a particular mathematical concept to real-world problems. Some of students' responses from the questionnaire include; *'I get stuck on the way whenever I try practicing stoichiometric mathematical problems so, I halt everything'*.

Again, a student from the current study is given a problem that involves calculating stoichiometric ratio of a reaction. The student struggles to visualize the molecules and rely on memorization, leading to incorrect calculations. Also, in predicting the outcomes of reactions, including the formation of products and the consumption of reactants, students may struggle to visualize the reaction mechanism and rely on memorization, leading to incorrect predictions. When students are demotivated and disengaged, they may experience a range of negative consequences.

Table 2 shows that over 70% of the students disagreed or strongly disagreed that they weren't motivated and engaged during stoichiometry lessons. When students do not see the relevance and meaning of stoichiometry concepts, they become demotivated, (Killen, 2015). Demotivated students may not put in the necessary efforts and persistence to master concepts, leading to a slack in performance. A student is struggling to understand the concept of mole ratios in stoichiometry, instead of asking for help, the student gives up and stops attending classes. As a result, students fall

behind in the course and receives poor grade. Such a student also struggles to connect these concepts to real world applications, leading to a lack of relevance and meaning. When the student is learning about the concept of limiting reactants however, does not see the relevance of this concept to real world applications such as chemical manufacturing or environmental science, such a student becomes disengaged and does not put in the effort to understand the concept.

In Appendix C, students lose interest and demotivated due to some factors. Examples of the responses from students include: “Stoichiometry is too abstract”, “I find stoichiometry too boring and difficulty”. All these responses clearly show the level of demotivation and disinterest among students due to the following reasons:

- difficulty seeing relevance
- abstract concepts
- perceived difficulty of concepts

Students also get demotivated when teaching methods are unengaging (Hativa, 2020).

In Appendix C of students’ responses, it appears that the issues are teacher related issues. Some of the responses from the students in the open-ended questionnaire included “*The teacher doesn’t make the class interactive encouraging collaborative learning.*”, “*The teacher doesn’t provide real life examples*”. “*The teacher only speaks to himself and also speaks too fast*”. All these clearly take off their attention during the learning process resulting in a declining of their performance. Learners’ poor performance in stoichiometry can be attributed to the following findings obtained:

1. Lack of concrete consistent prior knowledge leading to knowledge gaps and difficulties in transfer of learning.
2. Low level of motivation causing disengagement and disinterest in the lesson.

3. Lack of problem-solving skills in stoichiometry.
4. Inadequate teaching strategy on the part of the teacher.
5. Abstract concepts leading to an unfriendly learning environment

4.3 Research question three (3)

What is the effect of using the interactive simulation intervention on students' academic performance in stoichiometry?

This inquiry sought to ascertain how students' performance in stoichiometry was impacted by the use of interactive simulations. The data analysis employed both descriptive and inferential statistics. There is no statistically significant difference between students' academic performance in the concept of stoichiometry before and after the simulation intervention, according to the null hypothesis developed to address the question.

Using the scores from the pre-intervention and post-intervention tests, the students' performance was analyzed using a paired sample t-test in order to test the null hypothesis. With a 95% confidence level, the significant level was at alpha (α) = 0.05.

The null hypothesis was to be rejected if $t\text{-stat} > t\text{-critical}$ (+2.060). Additionally, reject the null hypothesis if the p-value is less than the alpha value (0.05). For the paired sample test, students' scores from the pre-test and post-test were utilized. Table 3 displays the findings.

Table 3: Paired or dependent sample t - test

	Mean difference	Df	T Statistics	T Critical	P Values	Cohen's d
Pair 1	7.57	27	6.42	2.060	0.0001	1.17

Post – test
scores

Pre – test
scores

The mean difference is 7.57 according to Table 3. This indicates that, in contrast to the "pre-intervention test," the pupils performed well on the post-intervention exam. Additionally, the null hypothesis is rejected because the P-value (0.000001) is less than the alpha value (0.05). This also indicates how well the students performed both before and after the intervention in terms of the stoichiometry concept. Students' academic performance in the concept of stoichiometry before and after the simulation intervention differed statistically significantly, as evidenced by the null hypothesis being rejected since, above all, the t-statistics (6.42) > t-critical (2.060). The effect size was then determined by the researcher. The Cohen's d categorization table is displayed in Table 4 in accordance with Butola (2025).

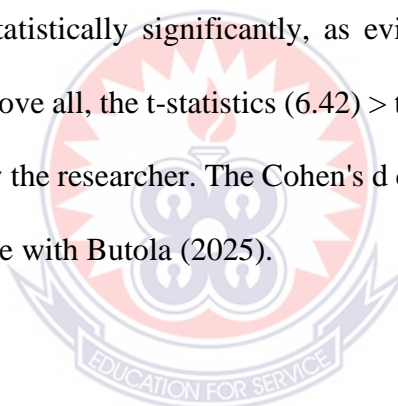


Table 3: Cohen's d categorization table

Cohen's d value	Effect Size	Interpretation
< 0.2	Small	Negligible effect
0.2 – 0.5	Medium	Moderate effect
0.5 – 0.8	Large	Significant effect
0.8 >	Very Large	Substantial effect

The interactive simulation intervention had a significant impact on students' performance, as indicated by Table 4's big effect size (Butola, 2025) and Cohen's d value of 1.17 from Table 3. The following were the results of the third research question:

1. The academic performances of the students improved immensely due to the use of the interactive simulation intervention because there was a statistically significant difference.
2. The effect size that the intervention had on the form two chemistry students was large.

4.4 Research question four (4)

What are the perceptions of students regarding the effectiveness of interactive simulations on their learning outcome in their study of stoichiometry?

After students had gone through the intervention and post-intervention test; a questionnaire consisting of a closed ended and opened – ended was administered to know students' true impressions towards the effectiveness of the interactive simulation intervention. The results are presented in Table 5.

Table 4: Results of the analysis from the questionnaire

Table 5: Frequency of Students' responses to close – ended questionnaire

S/N	Statement	SA	A	S/A	S/D	DA	SDA
1	I am now able to apply what I learnt through the lessons in more complex calculations	18 (64.3%)	6 (21.4%)	2 (7.10%)	1 (3.60%)	1 (3.60%)	0 (0.00%)
2	I have noticed a positive impact in my understanding of concept when engaged in an interactive simulated learning environment	20 (71.4%)	5 (17.9%)	2 (7.10%)	1 (3.60%)	0 (0.00%)	0 (0.00%)
3	I feel that I can perform better in my forthcoming exams and beyond.	16 (57.01%)	8 (28.60%)	2 (7.14%)	1 (3.60%)	1 (3.60%)	0 (0.00%)
4	Doing stoichiometry calculations in an interactive simulated environment is fun.	14 (50%)	8 (28.60%)	4 (14.3%)	1 (3.60%)	1 (3.60%)	0 (0.00%)
5	I feel more confident and motivated in learning stoichiometry than before.	18 (64.3)	6 (21.4%)	2 (7.1%)	1 (3.6%)	1 (3.6%)	0 (0.00%)

Note: SA – strongly agree, A- agree, S/A – slightly agree, S/D – slightly disagree, DA – disagree, SDA – strongly disagree

The analysis in Table 5 shows that over 80% of the students agree or strongly agree that they are able to apply what they learnt in stoichiometry through the use of interactive simulation in a more complex calculation. According to recent studies (Wouter, 2023), interactive simulations can enhance students' understanding and application of stoichiometric concepts. These simulations allow students to manipulate variables, observe the effect and receive immediate feedback which enhances the application of concepts. Students asserted that interactive simulations helped them to apply stoichiometric concepts in more complex calculations. Students struggling to understand how to calculate the amount of product formed in a reaction visualized the process and applied the formulae correctly. This is likely due to the interactive and engaging nature of the simulation, which allowed students to visualize and experiment with different scenarios in a safe and controlled environment.

From Table 5, students asserted firmly that their engagement in the simulation intervention brought a positive impact in their understanding of stoichiometric concepts. This is in conformity with a study by Bandura (2022) which found that interactive simulation improved students' understanding of concepts, where a student was able to visualize the molecules and see how they interacted with each other and again how different molecules fit together to keep in the outcome of a reaction.

