UNIVERSITY OF EDUCATION, WINNEBA

EFFECT OF LABORATORY ACTIVITIES ON STUDENTS' ACADEMIC PERFORMANCES IN ACID-BASE TITRATION AND NEUTRALISATION: THE CASE OF ST. ROSE'S SENIOR HIGH SCHOOL.

ADRAIN TIFIGRA BATUNG

MASTER OF PHILOSOPHY

2025

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ADRAIN TIFIGRA BATUNG

(8241180003)

A thesis submitted to the school of graduate studies in partial fulfilment of the requirement for the award of the degree of Master of Philosophy (Integrated Science Education)

DEPARTMENT OF INTEGRATED SCIENCE EDUCATION
FACULTY OF SCIENCE EDUCATION
UNIVERSITY OF EDUCATION, WINNEBA

2025

DECLARATION

Student's Declaration

I, ADRAIN TIFIGRA BATUNG, declare that this thesis, with the exception of quotations and references contained in the 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 I supervised the preparation of the thesis in accordance with the rules and regulations of the University of Education, Winneba.

NAME OF SUPERVISOR: DR. ERNEST I. D. NGMAN-WARA

SIGNATURE: ....

DATE: ....

DEDICATION

This thesis is dedicated to the Almighty God, friends and the Batung's family.

ACKNOWLEDGEMENTS

First and foremost, I give thanks to Almighty God for His abundant grace, guidance, and strength throughout the course of this research.

I am deeply grateful to my supervisor, DR. Ernest I. D. Ngman-Wara, whose invaluable guidance, constructive feedback, and encouragement shaped the direction and quality of this study. My heartfelt appreciation also goes to the lecturers and staff of the Department of Integrated Science Education, University of Education, Winneba, for their academic support and inspiration.

Special thanks are due to the Headmistress, staff, and students of St. Rose's Senior High School, Akwatia, for their cooperation and participation, without which this study would not have been possible. I also acknowledge the Ghana Education Service for providing the enabling environment to carry out this research.

Finally, I express my deepest gratitude to my family and friends for their prayers, patience, and unwavering support during the entire period of my study.

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ABSTRACT

This study examined the effect of laboratory activities on students' academic performances in acid–base titration and neutralisation at St. Rose's Senior High School, Akwatia. The research adopted a quasi-experimental design involving final-year science students who were divided into experimental and control groups. Purposive sampling was used to select two intact science classes totaling 110 students. The experimental group received laboratory-based instruction while the control group was taught through conventional methods. Data were collected using test (pre-test and post-test), an observation checklist and questionnaires. These data were analysed using descriptive and inferential statistics, including ANCOVA. Findings revealed that students faced significant difficulties in areas such as endpoint detection, accurate measurement, computation, and interpretation of results prior to the intervention. While the overall effect of teaching method was not statistically significant ($p = 0.052$), the experimental group showed marked improvement in post-test performance compared to the control group, with a small effect size ($\eta^2 = 0.035$), indicating that laboratory activities enhanced conceptual understanding, practical skills, and overall achievement. Students also expressed positive perceptions towards laboratory-based learning, citing improved motivation, confidence, and engagement. The study concluded that incorporating laboratory activities into chemistry instruction strengthens both theoretical and practical competencies, and recommends that chemistry teachers should adopt laboratory-based pedagogies and pay much attention to key titration skills such as endpoint detection, reading of meniscus and equivalent point.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter contains the background to the study, the statement of the problem, the purpose of the study, research objectives, research questions, hypotheses, the significance of the study, limitations, delimitations, organisation of the study and operational definitions of terms.

1.1 Background to the Study

Chemistry is concerned with the identification of matter-based chemicals, the study of their characteristics and reactions and the application of these processes to the creation of new substances (Okeke et al., 2022). The teaching of chemistry and the use of laboratory instruction are essential in translating these abstract concepts into tangible experiences that foster deeper understanding, practical skills and scientific inquiry. One crucial component of laboratory chemistry is titration. It is analytical method for examining content and purity of chemicals (Al-Shamisi et al., 2022). The manufacturing of chemicals, pharmaceuticals, and food processing are the three industries that mostly depend on titration techniques (Ababio, 2016).

Large-scale production, quality assurance and product research and development are the industry's goals for titration techniques. Acid or base titration is used in the food processing industry to measure the amount of nutrients and ascertain the nutrient contents of processed food items. The titration method is used in the pharmaceutical industry to help prepare pharmaceutical goods to reduce the likelihood of negative medication responses. This is crucial because each person reacts differently to pharmaceutical medications based on their age, weight, comorbidities, allergies, immunology and overall biochemistry.

Titration is used in the cosmetics industry to guarantee high-quality cosmetic products. Manufacturers of cosmetics must add ingredients in the right amounts and concentrations (Ababio, 2016). As a result, the titration procedure aids producers in identifying the best basis for cosmetics.

Beyond its industrial importance, titration also occupies a central position in chemistry education, particularly in laboratory instruction. Acid–base titration is a quantitative technique commonly used in chemistry practical lessons to determine acid or base concentration (Salem, 2000). Through this practical activity, abstract chemical concepts such as neutralisation, molarity, and stoichiometric relationships are transformed into observable and measurable experiences. As an experimental method, acid–base titration enables learners to develop conceptual understanding while engaging directly with laboratory processes. However, successful execution of titration experiments requires strict adherence to laboratory procedures and careful attention to detail.

Acid-base titration is a quantitative technique used in chemistry practicals to ascertain the acid content in the educational setting (Salem, 2000). It is a practical exercise that effectively applies laboratory information to improve conceptual understanding. An acid-base titration and neutralisation is an experimental method used to assist learner to learn more about a solution containing an acid or base. This kind of experiment necessitates careful attention to laboratory procedures.

Organizational, manipulative, measuring, observation, reading, computation, and safety skills are among the laboratory abilities used in acid-base titration (Zhang & Wink, 2021). Having all of your tools together before you begin is a prerequisite for developing organizational abilities. Before starting, for instance, make sure you have a calibrated burette, a burette stands, many beakers, a measured amount of analyte and a significant amount of titrant. Additionally, it entails labeling all reagents and equipment, setting up equipment, laying laboratory notebooks as far away from the experimentation area as feasible, putting common solutions on the other side of the bench, labeling all reagents, and keeping benches clean and organized. Controlling the burette and pipette and clamping the burette to the retort stand are examples of manipulative skills. Movement, co-ordination, strength and speed acts related to the usage of instruments are frequently linked to this practice (Erdemir et al., 2022). The ability to measure something accurately requires the possession of measuring skills. A 20 cm^3 or 25 cm^3 pipette is used to measure alkaline, graded glassware is used to measure liquids, the burette is filled with acid to the zero mark and the appropriate amount of indicator is dropped into the alkaline.

The ability to observe, evaluate, distinguish, identify and remember something is a component of observation abilities. This practice is often associated with mindfulness, as it encourages being present in the moment and paying close attention to details (Grangeia et al., 2022). Titration observation skills include observing colour changes from the beginning of the titration to the conclusion point. The ability to read, understand, interpret, decode, and record material for later use is known as reading and recording skills. In titration, the ability to read and record is necessary to make sure that the burette readings are viewed at eye level and to record the outcomes. Knowing how to shield our bodies from frightening, hazardous and dangerous objects is a safety skill. It is the capacity to safely handle chemicals, glassware and equipment while abiding by laboratory policies and procedures.

The capacity to calculate readings that display the start and final values is known as computation skills (Kumar et al., 2022). It is anticipated that students will be able to compute the average titres, the acid concentration and the base concentration using the computed result. The concepts that students have regarding formulating hypotheses, pipetting, assembling and standardizing equipment, measuring, observing, documenting, sterilizing equipment, safety and computation skills are all covered in the knowledge of laboratory skills in the context of acid-base titration (Zhang & Wink, 2021).

Despite the acknowledged importance of laboratory work, there is often a disconnect between theory and practice in many schools. Students frequently demonstrate significant difficulties in executing titration experiments, particularly with endpoint detection, accurate measurement, and data interpretation (Kumar et al., 2022). While existing literature emphasizes the value of hands-on activities, there is a gap in focused research that examines how targeted laboratory-based instruction specifically impacts both the academic performance in, and student perception of, acid-base titration concepts within the local context of senior high schools in Ghana.

This study, therefore, aims to address this gap by investigating the effect of structured laboratory activities on students' performances and perceptions in acid-base titration and neutralization at St. Rose’s Senior High School. The background establishes that while titration is a cornerstone practical skill, students often struggle with its application. The purpose of this study is to determine if and how a laboratory-focused intervention can mitigate these challenges, thereby strengthening the rationale for integrating more hands-on pedagogy to bridge the theory-practice divide.

1.2 Statement of the Problem

The role of laboratory activities in enhancing the understanding of scientific concepts cannot be overemphasized in science education, particularly in the teaching and learning of Chemistry. In Ghana, the senior high school chemistry curriculum emphasizes the conduct of practical work to guide students to improve their academic performance, process skills, and develop their critical thinking abilities (Ministry Of Education, 2010). The curriculum assigns two out of six periods per week specifically for practical work, where teachers are expected to engage students in hands-on activities (Ministry Of Education, 2010). This structure aims to foster scientific competencies such as critical and analytical thinking, logical reasoning, and problem-solving skills necessary for 21st-Century learning (Ministry Of Education, 2010). Additionally, the curriculum requires chemistry teachers to begin each lesson with a practical problem, encouraging students to investigate issues and draw conclusions. Practical work in Chemistry is therefore, intended not only to consolidate theoretical concepts but also to cultivate inquiry-based thinking, reasoning, problem-solving, and the development of scientific attitudes.

According to Facione (2015) students who actively participate in logical reasoning exercises develop stronger critical thinking and demonstrate higher academic achievement. In alignment with this, the curriculum promotes the development of analytical thinking and problem-solving techniques through effective engagement in practical work. It advocates for learning experiences that stimulate students’ reasoning, ensuring their participation in analytical and inquiry-driven tasks (MoE, 2010). To promote these outcomes, the curriculum’s profile dimension allocates a 30% weighting to practical and experimental activities. This dimension serves as a foundation for teaching and learning assessment. Chemistry education experts believe that this structure will allow students to enhance their manipulative skills and reflective thinking (Kelley & Knowles, 2016).

Despite these objectives, challenges in implementing practical activities, compounded by the pressure to complete the curriculum, have led many teachers to rely heavily on theoretical instruction (Azuuga et al., 2021). As a result, chemistry is often taught as a set of abstract ideas, with limited emphasis on practical engagement. Consequently, most chemistry teachers introduce chemical concepts without providing adequate laboratory experience to support logical reasoning (Mohammed et al., 2020). Students are thereby deprived of opportunities to develop creativity and critical thinking through practical work. Studies has shown that many senior high schools in Ghana fail to engage students effectively in practical activities, especially in acid-base titration (Ghartey-Ampiah, 2004; Azure, 2015; Agyemang, 2016). West Africa Examination Council (WAEC) Chief Examiners' Report (2020-2023) showed that the percentage of passes in chemistry practical examinations, particularly in acid-base titration and neutralisation has being inconsistent. The report further states that students' inconsistent performance in Chemistry paper 3 (practical) arises from students having difficulty in the identification of colour changes, inability to take and record readings accurately, poor calculations of results and they could not attach the correct units to the values calculated.

They lost marks for among other reasons like inability to write balanced equations with the right symbols; non-adherence to rubrics; and poor knowledge of basic chemical principles. Schools wait for a few days to practical to coach students on titration, and as a result, students may not be able to familiarise the laboratory skills needed for titration. Practicals do not take place in most schools owing to the lack of reagents in conducting the practical and also, the dilapidated state of most laboratories (Afemikhe et al., 2014). This situation is mirrored at St. Rose’s SHS, where Chemistry performance over the last five years has been inconsistent, with pass rates ranging from 42.5% to 69.9%. Reviews of students’ exercise books and interviews confirm that acid-base titration is often perceived as abstract and difficult, largely because it has not yet been taught either practical or theoretical. Students reported unfamiliarity with laboratory techniques, challenges with interpreting colour changes, taking accurate readings, performing calculations, and applying basic chemical principles. Given these challenges, a very relevant question is: Does laboratory activities influence students’ academic performance, particularly in acid-base titration and neutralization in chemistry? It is against this backdrop that the current study sought to examine the effect of laboratory activities on the academic performance of students in acid-base titration and neutralization in chemistry in St. Rose's SHS, Akwatia.

1.3 Purpose of the Study

The purpose of the study was to determine the effect of laboratory activities on students’ academic performance in acid-base titration and neutralisation at St. Roses SHS, Akwatia.

1.4 Objectives of the Study

The objectives of the study were to:

1 Identify students’ difficulties in the acid-base titration and neutralisation.

2 Examines the effect of laboratory activities compared to conventional teaching methods on students’ academic performance in acid-base titration and neutralisation in chemistry.

3 Assess students' perceptions about laboratory activities in teaching and learning of acid-base titration and neutralisation.

1.5 Research Questions

The study was guided by the following research questions:

1. What are students' difficulties with acid-base titration and neutralisation?
2. What is the effect of laboratory activities on students' post-test performance in acid-base titration and neutralisation as compared to conventional teaching methods?
3. What are students' perceptions about laboratory activities in teaching and learning acid-base titration and neutralisation?

1.6 Null Hypothesis (H_0)

There is no statistically significant difference in the post-test academic performance of students in acid-base titration and neutralisation between those taught using laboratory-based instructional activities and those taught using conventional teaching methods.

1.7 Significance of the Study

The study would help St. Roses SHS Students to further understand the concepts of acid-base titration and neutralization and thereby improves their academic performance in both internal and external examinations. Chemistry teachers could effectively adapt this teaching strategy (laboratory activities) to help SHS students improve their conceptual understanding of other Chemistry topics, particularly, mole concept.

The study could contribute to the broader field of educational research by adding to the body of evidence on the effectiveness of laboratory activities. District Directorate of Ghana Education Service could find invaluable insights from the study, which could potentially steer educational policies towards the integration of laboratory activity methodologies. By supporting or challenging current theories and approaches of teaching and learning in science education, the findings can help us better understand how students learn this subject.

Finally, it will highlight the importance of laboratory-based assessments in improving academic performance.

1.8 Delimitations of the Study

Delimitations refer to the boundaries intentionally set by researchers to define the scope of a study (Ramos et al., 2025). These are guided by inclusionary and exclusionary decisions that help narrow the focus of the research, clarify what will and will not be covered, and maintain objectivity throughout the process. Delimitations allow for sharper focus on the research problem and make it easier for other scholars to replicate or extend the study. They also shape the limits within which findings are interpreted and ensure clarity about a study's external validity and reliability.