In the open-ended questionnaire (Appendix E), the responses from students show that the simulation intervention impacted their understanding positively. Some of the students' responses include, *"The visual representations of the reactions helped me visualize the concepts in a way that I couldn't with just text and equations"*, *"I was able to connect the abstract concepts to contextual applications making learning more meaningful"*.

All these responses from students show their true impressions about the simulation intervention, how positively it impacted their understanding. A study by Khan (2023) found that students who used simulations to learn about stoichiometry showed a significant improvement in their understanding of the concepts compared to those who did not use simulations. This is also consistent with the findings of other studies which have shown that simulations can improve students' understanding and retention of complex concepts (Wouter, 2023).

In Table 5, students' confidence level was boosted of which about 80% and above agreed or strongly agreed that they can perform better in the forthcoming exams and beyond. These true impressions from students show how effective the interactive simulation was.

In Appendix E, students confidently affirmed on the recommendation of simulation in their future studies because they felt it helped them to retain information longer and also prepare them for future applications which is in consonance with real world connections in terms of career. Students' assertion that, being able to perform better in their forthcoming exams and beyond after going through the intervention is consistent with a study by Khan (2023), which shows that interactive simulations can improve students' confidence and self-efficacy in learning complex concepts. This increased self-efficacy leads to improved performance in exams and other assessments (Bandura, 2022).

Students further asserted that stoichiometry calculations in an interactive simulated environment is fun where over 85% agreed or strongly agreed in table 4 (SN 4). According to Dichev (2022) interactive simulations provide students with a sense of excitement and enjoyment in learning complex concepts. Collaborative learning can be

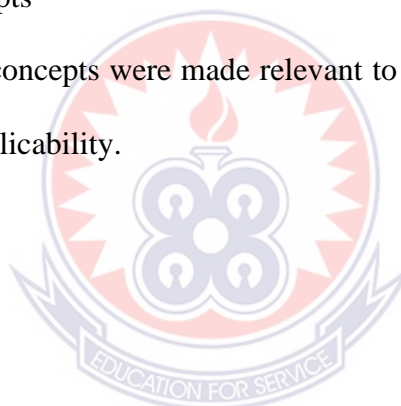
a fun and engaging experience for students where students work together to solve problems and complete tasks (Linn, 2022).

In the open-ended questionnaire (Appendix E), students were asked to give their true impressions on how they feel about their engagement and involvement in the lesson when using simulation intervention. Some of their responses include, “I was doubtful at first, but as we came together and practiced, it really helped me”, “I enjoyed involving myself in the activity it was really fun”. These simulations provide students with a hands-on-experience, allowing them to manipulate variables, observe the effects and receive immediate feedback (Dichev, 2022). This atmosphere of learning encourages explorative learning among students (kabir, 2016) and enables students to explore and experiment different scenarios which can foster a sense of curiosity and excitement (Dichev, 2022). When students are able to interact with simulations and see the results of their actions, they are most likely to be motivated to learn (Wouter, 2023).

In Table 5 over 85% of students agreed or strongly agreed that they are more confident and motivated in learning stoichiometry than before. Interactive simulations provide students with a sense of control over their learning which increases motivation among students (Khan, 2023). The assertions from students are also consistent with the findings of a study by Wouter (2023), which found that simulation-based learning led to improved learning outcomes and increased students’ confidence. As students share ideas, combine ideas and arrive at a solution to a particular issue, it serves as a form of internal motivation which help them fill in any knowledge gap (Bandura, 2022). When students feel in control of their learning, they are more likely to enjoy the experience and hence motivated (Linn, 2022). A study by Bandura (2022), shows that when students are demotivated, they are less likely to put in the efforts required to master a

concept. So, when students are able to interact with simulations and see the results of their action, they are more likely to be motivated to learn and are more engaged in the learning process. Based on students' true impressions about the simulation's intervention, it clearly shows the intervention was successful regarding the effectiveness of the interactive simulations on students' performance before and after the intervention. The findings from students' responses include:

1. Simulation intervention enhanced the understanding chemical reactions involving mole ratios
2. Problem solving skills were improved enabling accurate applications of chemical concepts
3. Stoichiometry concepts were made relevant to real world scenarios increasing interest and applicability.



CHAPTER FIVE

SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS

5.0 Overview

The primary findings and conclusions of the study are summarized in this chapter, along with recommendations and ideas for additional research.

5.1 Summary of the main findings of the study

This study's primary goal was to assess students' academic performance in chemical stoichiometry using interactive simulations. The following is a summary of the study's primary conclusions based on the research questions:

5.1.1 Students' prior conceptions about stoichiometry.

The findings that were drawn from the quantitative data obtained from the stoichiometry performance conceptions were:

1. The numbers in a chemical formula represents the number of molecules of each element.
2. The numbers in a chemical formula only represents actual number of atoms not the ratio of atoms.
3. Reactants with the smaller mass is always the limiting reagent or the reactant with bigger mass is the excess reactant.
4. A limited reagent is one with a small number coefficient.
5. An excess reagent is one with a big number coefficient.
6. Students presumed that increasing concentration of reactants affected the mole ratios.
7. Acids and bases always react in a 1: 1 ratio and,

8. There was overreliance on procedural knowledge rather than conceptual understanding.

5.1.2 Factors influencing students' poor performance in stoichiometry.

The findings drawn from the questionnaire were:

1. Lack of concrete consistent prior knowledge leading to knowledge gaps and difficulties in transfer of learning.
2. Low level of motivation causing disengagement and disinterest in the lesson.
3. Lack of problem-solving skills in stoichiometry.
4. Inadequate teaching strategy on the part of the teacher, and
5. Abstract concepts leading to an unfriendly learning environment

5.1.3 The effect of interactive simulations on students' academic performance in stoichiometry.

The findings drawn from the research question three were:

1. The academic performance of the students improved immensely due to the use of the interactive simulation intervention because there was a statistically significant difference before and after the intervention delivery, and
2. The effect that the interactive simulation intervention had on the students was large (1.17)

5.1.4 Students' perceptions regarding the effectiveness of the interactive simulation intervention on students' academic performance in stoichiometry.

The finding drawn from the questionnaire were:

1. The simulation intervention enhanced the understanding chemical reactions involving mole ratios.

2. Problem solving skills were improved enabling accurate applications of chemical concepts, and
3. Stoichiometry concepts were made relevant to real world scenarios increasing interest and applicability.

5.3 Conclusion

This study's primary goal was to assess students' academic performance in chemical stoichiometry using interactive simulations. The following is a summary of the study's primary conclusions based on the research questions:

The gathered findings also showed that using interactive simulations improved the academic performance of learners and they had a deeper understanding of the concept. Lastly, students generally perceived the simulation-based intervention as effective in improving their understanding of stoichiometry.

5.2 Recommendations from the Study

The following recommendations were given based on the study's findings and the conclusion reached:

1. The study recommends chemistry educators at Keta Senior High Technical School to design instructional strategies (computer simulations) that specifically address students' prior conceptions in stoichiometry.
2. Another recommendation is for teachers in Keta Senior High Technical School to Implement student-centered instructional approaches, such as computer simulations which may help address the causes of poor learning outcomes among learners.

3. The study recommends chemistry educators at Keta Senior High Technical School to Incorporate simulations into stoichiometry instruction to enhance student understanding and academic performance.
4. The study recommends chemistry educators at Keta Senior High Technical School upon understanding students' perceptions, they can refine and improve the effectiveness of simulation-based interventions, leading to better learning outcomes.

5.4 Suggestions

The following topics should be investigated in order to shed more light on the use of computer simulations in Ghanaian classrooms.

1. To find out how the interactive simulation intervention would affect children in rural and urban settings, municipalities and districts in the Volta region should do the same.
2. Another recommendation is that teachers receive suitable in-service training on using technology in the classroom from the Ghana Education Service. Thus, by incorporating technology into instruction, the instructor establishes a learning environment in which students participate in activities and communicate with one another to build knowledge.
3. Another recommendation is that department heads and instructors at postsecondary educational and training institutions offer the required assistance through training for the effective integration of technology for teaching and learning, and that school principals provide the required environment and support.

REFERENCES

- Akpan, V. I., Igwe, U. A., Mpawah, I. B. I., & Okoro, O. C. (2020). Social constructivism; implication on teaching and learning. *British Journal of Education*, 8(8), 49-56.
- Akesela, M. (2005). *Supporting meaningful chemistry learning and higher-order thinking through computer-assisted inquiry: A design research approach*. University of Helsinki.
- Aliu, A. A. (2011). *Effect of concept mapping approach on students' achievement and retention. In electrolysis*. Unpublished M.Ed Dissertation, Lagos State University, Lagos State.
- Alkahtani, A. A. (2016). The challenges facing participants in integration of ICT skills and equipment into the classrooms in SAUDI secondary schools. *Social Science Learning Education Journal*, 1, pp. 39-47. doi: 10.21608/mfes.2019.103125
- Alshenqeeti, H. (2014). Interviewing as a data collection method: A critical review. *English Linguistics Research*, 3(1), pp. 39–45. doi: <https://doi.org/10.5430/elr.v3n1p39>
- Amineh, R. J., & Asl, H. D. (2015). Review of constructivism and social constructivism. *Journal of social science, literature and languages*, 1, 9-16.
- Anderson, J. L., & Wall, S. D. (2016). Kinecting physics: Conceptualization of motion through visualization and embodiment. *Journal of Science Education and Technology*, 25, 161–173.
- Anuradha, P. (2023). What is the difference between thematic and content analysis? Pedia. <https://pedia.com/what-is-the-difference-between-thematic-and->

Content analysis/Appleton and D.L. Hanuscin (Eds), *Handbook of research on science*

- Arasasingham, R.D., Taagepera, M., Potter, F., & Lonjers, S. (2004). Using knowledge space theory to assess student understanding of stoichiometry. *Journal of Chemical Education*, 81(10), 1517.
- Ary, D., Jacobs, L. C., Sorensen, C., & Razavieh, A. (2010). *Introduction to research in Education*, 8th ed. Wadsworth: Cengage Learning.
- Arya, A., & Kumar. A. (2018). *Mole concept and problem-solving approaches in life sciences*. New Delhi: Drawing Pin Publishing. doi: 10.13140/RG.2.2.29899.90406/1
- Astutik, S., & Prahani, B.K. (2018). The practicality and effectiveness of collaborative creativity learning (CCL) model by using PhET simulation to increase students' scientific creativity. *International Journal of Instruction*, 11(4), pp. 409–424.
- Bailey, C. G. (2007). Examining the effectiveness of computer animations as a tool in teaching high school introductory chemistry (Master's project report, Regis University).
- Bandoy, J. V. B., Pulido, M. T. R., & Sauquillo, D. J. (2015). The effectiveness of using PHET simulations for physics classes: A survey. In the Proceedings 275 of the International Conference on Engineering Teaching and Learning Innovation (ICEE-PHIL1 2015) (p. 80). Philippine Association of Engineering Schools.
- Banduara, P., (2022). The benefits of simulations on students conceptual understanding in science.

- Bas, S., & Tega, G. (2023, March 21). What is conceptual framework? Tips and examples. Scribbr. <http://www.scribbr.com/methodology/conceptual-framework/>
- Bayrak, B. K., & Bayram, H. (2010). Effect of computer aided teaching of acid/base subject on the attitude towards science and technology class. *Procedia-Social and Behavioral Sciences*, 2(2), pp. 2194–2196.
- Bell, R. L., & Smetana, L. K. (2008). Using computer simulations to enhance science teaching and learning. *National Science Teachers Association*, 3, pp. 23–32.
- Bhandari, P. (2023, March 04). Population Vs. Sample/ definitions, differences and examples. Scribbr. <https://www.scribbr.com/methodology/population-vs-sample>
- Bílek, M., Nodzyńska, M., Kopek-Putała, W., & Zimak-Piekarczyk, P. (2018). Balancing chemical equation using sandwich making computer simulation games as a supporting teaching method. *Problems of Education in the 21st Century*, 76(6), p. 779
- Bindu, C. N. (2016). Impact of ICT on teaching and learning: A literature review. *International Journal of Management and Commerce Innovations*, 4(1), pp. 24–31
- BouJaoude, S., & Barakat, H. (2000). Secondary school students' difficulties with stoichiometry. *School Science Review*, 81(296), pp. 91–98.
- Bozkurt, E., & Ilik, A. (2010). The effect of computer simulations over students' beliefs on physics and physics success. *Procedia – Social and Behavioral Sciences*, 2(2), pp. 4587–4591.
- Bridges, C. D. (2015). Experiences teaching stoichiometry to students in Grades 10 and 11 (Doctoral dissertation, Walden University, Minneapolis).

- Brierley, J. A. (2017). The role of a pragmatist paradigm when adopting mixed methods in behavioral accounting research. *International Journal of Behavioral Accounting and Finance*, 6(2), pp. 140–154. doi:
- Brunner, J. A. (1961). The role of a pragmatist paradigm when adopting mixed methods in behavioral accounting research. *International Journal of Behavioral Accounting and Finance*, 6(2), pp. 140–154. doi:
- Butola, J. A. (2025). The role of a pragmatist paradigm when adopting mixed methods in behavioral accounting research. *International Journal of Behavioral Accounting and Finance*, 6(2), pp. 140–154. doi:
- Johnson, R. B., Onwuegbuzie, A. J. & Turner, L. A., (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, 1(2), p p.112–133. doi: 10.1177/155868980629822410.1504/IJBAF.2017.10007499
- Ceberio, M., Almudi, J. M., & Franco, Á. (2016). Design and application of interactive simulations in problem solving in university-level physics education. *Journal of Science Education and Technology*, 25(4), pp. 590–609.
- Chandrasegaran, A. L., Treagust, D. F., Waldrip, B. G., & Chandrasegaran, A. (2009). Students' dilemmas in reaction stoichiometry problem solving: deducing the limiting reagent in chemical reactions. *Chemistry Education Research and Practice*, 10(1), pp. 14–23. doi: 10.1039/b901456j
- Chandrasegaran, A. L., Treagust, D. F., Waldrip, B. G., & Chandrasegaran, A. (2022). Students' dilemmas in reaction stoichiometry problem solving: deducing the limiting reagent in chemical reactions. *Chemistry Education Research and Practice*, 10(1), pp. 14–23. doi: 10.1039/b901456j
- Chang, R. (2010). *Fundamental Chemistry*, 6th Ed. New York: McGraw Hill.

- Chao, J., Chiu, J. L., DeJaegher, C. J. & Pan, E. A., (2016). Sensor-augmented virtual labs: using physical interactions with science simulations to promote understanding of gas behavior. *Journal of Science and Educational Technology*. 25, pp. 16–33. *Chem Educ Res Pract*. (2010). Chemical stoichiometry. *Review of Education institute of education journal, Chemistry teaching at secondary school level in Lesotho*. pp11(3):154–164. <https://doi.org/10.1039/C005464J>.
- Clark, D., Nelson, B., Sengupta, P., & D'Angelo, C. (2009, October). Rethinking science learning through digital games and simulations: Genres, examples, and evidence. In *Learning science: Computer games, simulations, and education*. Workshop sponsored by the National Academy of Sciences, Engineering, and Medicine, Washington, DC.
- Cooper, V. I., Frank, U. A., & Mpawah, I. B. I. (2022). The influence of balancing chemical equations: Students conceptual understanding in Stoichiometry. *Journal of Chemical Education Research*, 2, 1-9.
- Correia, A. P., Koehler, N., Thompson, A., & Phye, G. (2019). The application of PhET simulation to teach gas behavior on the submicroscopic level: secondary school students' perceptions. *Research in Science and Technological Education*, 37(2), pp. 193–217. doi: <https://doi.org/10.1080/02635143.2018.1487834>.
- Creamer, E. G. (2017). *An introduction to fully integrated mixed methods research*: Sage Publications.
- Creswell, J. (2009). *Research design. Qualitative, quantitative and mixed methods approach*. 3rd ed. Sage Publications.

- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed Methods approach*. Sage Publications.
- Creswell, J. W., & Garrett, A. L. (2008). The “movement” of mixed methods research and the role of educators. *South African Journal of Education*, 28(3), pp. 321–333. doi: <https://doi.org/10.15700/saje.v28n3a176>.
- Davidowitz. B., Chittleborough. G., & Murray E. (2010). Student-generated sub micro diagrams: a useful tool for teaching and learning chemical equations and stoichiometry. *Chem Educ Res Pract*. 2010; 11(3):154–164. <https://doi.org/10.1039/C005464J>.
- De Vos, A. S., Delport, C. S. L., Fouché, C. B., & Strydom, H. (2011). *Research at grass roots: A primer for the social science and human professions*. Van Schaik Publishers.
- Develaki, M. (2019). Methodology and epistemology of computer simulations and implications for science education. *Journal of Science Education and Technology*, 28(4), pp. 353–370.
- Dichev, T., (2022). The positive effect of interactive simulations on students conceptual understanding in stoichiometry.
- Dimitrov, D. M., & Rumrill Jr, P. D. (2003). *Pretest-posttest designs and measurement of change. Disciplines*. Chittagong: Mohammad Javed Rahim Book Zone Publication. doi: 10.1007/s11577-017-0454-1.
- Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? *Instructional Science*, 41(1), pp .105–124.
- Edmonds, W. A., & Kennedy, T. D. (2016). *An applied guide to research designs: Quantitative, qualitative, and mixed methods*. Sage Publications.

- Fach, M., De Boer, T., & Parchmann, I. (2007). Results of an interview study as basis for the development of stepped supporting tools for stoichiometric problems. *Chemistry Education Research and Practice*, 8(1), pp. 13–31.
- Fang, S. C., Hart, C., & Clarke, D. (2016). Identifying the critical components for a conceptual understanding of the mole in secondary science classrooms. *Journal of Research in Science Teaching*, 53(2), pp. 181–214. doi: <https://doi.org/10.1002/tea.21298>
- Feilzer, M. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, 4(1), pp. 6–16. doi: 10.1177/1558689809349691
- Froyd, J., & Simpson, N. (2010). Student-centered learning addressing faculty questions about Student centered learning. 7FC3682620074B449AA1?doi=10.1.1.526.348&rep=rep1
- Gambari, I. A., Gbodi, B. E., Olakanmi, E. U., & Abalaka, E. N. (2016). Promoting intrinsic and extrinsic Motivation among chemistry students using computer assisted instruction. *Contemp Educ Technol*. pp (1):25–46. <https://doi.org/10.30935/cedtech/6161>.
- Gauchon, L., & Méheut, M. (2007). Learning about stoichiometry: from students' preconceptions to the concept of limiting reactant. *Chemistry Education Research and Practice*, 8(4), pp. 362–375.
- George, M. J., & Kolobe, M. (2014). Exploration of the potential of using a virtual laboratory for Chemistry teaching at secondary school level in Lesotho.
- Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*, 8(4), pp. 597–607.

- Grant, A. (2023, March 6). What is data analysis and why is it important? Make Use Of. <https://www.makeuseof.com/tag/what-is-data-analysis/>
- Griffiee, D. T. (2005). Research tips: Interview data collection. *Journal of Developmental Education*, 28(3), pp. 36–37
- Gulacar, O. (2007), An investigation of successful and unsuccessful students' problem solving in stoichiometry (Doctoral dissertation, Western Michigan University, Kalamazoo, Michigan).
- Gupta, T. (2019). Promoting mathematical reasoning and problem solving through inquiry-based Relevance focused computer simulations: a stoichiometry lab. *Chem. Teach.* <https://doi.org/10.1515/cti-2018-0008>
- Lownes, R. S., & Jackson, M. (2015). The use of computer simulation to compare student performance in traditional versus distance learning environments. *Issues in Informing Science and Information Technology*, 12(1), pp. 95–109.
- Hanson, R. (2016). Ghanaian teacher trainees' conceptual understanding of stoichiometry. *Journal of Education and e-Learning Research*, 3(1), pp. 1– 8.
- Hardman, J. (2005). *Activity theory as a framework for understanding teachers' perceptions*. Harvard University Press.
- Hativa, L. (2020). How demotivation affects Students achievement in science. *School Science Review*, 79(289), pp. 33–41
- Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., La Velle, L., McFarlane, A., Ruthven, K., & Winterbottom, M. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers and Education*, 48(1), pp. 137–152.

- Hursen, C. & Asisoy, G. (2015). The effect of simulation methods in teaching physics on students' academic success. *World Journal on Educational Technology: Current Issues*, 7(1), pp. 87–98
- Jaranilla, J. A., Prudente, M. S., & Perez, D. R. (2017). Exploring students' conceptions on stoichiometry using SCQS and VCQS. *Asia Pacific Journal of Education, Arts and Sciences*, 4(2), pp. 45–51.
- Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning. A case study on students' understanding of trajectory motion. *Computers and Education*, 36(2), pp. 183–204. doi: [https://doi.org/10.1016/S0360-1315\(00\)00059-2](https://doi.org/10.1016/S0360-1315(00)00059-2)
- Julius, J. K. (2018). Influence of computer aided instruction on students' achievement, self-efficacy and collaborative skills in chemistry in secondary schools of Tharaka-Nithi County, Kenya (Unpublished PhD thesis, Kenyatta University).
- Kabir, S. M. S. (2016). Basic guidelines for research: An introductory approach for all Disciplines. Chittagong: Mohammad Javed Rahim Book Zone Publication.
- Kalyuga, L. (2020). The effect of computer simulations on acquisition of knowledge and cognitive load: a gender perspective. *African Journal of Research in Mathematics, Science and Technology Education*, 20(1), pp. 67–79. doi: <https://doi.org/10.1080/10288457.2016.1150558>
- Kanime, M. K. (2015). An Investigation into how Grade 11 Physical Science teachers mediate learning of the topic stoichiometry: a case study. [Masters dissertation]. Grahamstown, South Africa: Rhodes University.
- Kaptelinin, V., & Nardi, B. A. (2018). Activity theory: Basic concepts and applications of chemistry. *Journal of Chemical Education Research*, 2, 1-9.

- Karanasios, S. (2014). Framing ICT4D Research Using Activity theory: A match Between the ICT4D field and Theory. *Information Systems Journal*.
- Khan, T., (2023). How simulations affect students' motivation in chemical stoichiometry. *Journal of Science Education and Technology*, 32(2), 123-135.
- Killen, R. (2015). *Effective teaching strategies: Lessons from research and practice*. Cengage Learning Australia
- Kotoka, L. (2013). Effects of computer simulations on the teaching of atomic combinations to grade 11 physical science learners (Doctoral dissertation, Unisa, Pretoria, South Africa).
- Koedinger, S. (2020). The underlying principles of stoichiometric calculations. *Journal of Chemical Education*, 97(5), 1234-1245. doi: 10.1021/acs.jchemed.9b01058
- kohler, J. A. (1929). The role of a pragmatist paradigm when adopting mixed methods in behavioral accounting research. *International Journal of Behavioral Accounting and Finance*, 6(2), pp. 140–154. doi:
- Kunnath, B., & Kriek, J. (2018). Exploring effective pedagogies using computer simulations to improve Grade 12 learners' understanding of the photoelectric effect. *African Journal of Research in Mathematics, Science and Technology Education*, 22(3), pp. 329–339. doi: <https://doi.org/10.1080/18117295.2018.1531500>.
- Kunnath, B. J. (2017). The effect of computer simulations on Grade 12 learners' understanding of concepts in the photoelectric effect (Master's dissertation, Unisa, Pretoria, South Africa).