In this study, the researcher defined several key delimitations. The research was confined to St. Rose's Senior High School in the Eastern Region of Ghana, where the researcher teaches. It involved only final-year science students (SHS 3), allowing for adequate monitoring of their progress before their West African Senior School Certificate Examination (WASSCE). The focus was further narrowed to titrimetric analysis, a core component of the chemistry practical examination.

1.9 Limitations of the study

Limitations are potential weaknesses in a research study that are often beyond the researcher's control and may affect the interpretation, generalizability, or outcomes of the findings (Ghazvini, 2025). In this study, several limitations were identified. First, the research was confined to St. Rose's Senior High School. The choice of being the school was a deliberate feature of action research, which emphasizes practical problem-solving within a specific context. However, the confinement of the study to a single school setting reduces the extent to which the findings can be generalized to other schools or contexts.

Another limitation relates to the involvement of students as participants. There was the potential for social desirability bias, where students may have provided responses that did not accurately reflect their true experiences or understanding, particularly during administration questionnaires or interviews. This could affect the credibility of the data. Additionally, since the study relied on class periods for the intervention, coordinating with teachers to use their instructional time posed logistical challenges. Some teachers were initially reluctant to release their periods for the research activities.

Student absenteeism during the intervention phase also presented a significant limitation. Several students were absent due to truancy or personal reasons, which may have introduced bias and affected the consistency of the results. The irregular participation could have influenced both the pre-test and post-test scores.

The researcher employed several strategies aimed at addressing these challenges. In line with action research principles, the researcher engaged in continuous communication with fellow teachers and the school administration to gain support and schedule research activities during periods that least disrupted the school's timetable. Absenteeism was addressed through the organization of makeup sessions for students who missed key intervention lessons. Moreover, efforts were made to establish a trusting environment during data collection, assuring students of confidentiality to reduce the likelihood of socially desirable responses.

Despite these limitations, the study provides valuable insights into how laboratory activities can impact students' academic performance in acid-base titration and neutralization, within a real classroom context.

1.10 Organisation of the Study

The study report was divided into five chapters. The first chapter served as the introduction to the study. This chapter provides the essential context for the study, detailing its background, statement of the problem, the study's purpose, the research questions guiding the study, hypothesis and the study's significance. Additionally, it discusses the limitations and delimitations identified during the research process. Chapter two was devoted to the review of literature on the effect of laboratory activities on senior high school students' academic performance. Chapter three focused on the method used to gather data in the study. The chapter contains the research approach and research design used in this study. It also discusses the population of the study, the sampling and sampling technique. The research instrument used to collect data for this study was described and it validity and reliability determined. The pre-intervention activities, intervention and post-intervention activities were described. Also, data collection procedure and data analysis were presented. The chapter ends with ethical consideration. Chapter Four presented and discussed the findings. Finally, chapter five, which was the final chapter, consisted of a summary, conclusions, recommendations, and suggested areas for further study.

1.10.1 Operational definition of terms

Academic Performance: Is the degree of success or accomplishment a student achieves in their educational endeavors; it is commonly gauged by tests, assignments, courses, and final grades. It shows how well a student is able to accomplish learning goals, gain knowledge and use acquired abilities.

Laboratory Activities: Refer to structured experimental tasks undertaken by students either independently or under the guidance of a teacher as part of the science learning process. These activities involve hands-on manipulation of materials, observation of phenomena, data collection, and analysis, all within a controlled environment such as a school laboratory.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

The review of related literature is covered in this chapter and is divided into three main sections: the theoretical framework, the conceptual Review and the review of empirical evidence. The conceptual review addresses a number of areas related to acid-base titration and neutralization, including its application in science instruction and the function of the laboratory in fostering students' comprehension. It further discusses the impact of chemistry practicals on student learning as well as teacher qualification, along with student achievements at the secondary level. Its theoretical base stems from comprehensive theories in education concerning the acquisition of knowledge through learning experiences by learners. These include the Experiential Learning Theory, where learning through direct experience is recognized; the Social Cognitive Theory, where the effect of observation and social interaction on learning is addressed and Vygotsky's Social Constructivist Learning Theory, where learning is addressed within the social and cultural context role in knowledge building and the empirical review.

2.1 Conceptual Review

A conceptual review is a written or visual presentation that explains either graphically, or in narrative form, the main things to be studied, such as, the key factors, concepts or variables and the presumed relationship among them. According to Mutai (2000), a conceptual review is a hypothesized model identifying various variables and the relationship among them. The conceptual review explores various aspects which are discussed below.

2.1.1 Acid-base titration and neutralization (titrimetric)

Acid-base titration represents one of those basic notions in chemical education and practice that bring very substantial value to stoichiometry, solution chemistry, and understanding reaction processes understanding. These notions constitute the grounds of theoretical and practical education or applications in almost all spheres, from business and ecology to medicine. Besides being so necessary for scientific basics, study of acid-base reactions bears relevance to developing particular features of analysis. Their pedagogical utility, teaching challenges, technological advances, and transdisciplinary uses are reviewed in the recent literature. Acid-base reactions are characterized by the reaction between proton donors and acceptors and their behaviour is described by several theoretical models. The Arrhenius definition provided the basic framework for the understanding of such reactions, defining bases as hydroxide ion providers and acids as proton donors in aqueous solutions (Arrhenius, 1884). Brønsted-Lowry's model dealt with the proton transfer mechanism.

Alongside this, the notion of acid-base chemistry was expanded toward non-aqueous systems. In fact, the Lewis definition extended this to encompass current ideas of complexation and catalysis also by centring its approach on the electron pair transfer (De Paula 2023). Neutralization is a reaction of acid and base, with the formation of water and a salt only. The stoichiometric relationship between acid and base provides the basis for the acid-base titration process, because the equivalence point depends on an exact combination of the reactants. Understanding this interplay with pH changes throughout titration, coupled with the application of an appropriate indicator or pH meter, forms the core of any attempt to become proficient in this area of analysis (Brown et al., 2021). Acid-base titration is a broad area that amalgamates theoretical ideas with the building of practical capabilities in an educational institution. This is one avenue whereby learners understand the basis of quantitative analysis, the preparation of solutions, and stoichiometry. The experiments on titration introduce students to the ability of critical thinking, data interpretation, and accuracy of measurement. Hoffstein and Mamlok-Naaman (2021) explain that practical experiences in the laboratory, such as titration, reduce the gap between theoretical ideas and their implementations in the field. It follows from studies that titration included in the curriculum raises students' interest and deepens their understanding of acid-base concepts. Abrahams et al. (2020) reported that students who participated more actively in a titration experiment had better idea memory and more complete understanding of practical applications. Besides, such trials create opportunities for the correction of common misconceptions, such as misunderstanding of the concept of equivalence points or the role of an indicator.

Acid-base titration is an abstract topic and therefore, puts a heavy load on the minds of students. The dynamic character of chemical equilibria, the logarithmic pH scale, and the interpretation of experimental data are only some aspects where students frequently have difficulties. According to Çalık et al. (2022) one of the most outstanding barriers to successful learning is persisting misconceptions related, for example, to misconceiving the role of bases and acids or to the importance of an equivalence point. The methodological complexity of titration is the necessity to keep track of a number of tasks-worsens these difficulties. For such challenges and improvements in understanding and confidence among students, educators need to use state-of-the-art teaching techniques such as visual aids, simulations, and scaffolded learning activities (Tatli & Ayas, 2023).

Improvements in teaching approaches have lately changed the way acid-base titration and neutralization principles are taught. Traditional laboratory experiments cannot be replaced since they give the students hands-on experience in analytical and experimental procedures. However, the integration of technology with interactive simulations and virtual laboratories has shed a new light on chemistry education. Virtual laboratories allow the students to try out different methods of titration, conduct experiments, and observe in real time the molecular interactions of reagents in controlled conditions. Madson and Nickerson (2021) indicate that virtual and physical laboratories collectively enhances student's engagement in conceptual understanding of acid-base concepts. Interactive simulations are not limited by the constraints of physical equipment and thus can support a range of scenarios that students could explore for nuances in titration. Such tools are especially useful in environments where access to traditional laboratory equipment may be limited, such as in remote or resource-poor settings.

Teaching acid-base titration and neutralisation has also been found to be successful when done through inquiry-based learning methods. This approach promotes scientific inquiry, problem-solving skills, and critical thinking by letting students plan and carry out their own experiments. By encouraging co-operation and peer-to-peer learning, collaborative learning exercises further improve the educational process (Hofstein & Lunetta, 2020). The vast number and diverse range of applications of acid-base neutralization and titration highlight their significance across multiple disciplines. Titration procedures are utilized as an effective form of quality control in many industries because it ensures that a product-like medications, foodstuffs, or beverages is produced with an exactly controlled profile. For instance, titration methods will need to be implemented to determine whether a product has requisite acidity or basicity for their regulatory compliance (Harris, 2023).

The acid-base titration capability cannot be sufficiently estimated without an evaluation of the acquisition of theoretical knowledge and practical abilities of students. Laboratory reports, practical tests, and problem-solving exercises are usually elaborated to assess how well students can perform titration and evaluate the results. Students will need constructive criticism if they are to improve their methods and broaden their conceptual understanding (Millar 2021). Examples of formative assessment techniques that enhance self-reflection and provide rich information on students' learning processes include peer assessments and in-class observations. Summative tests, meant to measure overall performance, support these strategies in assessing the application of knowledge by students in novel contexts. By using both techniques, a comprehensive assessment of students' proficiency with acid-base titration is ensured (Hofstein et al., 2022). The topics of acid-base titration and neutralization are indispensable in chemistry curricula because they allow students to develop their analytical skills, experimental skills and deeper understanding of general chemical principles. Although presenting these concepts can sometimes be challenging, advancements in pedagogy and technology have significantly improved their effectiveness and ease of instruction. Acid-base titration is important as it has interdisciplinary applications in education, industries, environmental science, and medicine.

2.1.2 Science laboratory and its Effects on Senior High School Science Students

The term "laboratory" has been defined in a variety of ways by numerous researchers, but they all ultimately convey the same concept. According to Kumi et al. (2022), a school laboratory is an educational space that teaches students about science and how scientists operate. According to Bello in Oguntona (2022) science should be learned by inquiry rather than dogma, and nature should serve as a laboratory. This approach supports autonomous, critical, and rational thinking. Adeyemi (2022) asserts that science laboratories are essential to high school science instruction. He emphasizes that laboratories are a key tool for developing students' formal reasoning abilities and comprehension, which enhances learning outcomes. Akano (2020) defines a laboratory as a location where individuals use human enterprise to study and interpret natural occurrences. Ogunleye (2022) states that laboratories are a key tool for developing students' formal thinking, skills, and comprehension, which improves the intended learning outcomes. Proeter (2019) describes a laboratory as a space or structure equipped with specialized tools for conducting scientific experiments, teaching science, or producing chemicals and medications. In summary, a laboratory is a setting where students conduct experiments to better understand scientific facts, events, and phenomena. Through practical experiments, this environment promotes meaningful learning of scientific theories and concepts.

The availability of laboratory facilities significantly influences students’ conceptual understanding and academic performance in chemistry, particularly in areas such as acid-base titration and neutralization. Various research has been conducted to explore the relationship between availability of laboratory facilities and students’ learning outcomes. A study conducted by Tiruneh et al. (2023) reveals that supervised laboratory instruction helps students to be motivated and enhances their conceptual understanding increased with regard to acid-base titration and neutralization. The study established that there was a high improvement in students' problem-solving skills when actively involved in laboratory activities, leading to better academic achievement. However, schools with minimal laboratory funding could not ensure equal learning outcomes for all students, resulting in disparities in academic performance among institutions. Umar (2018) further investigated the effect of cooperative and laboratory teaching methods on students' ability to retain knowledge. The results showed that students in schools with limited laboratory facilities were disadvantaged, as they could not conduct practical exercises to reinforce theoretical knowledge, especially regarding titrations and chemical preparations.

Efe (2022) examined how laboratory techniques impact students' development of science process skills.The study revealed that students in schools with inadequately equipped laboratories faced challenges in learning essential experimental skills, which hindered their understanding of acid-base processes. The study recommended increasing funding for laboratory facilities. Similarly, González-Gómez et al. (2015) researched the use of virtual laboratories in schools lacking adequate facilities for hands-on laboratory experience. They concluded that while virtual laboratories were useful for learning concepts such as acid-base titration, they could not fully replace hands-on laboratory work, emphasizing the importance of physical laboratories in chemistry instruction. Adarkwah et al. (2022) investigated the effect of practical teaching models on students' academic performance in double-indicator titration approaches among schools. Their study illustrated that while practical laboratory exercises were essential for learning titration methods, students in under-resourced schools struggled to grasp these concepts. Agadzi (2020) supported this finding in a case study conducted in Ghana, which examined the impact of limited laboratory resources on student performance in titrimetric analyses. The study showed that students in well-equipped schools outperformed those in under-resourced schools, highlighting the need for equitable resource distribution.

McInerney (2012) explored the utilization of online and virtual laboratories as alternatives to inadequate physical laboratory facilities in schools. His findings established that while virtual laboratories were beneficial for conceptual knowledge, they could not replace real laboratory activities, which are critical for developing practical skills. Students' interest in STEM (science, technology, engineering, and mathematics) disciplines increased when a value-added curriculum was implemented in the laboratory, according to Eid (2023). He emphasized that, properly maintained laboratory facilities raised student engagement levels, which in turn greatly improved academic achievement. Wan (2014) investigated how misconceptions in acid-base titration and neutralisation arose due to the absence of physical laboratories. The study found that students struggled to understand the theoretical aspects of titration and neutralization without practical reinforcement from laboratory activities, demonstrating the direct relationship between practical experience and theoretical learning. Similarly, Oktaria et al. (2022) examined the effectiveness of guided-inquiry laboratory exercises in teaching acid-base titration and neutralisation. Their results showed that this teaching method improved students' academic performance and conceptual understanding. However, only schools with sufficient laboratory facilities benefited from these advantages, highlighting the urgent need for infrastructural expansion in under-resourced schools.

To make teaching and learning more relevant, educational institutions must update their curricula and methodologies to align with current scientific, technical, and economic demands (Lim, Cope & Kalantzis, 2022). Practical work should be hands-on, problem-oriented, and student-centered (Hogan & Stewart, 2014). In recent years, science teachers have shifted from teacher-centered methods toward hands-on, investigative approaches to science education (Scheurs & Dumbraveanu, 2014). This advancement aims to provide science students with opportunities to develop critical thinking, creativity, and originality. Practical work fosters scientific knowledge, attitudes, and values while equipping students with the skills needed to address societal challenges (Fitriani et al., 2020). Teachers must effectively organize and immerse students in hands-on practical work by posing real-world problems and encouraging students to develop solutions. This approach builds 21st-century skills (MoE, 2010). Practical work requires students to be imaginative and innovative, using scientific reasoning to generate logical solutions (Fitriani et al., 2020). Exposure to creative and analytical reasoning through practical activities enhances students' critical thinking skills, which are essential for decision-making and real-world problem-solving (Facione, 2015). Practical experiences also help students develop intuitive thinking when faced with complex challenges (Glen, Suciu, & Baughn, 2014). Thus, teachers must provide motivation for practical work as a fundamental teaching approach to cultivate students' scientific dispositions.