- Leavy, P. (2017). *Research design: Quantitative, qualitative, mixed methods, arts based, and Community-based participatory research approaches*. Guilford Publications.
- Leedy, P. D. & Ormrod, J. E. (2014). *Practical research: Planning and design*. Pearson Education.
- Lerman, Z. M. (2014). The challenges for chemistry education in Africa. *African Journal of Chemical Education*, 4(2), pp. 80–90.
- Linn, T. (2022). The effect of collaborative learning in science education. *Journal of Science Teacher Education*, 33(3), 257-274. doi: 10.1080/10476596.2022.2038745
- Lisene, L. N., & Jita, T. (2018). Exploring the integration of modern technologies in the teaching of physical science in Lesotho. *Perspectives in Education*, 36(1), pp. 111–127. doi: <http://dx.doi.org/10.18820/2519593X/pie.v36i1.8>
- Liu, H. C. (2005). Examining the use of computer simulations to promote learning of electrochemistry among college students (Doctoral dissertation, Iowa State University).
- Liu, D. & Mcneil, J., (2022). The effect of chemical formulae on understanding on Students' conceptual in stoichiometry. doi: <https://doi.org/10.6007/ijarbss%2Fv8->
- Makhechane, M., & Qhobela, M. (2019). Understanding how chemistry teachers transform Stoichiometry concepts at secondary level in Lesotho. *S Afr J Chem*. Pp. 72:59–66. <https://doi.org/10.17159/0379-4350/2019/v72a9>.
- Malcolm, S. A., Mavhunga, E., & Rollnick, M. (2018). A lesson on teaching the mole concept //conceptually: A learning study. In Book of proceedings: 26th conference of the Southern African association for research in mathematics,

- science and technology education (pp. 134-149). University of Gaborone, Botswana: SAARMSTE.
- Malcolm, S. A., Rollnick, M., & Mavhunga, M. E. (2014). Conceptualization of the mole: An argument for a refined conception of the mole for effective teaching of stoichiometry. Presented as a short paper at the 22nd Annual Conference of SAARMSTE. Port Elizabeth, South Africa
- Malia, N. S., & Kambleb, S. S. A. (2020). Curricular engagement with reference to Vygotski's Thoughts. *Journal Lingkar Studi Komunikasi*, 6(1).
- Marais, F. & Combrinck, S., (2009). An approach to dealing with the difficulties undergraduate chemistry students experience with stoichiometry. *South African Journal of Chemistry*, 62, pp. 88–96.
- Maree, K. (2016). The purpose, design and administration of a questionnaire for data Collection. *Radiography*, 11(2), pp. 131–136. doi: <https://doi.org/10.1016/j.radi.2004.09.002>
- Mayer, R. E., & Moreno, R. (2017). Nine ways to reduce cognitive load in multimedia learning. *Educ Psychol*. 2017; 38(1):43–52. <https://doi.org/10.1207/S15326985EP38016>
- Naidoo, J. (2017). Exploring the use of activity theory as a framework for the teaching and Learning of mathematics. *Pythagoras*, 33(1), pp. 1–9.
- Ndlovu, B. P. (2017). Examining the development of topic specific pedagogical content knowledge in stoichiometry in pre-service teachers (Master's dissertation, University of the Witwatersrand, Johannesburg).
- Nkemakolam, O. E., Chinelo, O. F., & Madichie, C. J. (2018). Effect of computer simulations on secondary school students' academic achievement in chemistry

- in Anambra State. *Asian Journal of Education and Training*, 4(4), pp. 284–289.
- Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving To meet the trustworthiness criteria. *International Journal of Qualitative Methods*, 16(1). doi:<https://doi.org/10.1177/1609406917733847>
- Origil A., 2022. The impact of chemical formula on student’s performance in stoichiometry. *Journal of Education and Training*, 4(4), pp. 284–289.
- Okanlawon, A. E. (2010). Constructing a framework for teaching reaction stoichiometry using pedagogical content knowledge. 19(2), pp. 27–44.
- Oliorundare, A. S. (2014). Correlates of poor academic performance of secondary school students in the sciences in Nigeria. Paper presented at the International Institute for Capacity Building in Higher Education, Virginia State University, Virginia, USA. 20th – 31st June
- Olorunyomi, A. A. (2013). Effect of experiential teaching method on students’ achievement In Chemistry. Unpublished M.Ed dissertation, Ekiti State University, Ado Ekiti.
- Omwirhiren, M. (2015). Analysis of students’ error in learning of mole concept among selected senior secondary school chemistry students in Zaria, Nigeria. *Journal of Research and Method in Education*, 5(5), pp. 1–7.
- Opara, M. F. (2014). Improving students’ performance in stoichiometry through the implementation of collaborative learning. *Journal of Education and Vocational Research*, 5(3), pp. 85–93.
- Osman, K., & Sukor, N. S. (2013). Conceptual understanding in secondary school chemistry: A discussion of the difficulties experienced by students. *American Journal of Applied Sciences*, 10(5), p. 433.

- Özmen, H. (2008). The influence of computer-assisted instruction on students' conceptual understanding of chemical bonding and attitude toward chemistry: A case for Turkey. *Computers and Education*, 51(1), pp. 423–438. doi: <https://doi.org/10.1016/j.compedu.2007.06.002>
- Parvaiz, G. S., Mufti, O. & Wahab, M. (2016). Pragmatism for mixed method research at higher education level. *Business and Economic Review*, 8(2), pp. 67–79.
- Paulson, A., Adams, W., & Perkins, K. (2009). PhET simulations: Should we show the invisible? In American Association of Physics Teachers Conference 2009, Ann Arbor, MI.
- Pekdağ, B., & Azizoğlu, N. (2013). Semantic mistakes and didactic difficulties in teaching the “amount of substance” concept: a useful model. *Chemistry Education Research and Practice*, 14(1), pp. 117–129. doi: <https://doi.org/10.1039/C2RP20132A>
- Perkins, K., Lancaster, K., Loeblein, P., Parson, R., & Podolefsky, N. (2010). PhET interactive Simulations: New tools for teaching and learning chemistry. Boulder: University of Colorado. [Online]. [http://www.ccce.divched.Org/Fall1010CCCENewsletterP7/phet- Interactivesimulations-new-tools-for-teachine-and-learning-chemistry.pdf](http://www.ccce.divched.Org/Fall1010CCCENewsletterP7/phet-Interactivesimulations-new-tools-for-teachine-and-learning-chemistry.pdf) [29 November
- Plass, J. L., Homer, B. D., & Hayward, E. O. (2009). Design factors for educationally effective animations and simulations. *Journal of Computing in Higher Education*, 21(1), pp. 31–61. doi: 10.1007/s12528-009-9011-x
- Plass, J. L., Milne, C., Homer, B. D., Schwartz, R. N., Hayward, E. O., Jordan, T., Verkuilen, J. F., Wang, Y., & Barrientos, J. (2012). Investigating the

- effectiveness of computer simulations for chemistry learning. *Journal of Research in Science Teaching*, 49(3), pp. 394–419.
- Podolefsky, N. S., Perkins, K. K., & Adams, W. K., (2009, November). Computer simulations to classrooms: tools for change. In AIP Conference Proceedings (Vol. 1179, No. 1, pp. 233–236). American Institute of Physics.
- Potane, J., & Bayeta, J. R. (2018). Virtual learning through PhET interactive simulation: A proactive approach in improving students' academic achievement in science. *CDO Basic Education Research Journal*, 1(1), pp. 21–36.
- Qhobela, M., & Moru, E. K. (2014). Using cognitive load theory to inform simulation design and practice. *Clinical Simulation in Nursing*, 11(8), pp. 355–360. doi: <https://doi.org/10.1016/j.ecns.2015.05.004>
- Reigeluth, C. M. (2009). *International Design Theories and Models*. New York: Routledge Publications. pp. 508.
- Ross, K. (2016). Factors influencing the academic success of first-year students in chemistry at an agricultural training institution (Master's dissertation, Stellenbosch University, Stellenbosch, South Africa).
- Rutten, N., Van Joolingen W. R., & Van der Veen J. T. (2012). The learning effects of computer simulations in science education. *Computers and Education*, 58, pp. 136–153. doi: 10.1016/j.compedu.2011.07.017
- Samuels, P. (2017). *Advice on reliability analysis with small samples. Revised Version*. Technical Report. Birmingham ResearchGate
- Sarabando, C., Cravino, J.P., & Soares, A. A. (2014). Contribution of a computer simulation to students' learning of the physics concepts of weight and mass. *Procedia Technology*, 13, pp. 112–121.