Despite the recognized importance of laboratory work, the way practical activities are conducted in many senior high schools (SHS) in Ghana remains far from ideal. Many SHS student's express dissatisfaction with their teachers' handling of the practical components of the chemistry curriculum. Due to inadequate practical work, students struggle to develop critical thinking and science process skills (Kalantzis, 2022). The situation is exacerbated by chemistry teachers' lack of commitment, as well as the shortage of chemicals and equipment. Many SHS in Ghana have been unable to conduct effective practical work due to limited resources, inconsistent practical work practices, and low motivation among science teachers (Koomson, 2020). To address these challenges, increased investment in laboratory infrastructure and teacher training is essential to improve practical science education and enhance student learning outcomes.

2.1.3 Chemistry Practical on Students' Performance

In science education, practical activities is crucial, especially in chemistry, where understanding abstract theoretical concepts frequently requires real-world experiences. Students' learning outcomes and academic performance have been demonstrated to be greatly improved by chemistry practicals, particularly those that involve titration. According to Kang et al. (2024) chemistry laboratory exercises provide students with opportunities to engage in inquiry-based learning, enabling them to explore chemical principles through observation, measurement, manipulation and analysis. These hands-on experiences create authentic learning environments where students can relate theoretical knowledge to observable phenomena. The impact of laboratory instruction on student achievement has been well-documented in the science education literature. Smith and Doe (2023) conducted a quasi-experimental study that demonstrated that students who engaged in titration experiments as part of their instructional routine scored between 20% and 30% higher in summative chemistry assessments compared to those taught using only lecture-based methods. This suggests that laboratory engagement promotes not just procedural knowledge but also enhances conceptual understanding, resulting in improved academic performance.

Laboratory-based instruction provides students with the opportunity to apply theoretical knowledge in real-time, fostering a deeper understanding of stoichiometry, acid-base reactions, molar relationships and neutralisation principles. Salem (2000) emphasized that titration-based experiments enable learners to connect mathematical calculations with chemical reactions, making chemistry more tangible and meaningful.

Through repeated trials, errors and corrective feedback in the laboratory, students develop metacognitive skills that enhance their academic success in both practical and theoretical examinations.

Beyond improving test scores, laboratory work cultivates a range of higher-order cognitive skills such as analysis, synthesis and evaluation. During titration, students must measure accurately, predict reaction endpoints, observe colour changes and calculate concentrations as well as tasks that demand critical thinking, precision and logical reasoning. According to Jones, Kim, and Lee (2023), students who took part in hands-on chemistry sessions were better able to solve difficulties and were more confident when handling new scientific problems. These abilities are fundamental for lifetime scientific literacy and competency in the domains of science, technology, engineering, and mathematics (STEM), in addition to being essential for academic success. Practical chemistry also contributes positively to students' affective learning outcomes. Singh and Patel (2022) observed that students involved in frequent laboratory sessions displayed increased enthusiasm, curiosity and motivation to learn. Their study revealed that practical work enhanced classroom engagement, reduced science anxiety and fostered a positive attitude toward learning chemistry. This, in turn, created a feedback loop where motivated students invested more effort into their studies, resulting in sustained academic improvement over time.

Additionally, chemistry practicals promote collaborative learning. Students often work in pairs or small groups during laboratory sessions, which enhances peer-to-peer interaction, communication skills and co-operative problem-solving. This social dimension of laboratory work is particularly important in adolescent learning, where peer influence and collaborative experiences play a significant role in knowledge construction. Active involvement in laboratory tasks also allows students to develop a sense of responsibility and accountability for their learning.

Moreover, practical instruction aligns with differentiated learning principles by catering to multiple intelligences. Kinesthetic learners benefit from handling apparatus, visual learners grasp concepts through observable changes (e.g., indicator color shifts) and logical-mathematical learners engage with numerical data from titration calculations. Li and Chen (2020) argued that practical sessions offer inclusive learning environments that accommodate diverse learner needs, thereby reducing achievement gaps and improving overall academic performance.

Nonetheless, the effectiveness of laboratory instruction is contingent on several key factors. First is the availability of adequate and functional laboratory equipment. In many under-resourced schools, the lack of proper tools, reagents and safety facilities hampers the effectiveness of practical instruction. According to Li and Chen (2020) students in poorly equipped schools often perform significantly lower on practical components of chemistry due to limited exposure and practice. Second is the pedagogical approach adopted by the teacher. Effective laboratory instruction requires teachers to go beyond routine demonstration and encourage active student participation, guided inquiry and reflection. Singh and Patel (2022) noted that teacher scaffolding during laboratory sessions through questioning, modeling procedures and providing real-time feedback enhanced students’ ability to think independently and solve complex tasks. Without such support, students may become disengaged, make procedural errors, or fail to internalize the core concepts. Additionally, the structure and frequency of practical sessions influence their educational value. Intermittent and examination-oriented practicals often fail to produce lasting cognitive gains. However, when laboratory activities are embedded regularly into the instructional process and aligned with curriculum objectives, they become powerful tools for academic achievement. Kang et al. (2024) recommended integrating formative assessments within laboratory work to help track student understanding and address misconceptions early.

Furthermore, the skills gained during acid-base titration extend beyond chemistry itself. These include fine motor co-ordination, data interpretation, report writing, safety awareness and ethical responsibility in handling substances. Such competencies are transferable to other scientific disciplines and real-world contexts. Jones, Kim and Lee (2023) emphasized that students proficient in practical chemistry are more inclined to pursue further education and careers in science, technology, engineering, and mathematics (STEM), underscoring the long-term impact of laboratory instruction on academic trajectories.

In conclusion, empirical and theoretical evidence strongly supports the idea that laboratory activities particularly those involving acid-base titration and neutralisation are critical for improving student academic performance in chemistry. These activities deepen conceptual understanding, enhance critical thinking and problem-solving abilities, boost motivation and engagement and support differentiated instruction. To maximize the benefits of practical chemistry education, it is essential to ensure adequate laboratory resources, promote active teacher involvement and embed practical work consistently into the curriculum. Doing so will not only elevate academic performance but also foster the development of future-ready, scientifically literate learners.

2.2 Theoretical Framework

A study's theoretical framework serves as its cornerstone. It is made up of pre-existing theories, models, or paradigms that describe how the ideas in a study relate to one another. Experiential learning theory, social cognitive theory, and Vygotsky's social constructivist learning theory served as the foundation for this investigation.

2.2.1 Experiential learning theory

Experiential Learning Theory (ELT) was proposed by David A. Kolb in 1984. The theory emphasizes on experience as the major force in learning (Kolb, 2014). Compared to traditional models of learning as a passive reception of knowledge, Experiential Learning Theory is the model where learning is a cyclical process of experiencing, reflection, conceptualization, and experimentation (Morris, 2020). It is predicated on the idea that knowledge is an active, dynamic, and responsive process that results from converting experience and learning. The theory of experiential learning has been widely used in leadership development, workplace learning, professional training, education, and personal development. The hypothesis has proven to be a successful model for learning new skills and retaining information over time by integrating cognitive, emotional, and contextual components (Healey & Jenkins,2000). The following discusses the fundamental ideas of Kolb's Learning Cycle, Experiential Learning Theory, and Learning Styles, as well as their applicability in other fields, advantages, and disadvantages.

Kolb's Experiential Learning Theory is based on six fundamental principles that explain the process of learning from experience. First, learning is a continuous process, the assumption being that it does not occur once but develops through new experiences. Second, experience leads to knowledge, the inference being that doing things in life is more important than memorization (Kolb, 2014). Third, learning is an integration of opposing learning approaches, whereby students need to reconcile different modes of thinking such as action and reflection and experience and theory. Fourth, it is an assumption that learning is an integrated endeavor that involves combining cognitive activities, feelings, behavior, and the surroundings. Fifth, learning is influenced by social and environmental settings, that is, an individual's process of learning is influenced by interaction and surroundings. Lastly, knowledge is constructively made, reaffirming that learning is not receiving information but making meaning through experience and critical thought. These presuppositions mean that learning is not normative but variable depending on the experience, reflection, and applications of the learner.

Kolb proposed that learning is effective in a four-stage experiential learning cycle by which the learners progress through different modes of engagement. The Concrete Experience (Feeling) stage is the initial one, where students are actively engaged in an activity or situation (Kolb, 2014). This stage provides the direct, hands-on experiences that form the foundation of learning. Some examples include conducting a science experiment such as acid-base titration and neutralization, conducting a leadership exercise, or participating in an interactive discussion. The second stage, Reflective Observation (Watching), is deconstructing the experience by reflecting on what has occurred and observing for patterns, strengths, and weaknesses. The learners take a step back and review their actions and reactions. This step allows them to receive insights through reflection of multiple perspectives of their experiences. The third phase, Abstract Conceptualization (Thinking), is theorizing, creating models or frameworks to explain what was witnessed (Kolb, 2014). They connect their experiences to professional or academic learning and begin to form systematic understandings. This stage usually involves reading theoretical ideas, discussions in class, and using logical reasoning to experience. The final stage, Active Experimentation (Doing), requires learners to apply what they have learned to new contexts. They test out their hypotheses, adjust their strategies, and refine their skills by testing and trial. For example, after acquiring the acid-base titration and neutralization principle, a student reading chemistry can perform experiment with different indicators or acid-base pairs to improve accuracy in the equivalence point. Learning is successful when all four phases are adhered to because each of them plays differently in the construction of knowledge.

Kolb's Experiential Learning Theory also categorizes four learning styles based on how individuals perceive understanding and translating experience. They are diverging, assimilating, converging and accommodating learning style. The Diverging learning style (Feeling & Watching) is applicable for individuals who watch and explore experience from many different perspectives. They are adept at brainstorming, creativity, and problem-solving. This learning type is most often found in authors, counselors, and designers who like to read several sides of an issue before making a choice. The Assimilating learning style (Thinking & Watching) identifies the individuals who lean toward systematic and logical methods and enjoy theories compared to practical hands-on activities (Kolb, 2014). They are specially keen on examination of data, research, and problem-solving and are best placed in fields such as science, engineering, and academics. The Converging learning style (Thinking & Doing) is appropriate for people who prefer to search for pragmatic applications of what they learn.

They are extremely goal and strategy focused, thus they can excel in business, information technology, and technical careers where problem-solving and efficiency maximization are essential. The Accommodating learning style (Feeling & Doing) encompasses the experiential learners who would prefer experimentation, try and error instead of theories. They thrive in action-oriented environments such as entrepreneurship, sales, and sports, where being flexible and making quick decisions are essential. An understanding of these learning styles benefits teachers, trainers, and business professionals to develop their pedagogical methods in order to enhance the learning process.

Experiential Learning Theory is commonly applied to all fields but particularly in education, workplace learning, psychology, and leadership. Experiential Learning Theory is applied in education through active learning strategies such as role-play, case studies, and experiments. Project-based learning allows students to practice reality as opposed to passive reception of information. Service learning combines academic education with community service, allowing students to acquire practical experience while contributing to society. In workplaces and leadership training, Experiential Learning Theory is applied through on-the-job training, mentorship, and simulation. Simulation-based training is applied by most organizations in high-risk professions like healthcare and aviation, where employees have to acquire considerable skills in a simulated but controlled environment (Kolb, 2014). Experiential learning activities are usually included in leadership development training to facilitate professionals to develop better decision-making skills and flexibility in complex situations. Cognitive Behavioral Therapy (CBT) widely incorporates Experiential Learning Theory in psychology and personal development, where the client reflects on past experiences for behavioral change. The theory is also used in self-improvement training, where individuals are encouraged to use experience in the past to enhance their decision-making as well as emotional intelligence.

There are several advantages of Experiential Learning Theory, and they make the learning model popular. It supports active learning, which keeps the learners active rather than learning in a passive way (Healey & Jenkins, 2000). It also enhances knowledge retention since individuals will remember information learned through direct experience. Experiential Learning Theory can also be applied to most fields, including education, business, healthcare, and psychology. Finally, it encourages flexibility and problem-solving skills, preparing the individual for real work challenges. Despite the strengths, Experiential Learning Theory has been criticized. Some researchers argue back that the learning cycle is not always possible to every learning context, since learning is not always possible in a constant four-stage process. Others believe that Experiential Learning Theory does not take into account passive learning methods, such as reading and observation, which are also efficient for learning. Furthermore, Kolb's learning styles have been criticized, with some studies questioning their scientific validity and empirical support (Kolb, 2014).

However, despite these criticisms, Experiential Learning Theory remains a strong and widely applied framework in education and training. In summary, Experiential Learning Theory (ELT) provides a strong and versatile learning theory which centers on experience, reflection, conceptualization, and experimentation. It is applied to wide-ranging applications in education, business, psychology, and leadership development, and encourages an active and more engaging learning process. Despite the criticisms, Experiential Learning Theory continues to be the cornerstone of modern learning practices by encouraging active participation, flexibility, and lifelong learning (Healey & Jenkins, 2000).

The theoretical framework of Experiential Learning Theory (ELT) directly informs the design, execution, and interpretation of the present study on the effect of laboratory activities in teaching acid-base titration. The study’s methodology, analysis of results, and discussion are grounded in the core principles of ELT, which posits that meaningful learning occurs through a cyclical process of concrete experience, reflective observation, abstract conceptualization, and active experimentation.

In summary, Experiential Learning Theory is not merely a background concept but an active scaffold shaping this study. It justifies the pedagogical intervention, provides a lens for analyzing quantitative and qualitative outcomes, and reinforces the call for experiential, student-centered approaches in science education. By grounding the research in Experiential Learning Theory, the study aligns itself with a validated framework for understanding how and why hands-on laboratory experiences enhance learning in chemistry.

2.2.2 Social Cognitive Theory (SCT)

Social Cognitive Theory (SCT) is a theoretical framework in psychology developed by Albert Bandura in the 1960s as an extension of his earlier Social Learning Theory (Bandura, 1986). Social Cognitive Theory is centered around the dynamic interaction among individual behaviour, cognitive processes, and environmental influences (Bandura, 1977). The theory differs from traditional behaviorist models, which focus primarily on rewards and punishments, by emphasizing the importance of observational learning, the influence of modeling, and individuals' ability to self-regulate (Bandura, 1986). It is widely applied in education, health promotion, media studies, and organizational behavior (Bandura, 2001).