- Sari, S., Destianti, S. A., Irwansyah, F. S., Subarkah, C. Z., Aulawi, H., & Ramdhani, M. A. (2018, February). Solubility equilibrium learning supported by PhET-SS. In *Journal of Physics: Conference Series* (Vol. 1157, No. 4, p. 042010). IOP Publishing.
- Sarıçayır, H., Şahin, M., & Üçe, M. (2006). Dynamic equilibrium explained using the computer. *Eurasia Journal of Mathematics, Science and Technology Education*, 2(2), pp. 130–137.
- Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics*, 102(6), pp. 245–253.
- Schmidt, H. J., & Jignéus, C. (2003). Students' strategies in solving algorithmic stoichiometry problems. *Chemistry Education Research and Practice*, 4(3), pp. 305–317. doi: <https://doi.org/10.1039/B3RP90018E>
- Schoonenboom, J., & Johnson, R. B. (2017). How to construct a mixed methods research design. *Journal of Mixed Methods Research*, 11(1), 107–131.
- Stephens, A. L., & Clement, J. J. (2015). Use of physics simulations in whole class and small group settings: Comparative case studies. *Computers and Education*, 86, pp. 137–156. do i: <https://doi.org/10.1016/j.compedu.2015.02.014>
- Stern, L., Barnea, N., & Shauli, S. (2008). The effect of a computerized simulation on middle school students' understanding of the kinetic molecular theory. *Journal of Science Education and Technology*, 17(4), pp. 305–315. doi: 10.1007/s10956-008-9100-z

- Stern, B. (2015). The influence of prior knowledge in the process of conceptual change. *Journal of Educational Psychology*, 107(2), 281-294. doi: 10.1037/a0038366
- Sunyono, S., Yuanita, L., and Ibrahim, M. (2015). Mental models of students on stoichiometry concept in learning by method based on multiple representation. *The Online Journal of New Horizons in Education*, 5(2), pp. 30–45.
- Sutherland, A. (2022). Understanding stoichiometric ratios and its relationship with chemical equations. *Journal of Chemical Education*, 99(5), 1521-1532. doi: 10.1021/acs.jchemed.1c00923
- Taha, H., Hashim, R., Ismail, Z., Jusoff, K., & Yin, K. Y. (2014). The influence of students' concept of Mole, problem representation ability and mathematical ability on stoichiometry problem solving. *Scottish Journal of Arts, Social Sciences and Scientific Studies*, 21(1), 3-21.
- Talanquer, V., (2022). How incorrect balancing of chemical equations affect Students Achievement in stoichiometry. doi: 10.1088/1742-6596/1287/1/012055
- Tang, H., & Abraham, M. R. (2015). Effect of computer simulations at the particulate and Macroscopic levels on students' understanding of the particulate nature of matter. *Journal of Chemical Education*, 93(1), pp. 31– 38.
- Tareef, A. B. (2014). The effects of computer-assisted learning on the achievement and problem-solving skills of the educational statistics students. *European Scientific Journal*, 10(28).
- Tavares, D. L., Perkins, K., Kauzmann, M., & Velez, C.A. (2019, August). Towards a teacher dashboard design for interactive simulations. *Journal of Physics: Conference Series*, 1287(1). doi: 10.1088/1742-6596/1287/1/012055

- Udo, M. E., & Etiubon, R. U. (2011). Computer-based science simulations, guided discovery and students' performance in chemistry. *Modern Applied Science*, 5(6), p. 211.
- Udo, M. E. (2010). Effects of guided-discovery, student-centred demonstration and the expository instructional strategies on students' performances in chemistry. *African Research Review*, 4(4), pp. 389–398.
- Ulukök, S., & Sari, U. (2016). The effect of simulation-assisted laboratory applications on pre-service teachers' attitudes towards science teaching. *Universal Journal of Educational Research*, 4(3), pp. 465–474. doi: 10.13189/ujer.2016.040301
- University of Nigeria Nsukka, 23(1) 1-22.
- Upahi, J. E., & Olorundae, A. S. (2012). Difficulties faced by Nigerian senior high school chemistry students in solving stoichiometric problems. *Journal of Education and Practice*, 3(12), pp. 181—189.
- Van der Westhuizen, L. (2015). The development of the conceptual understanding of first-year chemistry university students in stoichiometry using thinking skills, visualization and metacognitive strategies (Master's dissertation, North-West University, Potchefstroom, South Africa).
- Vygotsky, L. S. (1978). *Mind in society: The development of the higher psychological processes*. Harvard university press.
- Western Governor's University. (2020, May 27). What is constructivism? Retrieved from <https://www.wgu.edu/blog/what-constructivism2005.html#close>.
- Widiyatmoko, A. (2018). The effectiveness of simulation in science learning on conceptual understanding: A literature review. *Journal of International Development and Cooperation*, 24(1), pp. 35–43.

- Wieman, C. E., Adams, W. K., & Perkins, K. K. (2015). *PhET: Simulations that enhance learning. Science*, 322(5902), pp. 682–683.
- Woldeamanuel, M. M., Atagana, H., & Engida, T. (2014). What makes chemistry difficult? *African Journal of Chemical Education*, 4(2), pp. 31–43.
- Wong, S., & Cooper, P. (2016). Reliability and validity of the explanatory sequential design of mixed methods adopted to explore the influences on online learning in Hong Kong bilingual cyber higher education. *International Journal of Cyber Society and Education*, 9(2), pp. 45–64.
- Wouter, A. (2023). The influence of simulation-based learning in science. *Journal of Educational Computing Research*, 61(4), 435-450. doi: 10.2190/EC.61.4. b
- Wylie, D. (2020). Applications of stoichiometric principles in calculations. *Journal of Chemical Education*, 97(10), 2781-2788. doi: 10.1021/acs.jchemed.0c00643
- Yaayin, B., & Ayoberd, A. S. (2018). The influence of problem-based learning approach on students' perceptions and attitudes toward the mole concept in Tamale College of Education. *ADRRJ Journal (Multidisciplinary)*, 27(8), pp. 18–37.
- Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: an effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, 23(2), pp. 120–132. doi: <https://doi.org/10.1111/j.1365-2729.2006.00215.x>

APPENDICES

APPENDIX A

Pre-test

1. Magnesium ribbon is added to dilute sulphuric acid.
- Give a balanced chemical equation for this reaction.
 - Name the product(s) formed.
 - What is the name of the reaction between sodium hydroxide and dilute tetraoxosulphate(VI) acid.
 - Give a mole ratio between tetraoxosulphate(VI) and sodium hydroxide.
 - Write a balanced chemical equation between trioxonitrate(V) acid and sodium trioxocarbonate(IV).
 - Establish the mole ratio between trioxonitrate(V) acid and sodium trioxocarbonate(IV).
 - Calculate the molar mass of the following;
 - Na_2CO_3
 - H_2SO_4

$$[\text{Na} = 23, \text{C} = 12, \text{O} = 16, \text{H} = 1, \text{S} = 32]$$

2. Consider the reaction below,



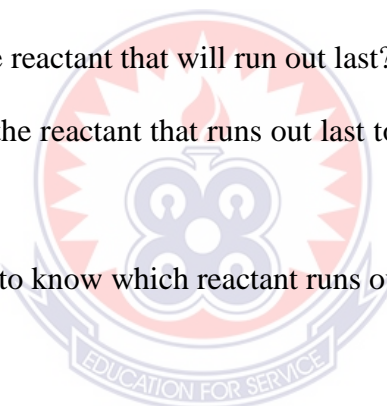
Assuming **12g** of CaCO_3 reacted with **10g** of HCl to form the product (CaCl_2), which of the two reactants is the

- Excess reagent
- Limiting reagent
- How much in grams of CaCl_2 was formed.