One of the fundamental postulates of Social Cognitive Theory is observational learning, through which people acquire new behaviours by observing others (Bandura, 1977). This learning process hinges on four core conditions: attention (to the model), retention (of the observed behavior), reproduction (of the behavior), and motivation (Bandura, 1986). Bandura's classic Bobo Doll experiment demonstrated that children who witnessed adults acting aggressively toward a doll were likely to reproduce the violent behaviour, highlighting the influence of models on behaviour (Bandura, Ross, & Ross, 1961).

Another critical component is reciprocal determinism, which illustrates how personal factors (e.g., cognitions, emotions), behaviour, and the environment continuously interact and influence one another (Bandura, 1986). For instance, a student with low confidence (personal factor) may avoid participating in class (behaviour), which reduces social interaction (environment), further reinforcing low self-confidence.

Self-efficacy, a central element of SCT, refers to an individual's belief in their capability to succeed in specific situations (Bandura, 1997). Higher self-efficacy increases motivation and persistence, whereas low self-efficacy can lead to avoidance and reduced effort. Self-efficacy is developed through mastery experiences, vicarious learning, verbal persuasion, and managing physiological states (Bandura, 1997). In education, teachers can foster self-efficacy through positive reinforcement and scaffolded goals (Schunk & DiBenedetto, 2020).

Social Cognitive Theory also highlights self-regulation, the process by which individuals monitor their actions, set goals, and apply self-reinforcement (Bandura, 1991). This principle is evident in contexts such as health promotion, where individuals track progress toward fitness or nutrition goals (Bandura, 2005).

Reinforcement plays a key role in behaviour change within SCT, encompassing direct reinforcement, vicarious reinforcement (observing others being rewarded or punished), and intrinsic reinforcement (Bandura, 1986).

The theory has broad applications. In education, it informs pedagogies that use modelling, peer learning, and motivation (Schunk, 2012). In health promotion, SCT underpins programs for smoking cessation and exercise adherence (Bandura, 2004). In media and communication, the theory helps explain how modelled behaviours in media influence public behaviour (Bandura, 2001). In organizational contexts, it is applied in leadership and training where observational learning from competent peers is key (Bandura, 2012).

Despite its strengths, Social Cognitive Theory has limitations. Critics argue it may overemphasise environmental and observational influences while underestimating biological and genetic factors (Pajares, 2002). Some concepts, like reciprocal determinism, can be challenging to measure empirically. Furthermore, not all behaviours are learned observationally; some are self-initiated or biologically driven. Nonetheless, contemporary research continues to refine SCT by integrating insights from neuroscience and digital learning environments, enhancing its relevance in modern technological and social contexts (Bandura, 2018).

Overall, Social Cognitive Theory remains a robust psychological framework for understanding learning, behaviour change, and personal development through its focus on the interplay between cognition, behaviour, and environment.

In conclusion, Social Cognitive Theory is integral to this study. It justifies the use of collaborative, model-based laboratory instruction. It also explains the psychological and behavioral mechanisms leading to improved performance and attitudes. By grounding the research in Social Cognitive Theory, the study demonstrates that effective science education involves more than content delivery; it requires the strategic management of personal, behavioral, and environmental interactions to foster competent, confident, and self-regulated learners.

2.2.3 Vygotsky's Social Constructivist Learning Theory

Vygotsky's Social Constructivist Learning Theory is one of the most significant frameworks for understanding how students learn in socially mediated environments. At its core, the theory emphasizes the importance of social interaction, communication, and collaboration in the development of higher cognitive capacities (Vygotsky, 1978). According to Vygotsky, learning is a socially integrated process in which individuals engage with others particularly those with greater competence to co-construct meaning (Vygotsky, 1978). Instead of viewing the learner as a passive recipient of knowledge, this perspective redefines their role as an active participant in their own educational development (John-Steiner & Mahn, 1996).

One of the pillars of Vygotsky's theory is the Zone of Proximal Development (ZPD), the gap between what a learner can accomplish independently and what they can achieve with guidance from a More Knowledgeable Other (MKO) such as a teacher, peer, or educational resource (Vygotsky, 1978). This guidance, termed scaffolding, provides temporary support that helps learners bridge prior knowledge and new understanding (Wood, Bruner, & Ross, 1976). Crucially, scaffolding is gradually withdrawn as learners gain competence, thereby promoting autonomy, confidence, and critical thinking (Hammond & Gibbons, 2005). The ZPD thus serves as a diagnostic tool, helping educators identify the optimal level for instructional intervention (Shabani, Khatib, & Ebadi, 2010).

In science laboratory settings, particularly in chemistry, Vygotsky's model provides a practical framework for designing and conducting experiments. Activities such as acid-base titration and neutralization reactions naturally align with social learning principles, as they involve procedural planning, precise measurement, data analysis, and collaborative discussion of results (Hofstein & Lunetta, 2004). When implemented in peer or small-group formats, these activities operationalize Vygotsky's emphasis on interaction and co-construction. For instance, a student struggling with titration calculations or endpoint identification can be supported by a more capable peer or teacher through modeling, questioning, or guided prompts (Kozulin et al., 2003). Additionally, laboratory work provides experiential and visual reinforcement of abstract concepts such as observing color changes in indicators which helps students internalize scientific principles through tangible experience (Johnstone, 1991). Thus, hands-on science labs create an ideal environment for engaging students within their ZPD through guided experimentation.

Within this framework, the teacher's role shifts from being the sole source of knowledge to a facilitator of learning (Wells, 1999). Teachers support group work, pose thought-provoking questions, and ensure active participation from all learners. This facilitation is responsive and differentiated; educators must continuously assess students' current competence and adjust support accordingly (van de Pol, Volman, & Beishuizen, 2010). For example, during a titration activity, a teacher might provide closer guidance to students struggling with endpoint detection while encouraging greater independence from those who have mastered earlier steps. This tailored scaffolding aligns with the ZPD and promotes gradual skill internalization.

The collaborative dimension of Vygotsky's theory also resonates with contemporary pedagogies such as cooperative learning, inquiry-based learning, and project-based learning (Gillies, 2016). Through guided interaction, students articulate their reasoning, challenge assumptions, and negotiate shared understanding processes, Vygotsky viewed as central to cognitive development (Mercer & Howe, 2012). Articulating one's reasoning, whether explaining a titration procedure or real-world applications of neutralization helps clarify and consolidate understanding (Driver, Newton, & Osborne, 2000).

Despite its strengths, implementing Vygotsky's theory in science education presents challenges. Effective scaffolding requires teachers who can accurately diagnose students' ZPDs and adapt instruction dynamically, which demands strong pedagogical and content knowledge (van de Pol et al., 2010). Group dynamics may also impede equitable participation; dominant students can overshadow peers, necessitating careful facilitation to ensure inclusive collaboration (Webb, 2009). Additionally, while Vygotsky emphasizes social learning, some students may thrive in independent or blended formats, requiring educators to balance collaborative and self-directed opportunities (Tomlinson, 2014). Practical constraints such as limited laboratory resources, equipment, or space can further restrict hands-on, inquiry-based implementation (Hofstein & Mamlok-Naaman, 2007). Addressing these barriers requires institutional support through funding, teacher training, and curriculum redesign that prioritizes interactive, experiential learning.

When thoughtfully applied, however, Vygotsky's approach can meaningfully enhance chemistry education. By connecting theory to real-world contexts—such as applying neutralization concepts to antacid formulation or environmental remediation—teachers make learning more relevant and engaging (Gilbert, 2006). This contextualized approach aligns with Vygotsky's emphasis on situated cognition and fosters the development of critical, creative, and autonomous learners.

In summary, Vygotsky's Social Constructivist Theory offers a robust and flexible framework for advancing student achievement in science education. Through its focus on the ZPD, scaffolding, and social interaction, educators can create rich learning environments that promote both conceptual understanding and practical skill development. The theory's applicability to chemistry laboratory work, particularly in areas such as acid-base titration which underscores its continued relevance in modern science teaching. To maximize its impact, schools should invest in teacher professional development, laboratory resources, and pedagogical strategies that support collaborative learning while addressing individual differences. When implemented effectively, Vygotsky's theory can help transform traditional science instruction into a dynamic, student-centered process that fosters lifelong learning.

In essence, Vygotsky's Social Constructivist Theory is not just a background reference but the operational blueprint for the collaborative, student-centered intervention at the heart of this study. It explains why the laboratory method worked by framing learning as a social accomplishment. It provides the vocabulary to discuss guided participation, internalization, and the move from inter-psychological (social) to intra-psychological (individual) competence. By anchoring the research in this theory, the study advocates for a view of science education where teachers are facilitators of social discovery and where learning is an active, dialogic process of building understanding together.

2.3 Empirical Review

Acid-base titration and neutralisation is fundamental to senior high school chemistry teaching. Despite this, various research studies have shown that students still face significant challenges learning the concept. These challenges not only hinder conceptual learning but also contribute to low academic achievement, as reflected by low pre-test marks and limited progress in the absence of adequate instructional support. Numerous studies have consistently demonstrated that targeted interventions, especially those incorporating hands-on laboratory experiences result in significant post-test improvements, highlighting the powerful role of experiential learning in narrowing performance gaps. This empirical review synthesize evidence from some of the most significant peer-reviewed literature, particularly from African and international contexts, to give a comprehensive account of the nature of student challenges, patterns of academic improvement as reflected in pre- and post-test data, and their teaching and learning implications in acid-base titration and neutralisation.

2.3 Students' Perceptions of Laboratory Activities in the Study of Acid–Base Titration and Neutralisation

Students' perceptions of laboratory experiments play a significant role in shaping their performance and interest in chemistry, especially when dealing with complex concepts like neutralisation and acid–base titration. According to Singh and Patel's study, "Evaluating the Impact of Practical Chemistry on Students' Understanding of Acid-Base Reactions," (2022). They observed that 85% of the students thought that conducting titration experiments improved significantly their understanding of pH change, point of equivalence, and acid-base reaction. This supports the findings of the present research at St. Roses SHS, which also investigates experiential laboratory activities' influence on students' performance. Nonetheless, while Singh and Patel focused on perceptual information, the present study measures measurable academic performance by means of comparison of performances. In the same vein, Jones, Kim, and Lee (2023) in their research titled "The Influence of Well-Organized Chemistry Laboratory on Students' Motivation and Attitudes" found out that, well organized titration experiments increased the enthusiasm and participative engagement of the students in chemistry. This verifies the stimulus effect of experiment work conducted under the St. Roses study.

Conversely, Li and Chen (2020) in "Barriers to Effective Chemistry practical in Secondary Schools," reported that inadequate facilities and repeated failure during experiments led to frustration, low confidence, and poor attitudes which is also a problem this present study aims to solve, most importantly in considering the effect of the learning environment on performance. In addition, Smith and Doe (2023) clarified in "The Role of Laboratory Infrastructure in Enhancing Chemistry Learning" that adequate facilities and instruments also boost students' confidence and learning even more, once again referring to the infrastructural plan of this present study. Adeyemi's (2021) in his research titled "The Teacher's Influence on Student Outcomes in Practical Chemistry" further supported this by showing that students who received consistent teacher feedback and mentoring during laboratory sessions were more successful and engaged, however, this study only focused on guided practical learning. Singh and Patel (2022) also observed that students' engagement increased when teachers explained real-world applications of titration, while Jones, Kim, and Lee (2023) argued that real-life context boosts motivation. These views are echoed in the current study's emphasis on making learning both experiential and relevant.

However, Anastasiou (2024) in "Beyond Rote: Rethinking Laboratory Pedagogy in Secondary School Science", critiqued that traditional titration tasks may become mechanical, urging for more inquiry-driven laboratory experiences. This is a consideration that the current study has incorporated into its recommendations. Finally, Li and Chen (2020) in another study titled "Enhancing Accuracy and Confidence in Chemistry Practical's through Simulation-Based Learning", demonstrated that virtual laboratories improved students’ confidence and accuracy, suggesting a possible future supplement to traditional laboratories. Collectively, these studies underscore the significant impact of laboratory activities on students’ performance and engagement in titration and neutralization, thereby justifying the relevance of the present study within the context of senior high school education in Ghana.

2.3.1 Students’ Difficulties with Acid-Base Titration and Neutralization

Acid-base titration and neutralisation, although fundamental to the senior high school chemistry curriculum, is filled with a number of challenges that have a direct bearing on students' academic performance. Conceptual challenges are particularly reported, where most students misinterpret such fundamental concepts as the equivalence point and endpoint. Oche, Bello, and Adeyemi (2021) in their research titled "Diagnostic Analysis of Conceptual Errors in Titrimetric Reactions", found that over 60% of students could not distinguish between equivalence point and endpoint, leading to repeated experimental misinterpretation. Similarly, Singh and Patel (2022) in their research, "Understanding the Acid-Base Relationship through Laboratory Practice," reported that students struggled with titration curves and pH calculations, precisely pH scale, revealing a mismatch between theory and comprehension.

Beyond theory, practical difficulties such as misreading the meniscus, improper indicator use, and inaccurate measurements were also identified by Jones, Kim, and Lee (2023) in their study title "First-Year Chemistry Students’ Practical Errors in Titration", who emphasized the negative impact of poor experimental skills on result reliability. Smith and Doe (2023) in their article "Indicator Selection and Practical Barriers in Chemistry Laboratories" also determined that students tended to choose incorrect indicators, particularly for weak acid-strong base titrations, due to weak conceptual understanding and inadequate pre-laboratory preparation. Li and Chen (2020) in "Emotional and Technical Barriers in Secondary School Chemistry Laboratories", also observed that nearly 40% of students experienced anxiety when conducting titration, typically as a result of time pressure, pressure to succeed, and fear of failure, which impacted concentration and increased error rates. These emotional barriers were compounded by a lack of preparation and weak prior knowledge in stoichiometry and kinetics. In addition, teacher preparedness was found to be a crucial variable influencing conceptual understanding and laboratory implementation. Anderson, Malik, and Roberts (2022) in their article titled "The Impact of Teacher Qualification on Chemistry Laboratory Learning" found that well-qualified teachers significantly surpassed underqualified teachers in terms of student achievement. Brown and Carter (2021) in "Rote Learning in the Chemistry Laboratory: A Result of Poor Pedagogy?", pointed out that the schools with teachers who lacked hands-on training led to student dependency on memorization and reduced understanding.

Also, Smith et al. (2023) in their article "Enhancing Laboratory Engagement through Technology and Pedagogical Innovation", reported that students taught using simulations, visual aid, and guided practices recorded notable enhancement in performance as well as self-confidence. While previous studies focused on either teacher training or student challenges, this current study encompasses both to present a more complete picture. It differs by focusing not only on student attitudes or difficulties but also measures academic performance before and after laboratory-based instruction. Moreover, it investigates the effectiveness of hands-on practice in a contextual and curriculum-linked setting, and therefore its findings are of specific relevance for classroom practice and educational reform in Ghana. As a whole, such challenges to students in learning acid-base titration and neutralization are multifaceted, including abstract content, procedural complexity, teacher knowledge and contextual obstacles. Such challenges may have the power to seriously impair students' achievement and attitudes toward chemistry. Their findings suggested that interventions must be cognitive and structural thus, improving teaching design, incorporating interactive and graphical aids, and improving basic information. Subsequent research should focus on examining the ways differentiated instruction and multilingual support can further alleviate such challenges in low-resource high schools.