APPENDIX B

Interview guide

1. Can you walk me through how you balanced the reactions in the pre-test (i.e.) reactions between $Mg_{(s)} + H_2SO_{4(l)}$ and $Na_2CO_{3(s)} + HNO_{3(l)}$?
2. What do you think is the most important thing to consider when balancing a chemical equation?
3. How do you decide which coefficients to add to an equation to balance it?
4. What is the essence of mole ratios in stoichiometric calculations?
5. Imagine **12g** of $CaCO_3$ reacted with **10g** of HCl . Which of the reactants will run out first?
6. What happens to the reactant that will run out last?
7. If you add more of the reactant that runs out last to the mixture, will it make more product?
8. Why it is necessary to know which reactant runs out first?



APPENDIX C

Questionnaire

Thank you for participating in this questionnaire.

SECTION A

Your honest response to the questionnaire will be highly appreciated. All answers to the questionnaire will be treated confidentially. Read through the instructions on how to approach each question.

Fill the spaces given below in one or two sentences for the questions. (**1.1-1.4**)

1.1 Why do you not like the teacher's teaching style of the topic stoichiometry?

1.2 What possible reasons make you lose interest in stoichiometry?

1.3 What possible reasons make you not have time to practice problems to solidify your understanding in stoichiometry?

1.4 Why haven't you tried seeking help or extra tutorial for stoichiometry from others? _____

SECTION B

Make use of the keys given below to answer the following questions by writing a code in each of the boxes next to the questions. (e.g. 1, 2, 3, 4, 5, 6)

<i>Strongly agree = 1</i>	<i>Agree = 2</i>	<i>Slightly agree = 3</i>	<i>Slightly disagree = 4</i>	<i>Disagree = 5</i>	<i>Strongly disagree = 6</i>
-------------------------------	------------------	-------------------------------	--------------------------------------	---------------------	----------------------------------

1. My poor chemistry knowledge affected my performance in stoichiometry.
2. I feel motivated and engaged during stoichiometry lessons.
3. I lack problem solving skills in stoichiometry.
4. Difficulty in visualizing stoichiometric reactions affected my performance.
5. Stoichiometry lesson was an interactive one and fun.

Thank you!



APPENDIX D

Post-test

Stoichiometry performance test

(SPT)

Answer all questions.

1. Zinc metal is added to dilute hydrochloric acid.
 - a) Give a balanced chemical equation for this reaction.
 - b) Name the product(s) formed.
 - c) Identify any gas produced.
 - d) What is the name of the reaction between potassium hydroxide and dilute tetraoxosulphate(VI) acid.
 - e)
 - i. Write a balanced chemical equation between trioxonitrate(V) acid and potassium trioxocarbonate(IV).
 - ii. Establish mole ratio between all the reactants and products in (i) above.

2. Consider the reaction below,



Assuming **10g** of **CaCO₃** reacted with **8g** of **HCl** to form the product.

Which of the two reactants is the

- a) Excess reagent
- b) Limiting reagent
- c) How much grams of **CaCl₂** was formed?

APPENDIX E

Questionnaire

SECTION A

1.1 How do you feel about your engagement in stoichiometry lessons in an interactive simulated learning environment?

1.2 What way(s) do you think interacting with peers using computer simulations helped you understand the concept better?

1.3 Can you share any specific instances where sharing ideas with peers improved your understanding in stoichiometry concepts?

1.4 Do you think computer simulations displaying visual representations of concepts have impacted your understanding positively? Why?

1.5 Why would you recommend interactive simulations in your future studies?

SECTION B

Make use of the keys given below to answer the following questions by writing a code in each of the boxes next to the questions. (e.g. 1, 2, 3, 4, 5, 6)

<i>Strongly agree = 1</i>	<i>Agree = 2</i>	<i>Slightly agree = 3</i>	<i>Slightly disagree = 4</i>	<i>Disagree = 5</i>	<i>Strongly disagree = 6</i>
---------------------------	------------------	---------------------------	------------------------------	---------------------	------------------------------

2.1 I am now able to apply what I learnt through the lessons in more complex

calculations.

2.2 I have noticed a positive impact in my understanding of the stoichiometry concept

when engaged in an interactive simulated learned environment.

2.3 I feel I can perform better in my forth coming exams and beyond in stoichiometry

related problems.

2.4 I think doing stoichiometry calculations in an interactive simulated environment is

fun.

2.5 I feel more confident and motivated in learning stoichiometry than before.

APPENDIX F

Marking Scheme

Pre-test

1. a) $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$ (3 marks)
- b) $MgSO_4$ and H_2 (2marks)
- c) (i) Neutralization reaction (2 marks)
- (ii) $H_2SO_4: NaOH = 2 : 1$ (1 mark)
- d) (i) $2HNO_3 + Na_2CO_3 \rightarrow 2NaNO_3 + CO_2 + H_2O$ (3 marks)
- (ii) $\frac{HNO_3}{Na_2CO_3} = \frac{2}{1}$ (1 mark)
- e) (i) $Na_2CO_3 = Ar (Na) + Ar (C) + Ar (O)$
 $= (23 \times 2) + 12 \times 1 + (16 \times 3)$
 $= 106g/mol.$ (2marks)
- (ii) $H_2SO_4 = Ar (H) + Ar (S) + Ar (O)$
 $= (2 \times 1) + (32 \times 1) + (16 \times 4)$
 $= 2 + 32 + 64$
 $= 98g/mol.$ (2marks)
2. $M (CaCO_3) = 100g/mol$
- $M (HCl) = 36.5g/mol$
- $n (CaCO_3) = \frac{m}{M} = \frac{12}{100} = 0.12$ moles (1 mark)
- $n (HCl) = \frac{m}{M} = \frac{10}{36.5} = 0.274$ moles (1 mark)
- $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$ (3 marks)
- Mole ratio of HCl to $CaCO_3 = 2 : 1$
- $\frac{CaCO_3}{HCl} = \frac{1}{2}$ (1 mark)
- 0.12 moles of $CaCO_3 \equiv 0.24$ moles of HCl in balanced equation. (1 mark)

So,

a) HCl is in excess (1 mark)

b) $CaCO_3$ is limiting (1 mark)

c) $\frac{CaCl_2}{CaCO_3} = \frac{1}{1}$ (1 mark)

$n(CaCl_2) = 0.12$ moles

$M(CaCl_2) = 111$ g/mol (1 mark)

$\therefore n(CaCl_2) = \frac{m}{M}$

$m = n \times M$ (1 mark)

$= 0.12 \times 111$ (1 mark)

$= 13.32$ g (1 mark)



APPENDIX G

MARKING SCHEMEPost-Test

1. a) $Zn + HCl \rightarrow ZnCl_2 + H_2$ (3marks)
- b) $ZnCl_2$ and H_2 (2marks)
- c) H_2 (2marks)
- d) Neutralization reaction (2marks)
- e) (i) $2HNO_3 + K_2CO_3 \rightarrow 2KNO_3 + CO_3 + H_2O$ (3marks)
- (ii) $\alpha) \frac{HNO_3}{K_2CO_3} = \frac{2}{1}$ (1mark)
- $\beta) \frac{HNO_3}{KNO_3} = \frac{2}{2}$ (1mark)
- $\gamma) \frac{K_2CO_3}{KNO_3} = \frac{1}{2}$ (1mark)
2. $2HCl + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O$ (3marks)
- M ($CaCO_3$) = 100g/mol
- M (HCl) = 36.5g/mol
- $n (CaCO_3) = \frac{10}{100} = 0.100$ moles (1mark)
- $n (HCl) = \frac{8}{36.5} = 0.219$ moles (1mark)
- 0.100 moles of $CaCO_3 \equiv 0.200$ moles of HCl in the balanced equation (1mark)
- So,
- a) HCl is the excess reagent. (2mark)
- b) $CaCO_3$ is the limiting reagent. (2mark)
- c) $n (CaCl_2) = 0.100$ moles
- $\therefore n (CaCO_3) \equiv n (CaCl_2)$



$$1 : 1$$

(1mark)

$$M (\text{CaCl}_2) = 111\text{g/mol}$$

(1mark)

$$n = \frac{m}{M}$$

$$m = n \times M$$

(1mark)

$$m = 0.100 \times 111$$

(1mark)

$$= 11.1\text{g}$$

(1mark)



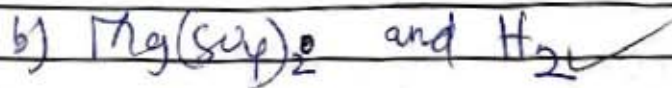
4.75
in either
margin

0.6
30

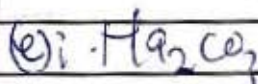
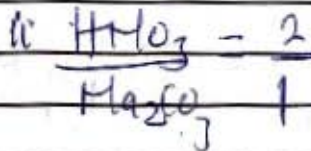
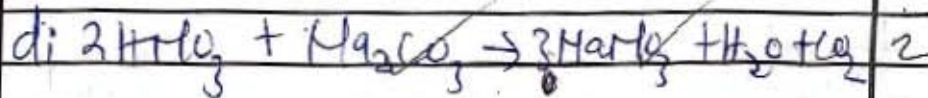
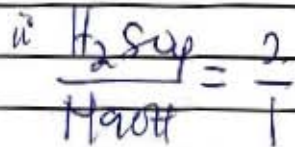
Question No.
Write on both sides of the paper

Do not
write
in either
margin

Q1

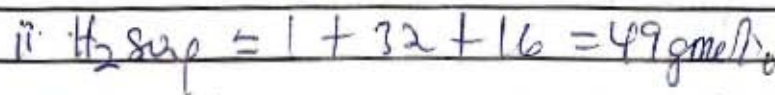


c) Neutralization reaction ✓ 1



$$24 + 12 + 16 = 60 \text{ g/mol}$$

0



Q2

a) $CaCO_3$ is the excess reactant because of higher mass 0

b) HCl is limiting reactant because of lower mass 0

0.6

in either margin	<div style="border: 1px solid black; border-radius: 50%; padding: 5px; display: inline-block;"> $\frac{06}{30}$ </div>	Question No..... Write on both sides of the paper	Do not write in either margin
		ⓐ	
		a) $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$	0
		b) $MgSO_4$ and H_2	4
		c) i) Neutralization reactions	1
		ii) $\frac{H_2SO_4}{NaOH} = \frac{2}{1}$	1
		di) $2HNO_3 + Na_2CO_3 \rightarrow 2NaNO_3 + H_2O + CO_2$	0 2
		ii) $\frac{HNO_3}{Na_2CO_3} = \frac{2}{1}$	1
		ei) Na_2CO_3 $23 + 12 + 16 = 106 \text{ g/mol}$	0
		ii) $H_2SO_4 = 1 + 32 + 16 = 98 \text{ g/mol}$	0
		ⓑ	
		a) $CaCO_3$ is the excess reagent because of higher mass	0
		b) HCl is limiting reagent because of lower mass.	0

Write either margin

27/30

Question No.
Write on both sides of the paper

Do not write in either margin

Q1

- a) $Zn + HCl \rightarrow ZnCl_2 + H_2$ 3
- b) $ZnCl_2$ ✓ 1
- c) H_2 ✓ 2
- d. Neutralization reaction ✓ 2
- e. $2HClO_3 + K_2CO_3 \rightarrow 2KClO_3 + CO_2 + H_2O$ 3
- ii $\frac{K_2CO_3}{1} = \frac{1}{2}$, $\frac{HClO_3}{2} = \frac{2}{1}$ 2

Q2

$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$ 3

$M(CaCO_3) = 100 \text{ g mol}^{-1}$, $M(HCl) = 36.5 \text{ g mol}^{-1}$

$n(CaCO_3) = \frac{m}{M} = \frac{10}{100} = 0.1 \text{ moles}$ 5

$n(HCl) = \frac{m}{M} = \frac{8}{36.5} = 0.219 \text{ moles}$

So 0.1 moles of $CaCO_3 \equiv 0.2 \text{ moles of HCl}$ in the balanced equation

a) HCl is excess b) $CaCO_3$ is limiting 2

c) $n(CaCO_3) \equiv n(CaCl_2)$ 1

$M(CaCl_2) = 111 \text{ g mol}^{-1}$

$n(CaCl_2) = \frac{m}{M} = m = n \times M$

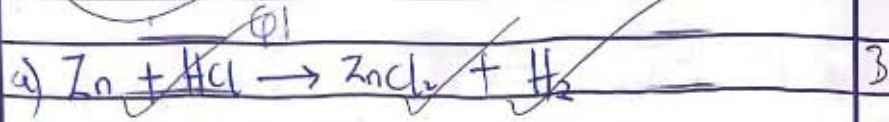
$0.1 \times 111 = 11.1 \text{ g}$ 2

Write
in either
margin

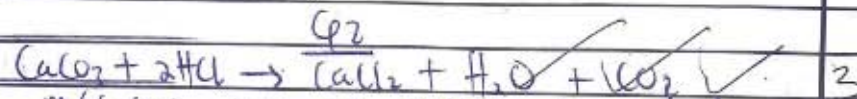
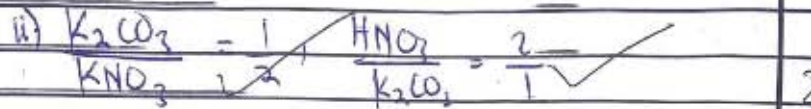
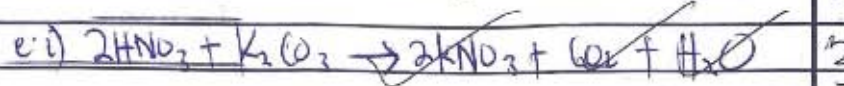
28
30

Question No.....
Write on both sides of the paper

Do not
write
in either
margin



d: Neutralization reaction 1



$M(CaCO_3) = 100 \text{ g/mol}$, $M(HCl) = 36.5 \text{ g/mol}$

$n(CaCO_3) = \frac{m}{M} = \frac{10}{100} = 0.1 \text{ moles}$

$n(HCl) = \frac{m}{M} = \frac{8}{36.5} = 0.219 \text{ moles}$

So 0.1 moles of $CaCO_3 \equiv 0.2$ moles of HCl in the balanced equation.

a) HCl is excess b) $CaCO_3$ is limiting. 1

c) $n(CaCO_3) \equiv n(CaCl_2) = 1:1$ 2

$M(CaCl_2) = 111 \text{ g/mol}$

$n(CaCl_2) = \frac{m}{M} = m \times M$ 3

$10 \times 111 = 1110 \text{ g}$ 1

28
30
margin

Write on both sides of the page

in either margin

Q1		
a. $Zn + HCl \rightarrow ZnCl_2 + H_2$		3
b. $ZnCl_2$ and H_2		2
c. H_2		2
d. Neutralization reaction		2
e. i) $2HNO_3 + K_2CO_3 \rightarrow 2KNO_3 + CO_2 + H_2O$		3
ii) $K_2CO_3 = \frac{1}{2}$, $HNO_3 = 2$ $KNO_3 = 2$, $K_2CO_3 = 1$		2
Q2		
$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$		3
$M(CaCO_3) = 100 \text{ g mol}^{-1}$, $M(HCl) = 36.5 \text{ g mol}^{-1}$		
$n(CaCO_3) = \frac{m}{M} = \frac{10}{100} = 0.100 \text{ moles}$		1
$n(HCl) = \frac{m}{M} = \frac{8}{36.5} = 0.219 \text{ moles}$		1
So 0.100 moles of $CaCO_3 = 0.2$ moles of HCl in the balanced equation		2
a. HCl is the excess reagent		2
b. $CaCO_3$ is limiting reagent		2
c. $n(CaCO_3) = n(CaCl_2)$ 1:1		
$\therefore M(CaCl_2) = 111 \text{ g mol}^{-1}$		
$n(CaCl_2) = \frac{m}{M}$, $m = n \times M$		
$= 0.100 \times 111 = 11.1 \text{ g}$		3

28