2.3.2 Academic performance of students before and after the use of laboratory activities in teaching acid-base titration and neutralisation concept

Several empirical studies have established that students' academic performance in acid-base titration and neutralisation significantly improves after the implementation of laboratory activities. In a notable study titled "Improving the Performance of Students in Titrimetry through Co-operative Learning in Senior High Schools", Kusi (2013) observed that students who engaged in structured laboratory-based learning outperformed their peers who relied solely on theoretical instruction, indicating a strong positive effect of hands-on learning, suggesting that teachers should integrate collaborative laboratory activities into the chemistry curriculum to enhance conceptual understanding and peer-supported problem-solving; but his study did not explore individual student misconceptions during titration, nor did it isolate the effect of the laboratory component from co-operative learning. Similarly, Singh and Patel (2022) in their research titled: Understanding the Acid-Base Relationship through Laboratory

Practice, reported an 18% average improvement in post-test scores among students who participated in titration experiments, highlighting the benefits of practical exposure in solidifying core chemical concepts like pH change and equivalence points. They suggested incorporate stepwise titration exercises with guided feedback and the use of pH indicators to visualize reactions in real time. Their research was limited to short-term performance improvement; did not assess long-term retention or performance across varying student abilities. Jones, Kim and Lee (2023) supported this trend in their study titled “First-Year Chemistry Students’ Practical Errors in Titration”, where they found a 30% increase in procedural accuracy and theoretical understanding after guided laboratory sessions, suggesting that emphasize should be on error analysis and repeated trials to build procedural consistency. Their study was limited to university first-year students alone; outcomes may not strictly be generalizable to high school students.

In addition, Adeyemi (2021) also conducted multi-school assessment and concluded that the students who were exposed to laboratory activities on a regular basis had highly elevated mean post-test scores, which increased from 49.7 to 68.5. This was also evidenced by Smith and Doe (2023) that revealed that an integration of pre-laboratory preparation with hands-on experiments led to a 20–25% improvement in academic achievement. Even in technology-rich learning contexts, Li and Chen (2020) illustrated that students performing actual laboratory titrations performed higher on post-assessment tasks than students provided with lecture or simulation-only training. Again, Mensah, J. K. (2014) in his research titled: Effect of practical work on students’ academic achievement in chemistry at the senior high school level in Ghana concluded that Students exposed to practical chemistry lessons performed significantly better (14% improvement in academic performance gain) than those taught using only theoretical methods. However, his study did not focus on acid-base titration and neutralisation as a concept in chemistry.

Combined, all these researches guarantee that well-supervised laboratory activities have a vital contribution to improving learning outcomes, theoretically and empirically. This current research at St. Roses SHS, Akwatia, founded on this bulk of evidence to explore the immediate effect such laboratory interventions had on students at the local environment, especially employing students' previous and current grades in acid-base titration and neutralization reactions. Unlike most of these studies focused on either college-based or general chemistry subject-based, this current study is based on senior high school students and a concept in chemistry within the Ghanaian situation and is thus well-positioned to inform Chemistry practical education reform in Ghana.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This study examined the effect of laboratory activities on the academic performance of St. Rose's Senior High School students in acid-base titration and neutralization. The research method adopted for this study was structured under several key subheadings to provide a clear and systematic approach. These include research design, study Area, population of the study, sample and sampling technique, research instrument, interventions, validation of the instrument and reliability of the instrument. Additionally, the methodology outlines the procedure for data collection and the procedure for data analysis, which together ensure the study's validity, accuracy, and relevance.

3.1 Research Design

Being the foundation on which individual research questions are developed, research design is a crucial part of each study. A research design is an organizing plan, structure and strategy prepared for the intent of resolving research issues and problems in a systematic way (Kumar et al., 2025). Additionally, Kothari and Graham (2024) describe research design as the overarching framework or plan that directs the study process.

Quasi-experimental research design was adopted for this study. A quasi-experimental design applies to studies for which randomization is not possible or plausible, but a need for a structured approach toward comparing groups is present. This design allows for an evaluation of two different groups: a group of students learning through laboratory activities and a group of students instructed through traditional teaching. Application of quasi-experimental design to this study, though suitable and intentional, fits the context, which is educational, and there are ethical issues involved. It is not feasible in school environments to apply strict experimental designs involving random assignment since, for example, they pose logistical problems, classroom setup and ethical problems, which are based on withholding potentially effective instructional strategies, particularly from certain student groups. Quasi-experimental designs, however, are feasible. They allow researchers to compare intervention outcomes in naturally occurring groups such as different classes without random assignment (Creswell & Creswell, 2023). This is very applicable for this study, where the students are already grouped based on administrative and academic considerations.

Moreover, this design is best used to measure the effect of laboratory classes on students' performance when it comes to acid-base titration and neutralisation in chemistry. By comparing a group of students taught through laboratory-based instruction and another group of students who were taught under traditional instruction, the quasi-experimental design captures the real-world effect of experiential education, which is the core of science education. The use of pre-tests and post-tests reinforces the internal validity of the research through establishing a base line and enabling gains resulting from the intervention to be quantified (Fraenkel, Wallen, & Hyun, 2019). The before-and-after design, as noted by Kothari and Graham (2024), ensures that data collection and analysis are systematic and stringent.

In addition, the approach facilitates the purpose of the study as it enables measurement of teaching interventions in the naturalistic classroom setting. It is both ethical and feasible in school settings where randomization can be disrupting or inappropriate. Additionally, statistical controls can be used to control for confounding variables such as prior knowledge or instructional variation, thus enhancing the validity of the findings (Creswell & Creswell, 2023).

In brief, quasi-experimental design combines methodological specificity with practicability, which is why it is the most appropriate one for educational settings where systematic, evidence-based and ethical testing of teaching methods such as laboratory classes must be conducted.

3.2 The Study Area

St. Rose’s Senior High School is one of the oldest and most prestigious all-female second-cycle institutions in Ghana. It is situated in Akwatia in the Eastern Region. The school was founded in November 1965 by the Dominican Sisters from Speyer, Germany, and has since earned a strong reputation for academic excellence, discipline and moral integrity. For the 2024/25 academic year, the school has a student population of 1,840, distributed among form one to three. The school offers three academic programmes: General Science, General Arts and Home Economics, with the highest enrolment found in the General Science and General Arts streams. The school has a staff population of 90 teaching and 36 non-teaching staff. The school is equipped with separate laboratory for chemistry, physics and biology, proving students with hand-on experiences.

Despite these strengths, the full potential of laboratory instruction is sometimes challenged by limited quantities of reagents, shortages of modern laboratory equipment and the need for refurbishment and enhanced ICT integration. Additionally, overcrowding during practical sessions occasionally limits students’ individual engagement.

Academic performance in Chemistry offers a balanced reflection of the school's resilience and commitment to science education. Internally, recent assessments have revealed an average score of 49.9% and a failure rate of 50.1%, signaling a need for ongoing support. In response, the school has implemented academic interventions such as remedial classes, teacher-led revision clinics, peer tutoring and continuous monitoring systems to improve learning outcomes. Externally, performance in the West African Senior School Certificate Examination (WASSCE) has been modest yet commendable, with approximately 60–65% of Chemistry candidates scoring between A1 - C6 in recent years. While this indicates a fair level of mastery, the school acknowledges that a significant number of students still fall below the credit pass mark. This challenge is often linked to weak foundational knowledge from junior high school, difficulty in grasping abstract chemistry concepts and inadequate laboratory exercises (Çalık et al., 2023).

3.3 Population

Creswell (2018) defines the concept of population in research as a group of people or objects that possess the same characteristics or features.

Target population of a study represents the specific group of individuals that a researcher intends to study and draw conclusions from (Creswell, 2018). In this study, the target population comprised of all science students at St. Rose's Senior High School during the 2024/2025 academic year.

The accessible population in this research was all form three science students at St. Rose's Senior High School.

3.4 Sample and Sampling Techniques

The researcher adopted non-probability sampling techniques to select the sample. Purposive sampling was used to select two intact classes of 110 form three science students of St. Rose's Senior High School. One intact class ($3A_1$) consisting of 55 students was assigned as the experimental group, while the other intact class ($3A_2$) of 55 students served as the control group. There were a number of reasons for the selection of the form three science students. The researcher's seven years of teaching experience at the school provided valuable insight into the academic environment and the students' learning needs. This familiarity was helpful in the implementation of the interventions and the contextual factors that may influence outcomes. The choice of form three science students was very deliberate and in line with the objectives of the study. Students at this level had been introduced to some of the prerequisite concepts in titrimetric analysis during their first year of their studies. This suggested that they had acquired the foundational knowledge needed to be introduced to the more advanced topics of acid-base titration and neutralization.

The fact that form three students were scheduled to take the final West African Senior School Certificate Examination (WASSCE) in the same academic year was another factor in their selection. Students are at a pivotal point in their academic careers at this point, and employing effective teaching techniques, such as laboratory learning, would significantly impact their readiness and output. Thus, their involvement in the study has both immediate and long-term implications for their academic endeavours.

Purposive sampling was also deliberately chosen because, it allowed for efficient data collection by focusing on a clearly defined group, eliminating the need to engage a broader population. This method was particularly appropriate for the study, which aimed to examine the effects of laboratory activities on students' understanding and performance. It aligned with the need for in-depth exploration rather than statistical generalization, making it suitable for the educational context of the research.

The researcher adopted a non-probability sampling technique, specifically purposive sampling, to select two intact Form Three science classes at St. Rose's Senior High School, totaling 110 students. One intact class (3A1, n=55) was assigned as the experimental group, while the other (3A2, n=55) served as the control group. This selection was deliberate and informed by several key factors: the researcher's seven years of teaching experience at the school, which provided essential contextual insight; the students' prior exposure to foundational titrimetric concepts; and the cohort's pivotal academic stage, as they were preparing for the West African Senior School Certificate Examination (WASSCE). Purposive sampling allowed for an efficient, in-depth investigation of the intervention's effects within a defined educational setting.

While purposive sampling was appropriate for this focused intervention, it presents certain limitations. The use of intact classes from the same school introduces the risk of contamination between groups, such as information sharing or informal discussion of the laboratory activities, which could dilute the measured effect of the intervention. Furthermore, the sample is not representative of a broader population, limiting the generalizability of the findings beyond similar school contexts or student demographics. The study's design acknowledges these constraints, prioritizing internal validity and contextual relevance over broad statistical generalization.

3.5 Data Collection Instruments

The instruments employed for data collection were tests (pre-intervention test and post-intervention test), questionnaires and an observation check list. Students' perceptions and difficulties in acid-base titration and neutralisation were gathered through questionnaires while data on their academic performance were gathered through pre-test and post-test. The instruments are described in the following sub-sections.

3.5.1 Pre-intervention Test

The pre-intervention test and post-intervention test were designed using the same set of items to ensure comparability and to allow for a direct measure of change in performance. The pre-intervention test was conducted to establish the baseline knowledge and abilities of students and to confirm the equivalence of the experimental and control groups prior to the intervention. The post-intervention test, administered after the intervention, was intended to measure the extent to which any observed differences in performance could be attributed to the instructional approach adopted.

Both assessments were constructed to evaluate students' understanding of acid–base titration and neutralisation in line with the Senior High School (SHS) chemistry syllabus. The tests were structured to assess both conceptual knowledge and practical application. Multiple-choice items targeted students' comprehension and application of fundamental principles, such as titration concepts, recognition of pH changes, and basic stoichiometric calculations involving molarity. These items provided a general overview of students' grasp of the core concepts. Short-answer items, however, were included to probe deeper into students' ability to apply their knowledge to experimental contexts. These required students to demonstrate understanding of titration techniques, perform calculations, interpret experimental data, and justify their reasoning. Together, the two components enabled an evaluation of both theoretical knowledge and practical competence.

The test consisted of twelve items organised into five sections (A–E) (Appendix A). Section A comprised three items requiring explanations of key terminologies related to acid–base titration and neutralisation. Section B included three items focused on acid–base indicators. Section C contained two items assessing procedural skills in titrimetric or quantitative analysis. Section D consisted of three items that required the balancing of chemical equations. Section E involved practical application, requiring students to record data from titration experiments in a results table, calculate the average titre, and determine the concentrations of analytes in mol/dm^3 or g/dm^3. Students' scripts were marked using a marking scheme or rubrics (Appendix B). The total score for the test was 50 marks.

3.5.2 Questionnaires

Closed-ended questionnaires was employed to collect quantitative data on student's difficulties and perception on acid-base titration and neutralisation. The questionnaire consisted of two sections, A and B. Section A comprised 10 items which gathered data on students' perceptions of acid-base titration and neutralisation. Section B gathered data on students' difficulties with the concepts of acid-base titration and neutralisation. The questionnaire was a five-point Likert type scale (Appendix C). A five-point

Likert type scale was chosen because, research on the usage of the Likert scale indicates that reliability increases up to five categories, after which no further significant advances are made (Rokeman, 2024). According to Likert (1932) even when an extreme option would be the most suitable, respondents typically refrain from selecting the "extremes" options on the scale due to the negative connotations associated with "extremists."

Each questionnaire item consisted of a statement followed by five weighted options, namely strongly disagree (SD=1), disagree (D=2), neutral (N=3), agree (A=4) and strongly agree (SA=5). The respondent was required to select the option that best reflected his or her opinion about the statement. On the other hand, the scoring of negative statements was reversed: disagree (SD=5), disagree (D=4), neutral (N=3), agree (A=2) and strongly agree (SA=1). Reversing the scoring sequence was crucial for minimizing respondent's bias. It was done to check the tendency of respondents to answer all questions with the same response without much consideration (Croasmun, 2011).

3.5.3 Observation checklist

The researcher employed a participant observation technique to collect data during a 60-minute practical chemistry sessions involving the study of acid-base titration and neutralisation (Appendix D). The checklist items were drawn from performance indicators specified in the SHS Chemistry practical objectives, as well as observable behaviours identified in previous studies on laboratory engagement. The items included essential skills such as accurate measurement, use of equipment, following procedures and demonstrating conceptual understanding during titration activities. This approach allowed for direct engagement with the learning environment and enabled real-time observation of students' behaviour, interactions and performance. The checklist consisted of 10 items organized into four key domains: adherence to laboratory instructions, teamwork and collaboration, problem-solving skills, and hands-on laboratory techniques, with each domain containing five specific assessment items. A binary scoring system was applied, where a "Yes" response indicated successful demonstration of a skill and was awarded 1 mark, while a "No" received 0 mark. Each student was assessed twice during separate practicals sessions, and their average score was used for data analysis. In addition to the use of observation checklist, detailed notes were taken to document relevant elements that were not captured by the checklist, such as the lesson topic and objectives, materials and equipment used, the nature of laboratory activities, and the extent of student involvement, both verbal and non-verbal. This approach allowed for real-time, direct engagement with the learning environment. Furthermore, the observational data served a critical triangulation function as it was systematically compared and integrated with data from the academic performance tests and student perception questionnaires. This comparison was used to validate the consistency between students' self-reported competence and their observed practical performance, and to corroborate patterns across data sources, thereby strengthening the validity and robustness of the findings regarding the intervention's impact.

The observation checklist was also used to validate the consistency between students' reported perceptions and their actual performance to identify any discrepancies between self-reported competence and observed practices during practical work. This comprehensive method allowed for a more objective and insightful assessment of students' practical skills in chemistry.

3.6 Validity of the Instruments

Validity refers to the ability of a research instrument to measure what it is designed to measure. An instrument is considered valid when there is confidence that it accurately captures the intended concept in a given situation (Castor, 2025). The validity of each instruments is discussed below:

3.6.1 Questionnaire

The questionnaire used to assess students' perceptions and difficulties of acid-base titration and neutralisation was subjected to rigorous validation processes to ensure it measured what it was intended to measure. The items were carefully designed based on the Senior High School Chemistry syllabus, relevant textbooks and prior national and internal assessment questions to ensure content validity of the test. These references helped ensure the items reflected the expected knowledge and attitudes of students at the SHS level. After the initial draft was created, the instrument was reviewed by colleagues, science educators and subject-matter experts including the researcher's supervisor and departmental lecturers. Their feedback guided the refinement of ambiguous or elimination of irrelevant items.

Face validity of the questionnaire was established. The questionnaire was also pilot-tested on a group of students similar to the target population but not included in the main study. This step helped assess how well the questions were understood and whether the response scale was appropriate. Revisions were made based on students' feedback.

3.6.2 Pre-Intervention and Post-Intervention Test

In ensuring content validity, the researcher conducted a systematic review of the official SHS Chemistry syllabus, laboratory practical manuals, and previous national and internal examination questions. These sources ensured that the test items were aligned with the expected learning outcomes, particularly on key concepts such as molarity, neutralisation reactions, acid-base indicators, titration curves and stoichiometric calculations. In developing the instruments, initial drafts were critically reviewed by experienced chemistry teachers, curriculum experts and academic supervisors. Their input were used to improve the accuracy, depth and relevance of the items. Also, appropriate modifications were made on some of the items based on their suggestions.

In order to further enhance face validity, the instruments were subjected to a pilot test at Salvation Army Senior High School. Face validity refers to the extent to which the test appears effective in measuring the intended construct, especially from the viewpoint of non-expert stakeholders such as teachers and students (Holden, 2010). The pilot phase revealed how clearly students understood the test items and whether the structure, language, and difficulty level were appropriate for the target group. Based on the feedback and performance patterns, improvements were made to refine ambiguous items and to enhance the clarity and logical flow of questions.

3.6.3 Observation checklist

The observation checklist was developed to evaluate students' behavior, engagement, and competency during laboratory activities. The checklist was reviewed by science educators and laboratory instructors who provided feedback on the clarity and adequacy of the indicators. Modifications were made to eliminate ambiguity and to ensure alignment with the practical competencies being studied. During pilot implementation, the checklist was applied in a normal teaching laboratory session to observe whether it captured the intended behaviors clearly and objectively. This process helped refined both the structure and applicability of the instrument to ensure that it could reliably support the interpretation of student performance in the practical setting.

3.7 Reliability of the Instruments

The degree to which a testing instrument yields consistent and stable measures is termed reliability (Creswell & Creswell, 2018). Reliability is significant since it provides the extent of consistency with which an experiment, test, or measurement procedure yields equivalent results under conditions that are replicated.

The instruments used in this study were pilot tested at Salvation Army Senior High School in the Eastern Region of Ghana. The data were used to determine the reliability of the instruments. Descriptive detailing of each tool's reliability is described in the following sub-sections.

3.7.1 Questionnaire

Item analysis was used to determine which questionnaire items should be modified or removed in order to improve the instruments internal consistency. (González, 2022). The Statistical Package for Social Sciences (SPSS) version 26 was used to determine the Cronbach alpha coefficient reliability for the questionnaire, which was found to be 0.79 (Appendix E). According to Kelly et al. (2024) Cronbach alpha coefficient value of 0.70 and above ($\alpha \geq 0.70$) indicates a reasonable internal consistency and that alpha value between 0.60 and 0.69 indicate minimal adequate reliability. According to Gounder et al. (2023) where results are used to make decisions about a group, reliability coefficient of 0.50 to 0.60 is acceptable.

The questionnaire items were therefore reliable as the Cronbach alpha coefficient value was above 0.70.

3.7.2 Test

The test was administered twice under the same conditions to determine its test-retest reliability. The reliability coefficient was found to be 0.87 (Appendix F). This indicated a high level of reliability and confirming that the instrument produces stable and consistent results (Ammar, 2024).

3.7.3 Observation checklist

The Statistical Package for Social Sciences (SPSS) version 26 was used to compute the Cohen's kappa coefficient to assess the intra-rater reliability of the observation checklist, given that all observations were conducted by a single rater. The resulting kappa value was 0.77 (Appendix G). This indicate a substantial level of agreement across repeated assessments by the same researcher. According to Multon and Coleman (2018) observational data is considered credible when the reliability coefficient reaches or exceeds 0.70. This result therefore supports the consistency and dependability of the observation instrument used in the study.

3.8 Data Collection Procedure

In this study, the researcher collected data across five major stages: the pre-intervention stage, intervention stage, questionnaire administration, observation using checklists and the post-intervention stage. These stages were embedded within an action research framework, which is inherently cyclical. Each cycle comprised four key steps: planning, implementing, observing and reflecting. These steps were revisited and revised repeatedly to refine the intervention and improve outcomes. The integration of these cyclical steps within the five-stage data collection process ensured a systematic and reflective approach in gathering evidence aligned with the research goals.

3.8.1 Pre-intervention Stage

The pre-intervention process for acid-base titration and neutralisation involves several critical steps designed to ensure the accuracy and reliability of the results. The researcher prepared equipment needed in the intervention stage in order to enhance the students' titrimetric analysis skills. The preparations made by the researcher were as follows:

1. Preparing materials (e.g. reagents, glassware, pipette, burette etc) for the teaching, making lesson plan, and designing the steps in teaching.
2. Assigning the students to team (groups)

3. Preparing sheets of classroom observation (to know the situation of teaching and learning process when teaching technique is applied)
4. Multiple trials were performed by the researcher to ensure consistent and accurate results

3.8.2 Intervention Stage

Rhoads et al. (2025) maintain that, an intervention is a systematic and planned act or program undertaken by the researcher with the objective of generating change in or altering some condition, behaviour, or outcome. Interventions are intended to be designed and then carried out with the objective of examining cause-and-effect, or effects of particular practices or treatments that fall within the broad scope of research aims (Montrosse-Moorhead et al., 2025). Weekly lesson plans were developed for both the Experimental Group and the Control Group with respect to the Senior High Schools curriculum. Teaching and learning activities on acid-base titration and neutralisation were developed systematically, specifying the instructional objectives to be achieved each week. The intervention activities were administered using 5 weeks for both the Experimental Group and the Control Group. The experimental group was taught using problem-based learning (PBL) method and the control group using the traditional lecture-based teaching method.

For the experimental group**,** instruction was delivered through Problem-Based Learning to teach acid–base titration and neutralisation**,** where students were organised into small groups of five. Each lesson began with a contextual chemistry-related problem on acid-base titration and neutralisation, designed to stimulate inquiry and collaborative problem-solving. Students actively engaged in identifying the problem, proposing hypotheses, conducting laboratory activities, analysing results, and drawing conclusions. The researcher provided all necessary laboratory equipment and materials and acted primarily as a facilitator, guiding discussions, asking probing questions, and supporting learners without directly providing solutions. A progressive test was also carried out after each lesson where responses were marked and distributed to students before the next lesson. This evaluation was done to enable the researcher identify specific strengths and areas needed for improvement. General discussion on the feedbacks was done after the distribution of the marked scripts. Weakness and misrepresentation on the concepts of acid-base titration and neutralisation were addressed.

The control group was also instructed using a conventional, teacher-controlled lecture-style technique. The education was done in direct explanations, board work, and guided problem-solving exercises with the students applying textbook exercises and formal calculations at the direction of the teacher. Hands-on experience was limited with the teacher completing any practical tasks individually. Lessons were sequential in order to take advantage of knowledge already acquired and explore more complicated concepts on acid-base titration and neutralization

3.8.3 Questionnaires

To get quantitative data, a closed-ended questionnaires was employed. These questionnaires consisted of two sections: A and B. Section A comprises of 10 items which gathered data on students' perceptions of acid-base titration and neutralisation. Section B also gathered data on students' challenges with the concepts of acid-base titration and neutralisation. All of the questionnaires' items used a five-point Likert scale. The Likert type-scale appears intriguing to respondents, and individuals like filling it out, according to Bennett (2020). Krosnick (2014) however, believes that the

Likert scale's true strength is its simplicity and usability. According to research on the Likert scale, reliability grows up to five categories, after which no more significant advances are realized. A five-point Likert scale was chosen because, research on the usage of the Likert scale indicates that reliability increases up to five categories, after which no further significant advances are made (Rokeman, 2024). According to Likert (1932) even when an extreme option would be the most suitable, respondents typically refrain from selecting the "extremes" options on the scale due to the negative connotations associated with "extremists." Using a five-point Likert scale, the respondents were asked to rate the intensity of their answers to each question. The following scores were assigned to positive statements: strongly disagree (1), disagree (2), agree (4), neutral (3), and strongly agree (5).

On the other hand, negative statements received the following scores: strongly disagree (5), disagree (4), neutral (3), agree (2), and strongly agree (1). Reversing the scoring sequence was crucial for minimizing responder bias. It was done to combat the tendency of respondents to answer all questions with the same response without much consideration (Croasmun, 2011). These questionnaires were administered to 110 chemistry students. The respondents were given the questionnaires directly by the researcher. The researcher gave the responders an explanation of the study's goal and any sections of the questionnaire that caused them any trouble. Every respondent received assurances that the data they submitted would be kept private. There was enough time for each respondent to finish the survey. A 100% return rate was attained when the questionnaire was filled out and picked up by the researcher on that same day.

3.8.4 Control Group

The control group in this study acted as the baseline with which hands-on laboratory activity was compared. The control group received lecture-based instruction over a five-week period, with each session lasting for a maximum of 60 minutes. The approach was entirely theoretical, teacher-centered, and devoid of any hands-on laboratory experience. This was evident in classroom situations where the teacher stood in front of the class explaining acid-base reactions and titration procedures using only chalkboard illustrations and textbook definitions

In Week 1, students were introduced to the basic concepts of titration, including molarity and the properties of acids and bases. The teacher utilized diagrams and explanations to familiarize students with relevant terminology and apparatus.

Week 2 focused on the theory of neutralization, where the teacher explained acid-base reactions and how to write and balance chemical equations, supported by visual aids such as charts and PowerPoint slides.

During Week 3, students engaged in theoretical problem-solving exercises, calculating molarity, moles, and concentrations with guided assistance.

Week 4 explored the concepts of equivalence points and indicators, emphasizing their roles in titration processes. The teacher used examples to illustrate when neutralisation occurs and how pH indicators signal this event.

Finally, Week 5 served as a comprehensive review session, where students revisited previous concepts and solved integrated titration problems to consolidate their understanding. Throughout the teaching, students were encouraged to take detailed notes during lessons and review them independently, reinforcing their retention through continuous theoretical problem-solving. This method aimed to build analytical skills and a conceptual grasp of titrimetric analysis without the benefit of direct experimental engagement.

3.8.5 Experimental group

The experimental group was used to investigate the effect of hands-on laboratory activities on the academic performance of students in acid-base titration and neutralisation. This set of students participated in well-structured, regular laboratory activities that provided practical experiences with acid-base titration and neutralisation. The researcher implemented laboratory teaching and learning of titrimetric analyses by using a five weeks’ lesson plan with a maximum of 60 minute per each lesson. In the first week, Students were taught some of the rudiments and precautions to be taken during acid - base titration. The researcher put the students into ten groups of a maximum number of five students per each group. The under listed were some of the precautions the researcher took the students through:

1. Unless otherwise stated, it is usual that:

(i) The acid is put in the burette. **Reason**: The acid will not react with the glass or stop cork of the burette.

(ii) The alkali is normally put into the conical flask but **not** the burette. **Reason**: The alkali will react with the glass or stop cork of the burette if put in it. **Note**: If alkali is put in the burette, it must be washed thoroughly with plenty water immediately after use.

2. Rinse the burette with the acid solution to be used and fill it again with the same acid solution and adjust it to a convenient level. **Reason:** The rinsing is

necessary in order not to decrease the concentration of the acid by the water left on the sides of the burette after washing with distilled water.

3. Rinse a 20cm^3 or 25cm^3 pipette with the solution of the base (or acid) to be pipette. **Reason**: The rinsing is necessary in order not to decrease the concentration of the base (or acid) by the water left on the sides of the pipette after washing with water. Pipette out 20cm^3 or 25cm^3 portions of the base into three clean conical flasks.
4. The acid used for rinsing the burette should not be poured back into the given acidic solution

   Reason: This is to avoid diluting the acid with drops of water that might sticks to the sides of the burette when washed with water.

5. The base used for rinsing the pipette should not be poured back into the giving alkali solution.

   Reason: This is to avoid diluting the base with drops of water that might sticks to the sides of the pipette when washed with water.

6. Two or three drops of a suitable indicator are added to the pipetted solution, that is, small quantity of the indicator is used. **Reason**: To obtain sharp and clear colour change at the end point.
7. The acid is run gradually and carefully from the burette to the base in the flask and not added from a measuring cylinder. **Reason**: This is to ensure higher accuracy in the volume of acid used. Since the burette can be easily manipulated for drop-wise addition and for easier end point than a measuring cylinder.

8. A piece of white tile is usually placed under the conical flask during titration. **Reason**: This is to detect the end-point or to see colour change clearly.
9. The burette readings should be correct to two decimal places. **Reason**: This is the highest degree of accuracy the burette in school can record. **Note**: Titre values that are not consistent should not be averaged
10. At least two sets of readings should be obtained for the titration experiment. **Reason**: In order to get accurate titre values
11. The burette should be rinsed with solution to be put in it before use. **Reason:** This ensures that any residual water or other substances in the burette do not dilute or contaminate the solution, which could affect the accuracy of the titration
12. The pipette should be rinsed with solution be pipette before use. **Reason**: This ensures that the concentration of the solution remains consistent and is not altered by any leftover water or other solutions.
13. One needs to ensure that the burette does not leak. **Reason**: small leaks can lead to inaccuracies in the volume readings, which would compromise the titration results.
14. The funnel should be removed after filling the burette. **Reason**: Leaving the funnel in the burette can lead to unintended drips, causing the volume to change and leading to inaccurate measurements.
15. The conical flask should be washed / rinsed with distilled water only. **Reason:** Any water in the conical flask does not affect the outcome since it does not change the number of moles of the analyte or the titrant.
16. The reaction depends only on the amount of substance delivered, not the volume of liquid in the flask.

17. When filling the burette and pipette one needs to avoid trapping air bubble.

    Reason: Air bubbles trapped in the burette or pipette can significantly affect the accuracy of volume measurements.

Figures 1, 2, and 3 respectively, depict the equipment, steps, and safety measures that must be followed.

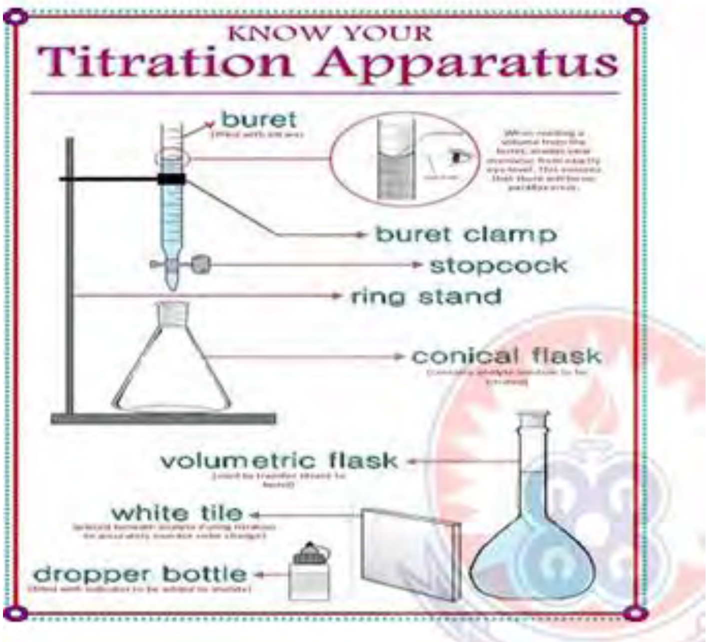

Figure 1: Titration Apparatus

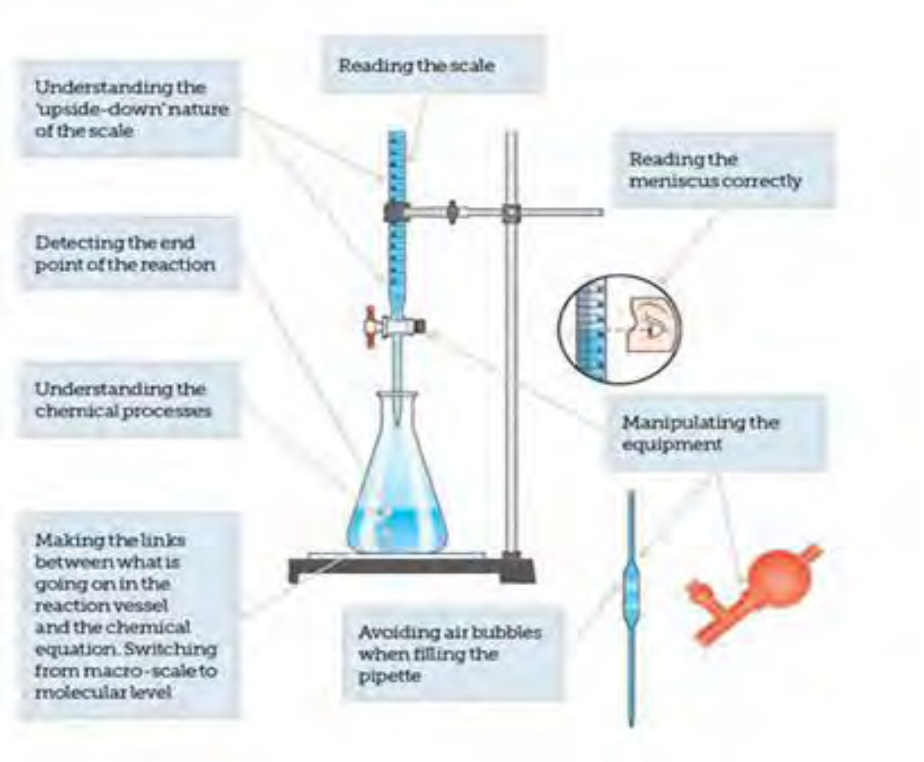

Figure 2: Some Manual Skills in Titration

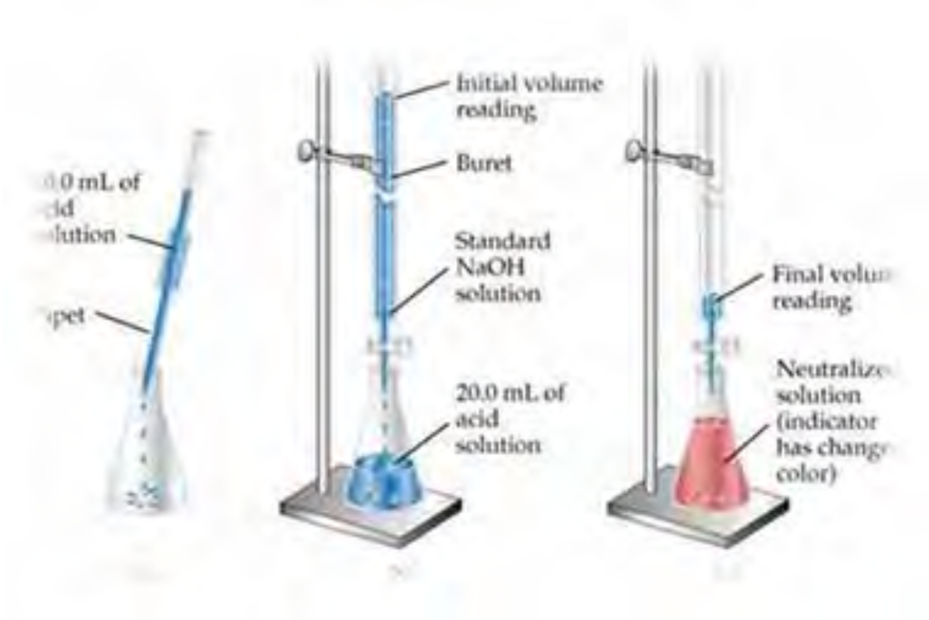

Figure 3: Set-up and procedure in titration process

The researcher used the second week to help students identify the choice of indicators been used in acid base titration as shown in Table 1.

Table 1: Suitable indicators for acid-base titrations

Titration	Acid-base indicator	Nature of salt formed on the titration
1.Strong acid against strong base e.g. $HCl_{(aq)}$ and $NaOH_{(aq)}$	Methyl orange or phenolphthalein	Neutral Reason: Ions (Na^+ and Cl^-) from the salt (NaCl) formed in the titration do not hydrolyse. Eg. $NaOH + HCl \rightarrow NaCl + H2O$ $NaCl(aq) \rightarrow Na^+ (aq) + Cl^-(aq)$
2.Strong acid against weak Base e.g. $HCl_{(aq)}$ and $NH_{3(aq)}$	Methyl orange	Acidic Reason: The cation ($NH4^+$) from the salt (NH_4Cl) formed in the titration, undergoes hydrolysis to yield excess $H3O^+$ making the solution acidic. Eg. $HCl + NH_3 \rightarrow NH_4Cl$ $NH_4Cl_{(aq)} \rightarrow NH_4^+{}_{(aq)} + Cl^-$ $NH_4+_{(aq)} + H_2O \leftrightarrow NH_3(aq)+H_3O+(aq)$
3. Weak acid against strong base e.g. $CH_3COOH_{(aq)}$ and $NaOH_{(aq)}$	Phenolphthalein	Basic Reason: The anion (CH_3COO^-) from the salt (CH_3COONa) formed in the titration hydrolyses to yield excess OH- making the solution basic. Eg. $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$ $CH_3COONa(aq) \rightarrow CH3COO^-(aq) + Na^+ (aq)$ $CH3COO^-_{(aq)} + H2O \leftrightarrow CH3COOH_{(aq)} + OH^-$
1. Weak acid against weak base e.g. $CH_3COOH_{(aq)}$ and $NH3_{(aq)}$	No suitable indicator	

Recording and Treatment of Titration data was done in week four as the researcher guided the students on how to record titration values as shown in the Table 2.

Table 2: A hypothetical table for recording an acid – base titration data

Burette readings (cm^3)	1st Titration	2ndTitration	3rd Titration
Final	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_3}$
Initial	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$
Volume of acid used (titre)	$\mathbf{A_1\text{-}B_1}$	$\mathbf{A_2\text{-}B_2}$	$\mathbf{A_3\text{-}B_3}$

If for example, the 1st and 2nd titrations are consistent, then

$$\text{Average volume of acid used} = \frac{(\mathbf{A1-B1})+(\boldsymbol{A2-B2})}{2}$$

In week four, the researcher gave the students instructions on how to balance chemical equations by guiding them to follow these steps:

Step 1: Students were instructed to use the appropriate chemical formula for each reactant and product when writing the unbalanced equation.

Step 2: In order to determine the appropriate coefficients, which were the numbers placed before chemical formulas to indicate how many units of each substance were needed to balance the equation.

Step 3: If required, they were to divide the coefficients by a common factor to reduce them to their smallest whole-number values.

Step 4: Finally, they were taught to check their answers to make sure that the numbers and kinds of atoms were the same on both sides of the equation. Examples of some balanced chemical equations are shown below.

(a). $NaOH + HCl \rightarrow NaCl + H_2O$

(b). $NaOH + HNO_3 \rightarrow NaNO_3 + H2O$

(c) $Na_2CO_3 + HNO_3 \rightarrow NaNO_3 + H_2O + CO_2$

Approaches Used in the Computation of Solution Concentration was done in week five. The researcher in his lesson explained to students the two major methods of standardizing solutions. Thus first principle method and mole ratio method. The researcher made the students aware that there are several methods that could be employed in standardization of solutions in volumetric analysis but only two would be considered. The standardization of solutions must usually be given to three significant figures.

Suppose a titration is carried out between solution A HCl) in a burette and solution B (NaOH) in a conical flask and the following results were obtained:

Average titre (V_A) = 23.00cm^3

Concentration of HCl (C_A) = 0.100 moldm^{-3} (3 significant figures)

Volume of NaOH used (V_B) = 25.00cm^3

Concentration of NaOH (C_B) =?

1. Using the First Principle method:

1000 cm^3 of HCl contains 0.100 mole HCl

$\therefore$ 23 cm^3 of HCl contains $\frac{23}{1000} \times 0.100 = 0.0023$ moles of HCl

Equation for the reaction is $HCl + NaOH \rightarrow NaCl + H2O$

From the equation, 1 mole of HCl ≡ 1 moles of NaOH

$\therefore$ 0.0023 mole of HCl $= \frac{0.0023 \ x \ 1}{1}$ 0.0023 mole of NaOH

Thus 25 cm^3 of NaOH contains 0.0023 mole of NaOH

$\therefore$ 1000cm3 of NaOH would contain$\frac{1000\ x\ 0.0023}{25}$ = 0.092 mol of NaOH

Thus concentration of NaOH = 0.092 moldm^{-3} (3 significant figures)

2. Mole ratio method.

Number of moles (n) = Concentration (mol dm^{-3}) × Volume (dm^{3})

Number of moles of HCl (n_A) = C_AV_A

Number of moles of NaOH (n_B) = C_BV_B

C_A = 0.1 mol dm^{-3}; V_A = 23.00 cm^{3}; V_B = 25 cm^{3}; C_B =?

Equation for the reaction is $HCl + NaOH \rightarrow NaCl + H2O$

From the equation, $nA = 1$, $nB = 1 \Rightarrow \frac{1}{1} = \frac{1}{1}$

$$\therefore \frac{CAVA}{CBVB} = \frac{1}{1} \Longrightarrow C_B = \frac{1X\ CAVA}{VB} = \frac{1X\ 0.100X23}{25} = 0.092\ \text{moldm}^{-3}$$

Following the guided practice, the researcher created opportunities for independent experimentation, where students were allowed to conduct titrations on their own. At this stage, the researcher assumed a more observational and facilitative role monitoring progress, encouraging autonomy, and offering assistance only when necessary. This approach gave students the chance to apply what they had learned from demonstrations and guided practice through trial and error. Through this independent engagement, students deepened their understanding of key concepts such as molarity, neutralisation reactions, and equivalence points. In addition to encouraging a sense of ownership and accountability in their learning, the method promoted the development of critical thinking, problem-solving, and active learning skills.

3.8.6 Observing the intervention

The researcher closely observed all activities during the teaching and learning process as students engaged in laboratory-based activities on acid-base titration and neutralisation. The researcher systematically monitored and recorded students' responses, practical skills and conceptual understanding as they performed titrimetric experiments.

Observational notes were also taken on students' participation, accuracy in titration procedures and their ability to interpret results. In addition, the researcher created a supportive and interactive learning environment to enhance students' motivation and engagement. This included offering guidance, addressing individual learning difficulties during the experiments and providing constructive feedback to reinforce effort and correct misconceptions. These laboratory activities were instrumental in improving students' academic performance by deepening their understanding of neutralisation reactions, enhancing their procedural competencies and fostering analytical thinking through hands-on experience.

3.8.7 Reflecting on the intervention

Reflection was conducted to identify areas of challenge and areas of enhancement in the teaching and learning process of acid-base titration and neutralisation. Based on classroom observations, the researcher critically evaluated the implementation process to uncover any flaws or teaching gaps that may have affected students' understanding or engagement. This reflective process provided a foundation for enhancing future instructional designs and pedagogical practices. The results of the assessment informed necessary adjustments to enhance the subsequent cycle of instruction to further suit the academic requirements of the students in the laboratory through targeted and responsiveness.

3.8.8 Revising the intervention plan

After the identified weaknesses during conducting the first activity, the researcher modified the instructional plan for the subsequent cycle. This was intended to rectify the observed challenges and improve the quality of the teaching strategy. Just like the character of classroom action research, the process was designed in such a way that it would be one or several cycles. These were to be repeated until the targeted research objectives had been achieved. Each cycle built on learning from the previous one, allowing continuous refinement in the pedagogical approach to improve student comprehension and academic success in acid-base titration and neutralisation.

3.8.9 Post- Intervention Stage

The post-intervention stage of the study involved monitoring the effects of the intervention strategies on the acquisition and development of requisite scientific process skills, conceptual understanding and performance by the students. At this stage, the post-intervention test (Test 2) was administered to the sample of the study.

3.9 Data Analysis

Before analysis, every piece of data was carefully examined for accuracy, consistency and completeness. The descriptive and inferential functions of the Statistical Package for Social Sciences (SPSS) version 27 were used to analyse the data. Specifically, questionnaire responses were analysed using descriptive statistics, while the test scores were subjected to inferential statistical analysis. The analyses of each data set are presented in the following sub-sections.

3.9.1 Questionnaire data

Prior to the analysis, each questionnaire item was coded and entered into SPSS version 27, with numerical values assigned to the Likert scale options (for example, 1 =

Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree) to facilitate the computation of descriptive statistics. The questionnaire data were cross-checked by the researcher to ensure completeness before analysis. Data collected on students' perceptions and difficulties regarding acid-base titration and neutralisation concepts were analyzed using the descriptive function of the Statistical Package for Social Sciences (SPSS) version 27. For easy interpretation, strongly agree and agree responses by participants were considered as agree whereas strongly disagree and disagree were considered as disagree. The data was organised into frequency counts, percentages, mean scores and standard deviation. For perception items, a mean score of more than 3 signified positive perception, less than 3 was negative perception and 3 was interpreted as neutral. Similarly, for difficulty items, more than 3 was taken as high in difficulty, less than 3 as low difficulty and 3 as moderate difficulty. Prior to the analysis, each questionnaire item was coded and entered into SPSS version 27 with numerical values assigned to the Likert scale options (for example, 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree) to facilitate computation of descriptive statistics.

3.9.2 Observation Checklist

The observation checklist was employed to confirm the behavioural and practical skills that students exhibited during laboratory sessions. It consisted of binary items (Yes/No) that reflected key observable indicators such as engagement, conceptual understanding, and competence in handling acid–base reactions. During the practical activities, the researcher recorded a tick (√) whenever a student displayed a particular behaviour or skill. The responses were first tallied into frequencies and subsequently converted into percentages to allow for easier comparison across items. For interpretation, percentage frequencies were adopted as the basis of analysis, since they provide a clearer picture of overall patterns than raw counts. Consistent with educational evaluation guidelines, where a 70% cut-off is widely considered a mark of proficiency or mastery (Bloom, 1976; Gronlund & Brookhart, 2009), the study applied the following classification: High competence (≥70%), Moderate competence (50–69%), and Low competence (<50%). This scale offered a systematic framework for judging students' observed competencies and for identifying areas where additional instructional support was needed.

The results in table 4 indicated that problem-solving skills (74.5%) and ability to follow instructions (70.9%) both exceeded the 70% threshold, placing them in the high-competence category. By contrast, students exhibiting their practical laboratory skills obtained 54.5%, which falls within the moderate-competence range. This outcome suggests that while students generally excelled in cognitive and procedural domains, they were less confident and consistent in hands-on laboratory tasks. The gap in practical competence points to the need for more targeted instructional reinforcement during laboratory work. Overall, the observation data confirmed that students had stronger abilities in problem-solving and compliance with instructions but required additional support in applying these skills practically.

3.9.3 Pre- intervention test and post-intervention test

Pre-test and post-test data were analyzed to determine how effective the educational intervention was. Descriptive statistics such as mean scores and standard deviation were calculated separately for the pre-test and post-test. Analysis of covariance (ANCOVA) was used to determine whether there was any difference in performance between the experimental group and the control group. According to Mayers (2013), Analysis of Covariance (ANCOVA) is a versatile statistical technique that can be applied in various research contexts. It is particularly useful for comparing post-test outcomes while statistically controlling for pre-test differences, thereby reducing error variance and accounting for the influence of confounding variables that were not controlled physically. In this study, a statistically significant increase in post-test mean scores ($p < 0.05$), after adjusting for pre-test scores, was interpreted as evidence that the intervention positively influenced students' academic performance.

Prior to conducting the ANCOVA, key assumptions were assessed to ensure the validity of the analysis. The assumption of independence of observations was met, as students were assigned to intact classes and had no interaction across groups during the intervention. Normality of residuals was verified through the Shapiro-Wilk test and Q-Q plots, indicating that residuals were approximately normally distributed. The assumption of linearity between the covariate (pre-test scores) and the dependent variable (post-test scores) was confirmed through scatterplot inspection. In testing for the homogeneity of regression slopes, an interaction term between group and pre-test scores was included and found to be non-significant ($p > 0.05$), satisfying this critical requirement. Levene's Test of Equality of Error Variances confirmed homoscedasticity, as the variances across groups were not significantly different. Additionally, the pre-test instrument demonstrated acceptable reliability with a Cronbach's alpha of 0.81, and pre-test data were collected prior to the intervention, satisfying the requirement that the covariate preceded the treatment. Following confirmation that all assumptions were adequately met, the ANCOVA analysis was performed. The results of the analysis were presented in a table.

3.9.10 Ethical Considerations

An introductory letter was obtained from the Department of Integrated Science Education which was used to obtain permission from the school authorities to conduct the study in the school.

First and foremost, participants were informed of the expectations both orally and in writing, and their consent sought. Clear guidelines were provided about the study's objectives and optional research participation. Participants were also told that there was no known risk, discomfort, or negative consequence if they chose to participate in the study or not. Furthermore, they were not coerced into taking part in the research. Participants were told not to write their names on the test sheet in order to conceal their identities and maintain the secrecy and anonymity of their answers.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Overview

This chapter presents and discusses the findings of the study in relation to the three research questions and the null hypothesis formulated. Data were collected using a structured questionnaire administered. The responses from the questionnaire served as the primary source of data for the descriptive statistical analysis. These data were organized into frequencies, mean scores, and percentages to provide an overview of student responses and trends.

Inferential statistical analysis was conducted using pre-test and post-test scores from both the experimental and control groups. These scores were subjected to Analysis of Covariance (ANCOVA) to determine the effect of the teaching intervention on students' academic performance in acid-base titration and neutralisation. The analysis was performed using Microsoft Excel 2016 and the Statistical Package for the Social Sciences (SPSS), version 27. The results of the analysis were presented in tables and described.

4.1 Presentation of Results based on the Research Questions

4.1.1. Research question 1: What are students' difficulties with acid-base titration and neutralisation concept?

The purpose of this research question was to identify the difficulties students encountered in acid-base titration prior to the intervention. To achieve this, a five-point Likert scale questionnaire was administered, designed to assess both conceptual understanding and practical competence. The questionnaire included ten items covering key areas such as understanding the equivalence point, neutralisation reactions, linking theory to practice, apparatus setup, indicator selection, liquid handling, and error minimisation.

Table 3 presents a summary of the experimental group students' self-reported difficulties in acid–base titration prior to the intervention, based on responses to a five-point Likert-scale questionnaire. The table shows the distribution of responses, as well as the mean scores and standard deviations for each item assessing students' conceptual understanding and practical competence.

Table 3: Students' difficulties with acid-base titration and neutralisation in chemistry (Experimental Group, N=55).

		Percentage Frequency Responses				
S/N	Statement	Agree	Neutral	Disagree	Mean	SD
1	I clearly understand the concept of equivalence point in acid-base titration.	10 (18.18)	23 (41.82)	22 (40.00)	1.78	0.73
2	I understand how acid and base neutralize each other in titration	12 (21.82)	21 (38.18)	22 (40.00)	1.82	0.76
3	I can easily relate the theoretical concepts of acid-base titration to the practical experiment.	13 (23.64)	22 (40.00)	20 (36.36)	1.87	0.76
4	I can easily determine the endpoint during the titration process	9 (16.36)	24 (43.64)	22 (40.00)	1.76	0.71
5	I can accurately select the correct indicator for different acid-base titrations.	11 (20.00)	23 (41.82)	21 (38.18)	1.82	0.74
6	I understand the colour change patterns of indicators used in titration.	10 (18.18)	24 (43.64)	21 (38.18)	1.80	0.73
7	I can confidently and correctly set up the apparatus for acid-base titration.	12 (21.82)	22 (40.00)	21 (38.18)	1.84	0.74
8	I can manage my time effectively during titration experiments.	11 (20.00)	23 (41.82)	21 (38.18)	1.82	0.74
9	I can accurately measure and handle liquids during the titration experiment.	9 (16.36)	24 (43.64)	22 (40.00)	1.76	0.71
10	I can identify and minimize errors effectively during the acid-base titration experiment.	10 (18.18)	23 (41.82)	22 (40.00)	1.78	0.73

Source: field data, 2025. * Percentages in parentheses

A close examination of students' responses revealed widespread conceptual and procedural difficulties in understanding acid–base titration and neutralisation. Overall, the data indicate significant gaps in both foundational knowledge and essential laboratory skills required for successful titration practice. These deficiencies were evident across key conceptual areas such as equivalence point, neutralisation reactions and theory to practice integration, as well as practical competencies including endpoint identification, indicator selection, apparatus setup, measurement accuracy, time management and experimental errors control.

In terms of conceptual understanding, students demonstrated limited knowledge of the equivalence point, neutralisation reactions, and the application of theoretical concepts to practical work (Items 1–3). Only a small proportion of students (ranging from 18.18% to 23.64%) indicated understanding of these core ideas, while approximately 78% either remained neutral or disagreed with statements assessing these competencies. The low mean scores (1.78–1.87) suggest weak conceptual clarity. This finding aligns with earlier studies by Kinyota (2019) and Abrahams and Reiss (2017), who reported that students often memorise titration procedures without adequately understanding the underlying chemical principles, particularly the distinction between equivalence point and endpoint. Such misconceptions have been shown to negatively affect experimental accuracy and interpretation of results.

Similarly, students exhibited substantial difficulty with procedural and laboratory skills essential for titration. Confidence levels were particularly low in identifying the endpoint (Item 4), selecting appropriate indicators and interpreting colour changes (Items 5 and 6), setting up titration apparatus (Item 7), measuring and transferring liquids accurately (Item 9), managing time effectively (Item 8), and identifying and minimising experimental errors (Item 10). Across these items, agreement levels remained below 22%, with mean scores clustering between 1.76 and 1.84. These findings support those of Kale et al. (2015) and Hofstein and Lunetta (2004), who found that limited exposure to hands-on laboratory activities restricts students' development of practical competencies and scientific confidence.

The observed disconnect between theoretical instruction and practical application further supports earlier evidence that students often learn chemistry concepts in isolation from laboratory experiences. Studies by Millar (2010) and Kinyota (2020) similarly noted that when laboratory work is not sufficiently student-centred or inquiry-driven, learners struggle to translate abstract concepts into meaningful experimental actions. This lack of integration may explain students' uncertainty in performing titration steps accurately and their inability to recognise or correct experimental errors.

In summary, the findings indicate that students lacked both conceptual understanding and hands-on competence in acid–base titration and neutralisation. The convergence of low conceptual clarity and weak procedural skills underscores the need for instructional approaches that emphasise active laboratory engagement, guided experimentation, and continuous formative feedback. Consistent with previous research, these results suggest that strengthening practical, learner-centred laboratory instruction is critical for improving students' understanding, accuracy and confidence in titration-related chemistry topics.

To further evaluate students' competence during the acid-base titration exercise, their practical performance was assessed across three key domains: problem-solving skills, ability to fellow instructions and practical laboratory skills. These domains provided a holistic view of students' ability to apply theoretical knowledge, follow procedural steps and demonstrate technical proficiency in the laboratory. Problem-solving skills assessed students' capacity to interpret experimental results, perform titration calculations and relate theoretical concepts to practical procedures. Following instructions measured students' adherence to laboratory protocols, safety rules and teacher guidance. Practical laboratory skills evaluated technical execution, including correct handling of apparatus, accurate measurement of solutions and recognition of endpoint colour changes. The results are summarized in Table 4.

Table 4: Percentage frequency of students' performance skills involved in acid-base titration

Domain	Frequency	Percentage
Problem-Solving Skills	41	74.5%
Following Instructions	39	70.9%
Practical Laboratory Skills	30	54.5%

Source: Field data, 2025

The results in Table 4 shows that the highest level of competence was observed in Problem-Solving Skills, demonstrated by 41 students, representing 74.5%. In line with Bloom (1976) and Gronlund and Brookhart (2009), percentage frequencies of 70% and above indicate high competence, 50–69% reflect moderate competence and scores below 50% suggest low competence. Performances in following instructions was also high, with 39 students (70.9%) meeting the proficiency benchmark, indicating that most students consistently adhered to procedures and laboratory safety requirements.

By contrast, the lowest performance was recorded in practical laboratory skills, where 30 students (54.5%) demonstrated competence. This result falls within the moderate competence range, showing that although some students were able to manipulate equipment correctly and take accurate measurements, many experienced difficulties in executing the experiment with precision.

Overall, the data suggest that students were strongest in cognitive and procedural domains, such as problem-solving and compliance with instructions, but less proficient in hands-on laboratory practice. The disparity between theoretical understanding and practical execution highlights the need to provide learners with more opportunities for direct laboratory engagement. These observation results corroborated the questionnaire findings, thereby adding credibility to the overall study conclusions.

Table 5 summarises the control group students' self-reported difficulties in acid–base titration prior to the intervention, based on responses to a five-point Likert-scale questionnaire. The table presents the percentage frequency distribution of students who agreed, neutral or disagreed with each statement, together with the corresponding mean scores and standard deviations. The ten statements assessed both conceptual understanding (such as equivalence point, neutralisation, and indicator behaviour) and practical competence (including apparatus setup, endpoint determination, liquid handling, time management, and error minimisation).

Table 5: Students Difficulties with Acid-Base Titration and Neutralisation (Control Group, N = 55)

S/N	Statement	Percentage frequency responses			Mean	SD
		Agree	Neutral	Disagree		
1	I clearly understand the concept of equivalence point in acid-base titration.	18 (32.73)	20 (36.36)	17 (30.91)	2.02	0.80
2	I understand how acid and base neutralize each other in titration	25 (45.45)	18 (32.73)	12 (21.82)	2.24	0.79
3	I can easily relate the theoretical concepts of acid-base titration to the practical experiment.	23 (41.82)	19 (34.55)	12 (21.82)	2.16	0.78
4	I can easily determine the endpoint during the titration process	14 (25.45)	24 (43.64)	17 (30.91)	1.95	0.75
5	I can accurately select the correct indicator for different acid-base titrations.	14 (25.45)	21 (38.18)	20 (36.36)	1.89	0.78
6	I understand the colour change patterns of indicators used in titration.	19 (34.55)	20 (36.36)	16 (29.09)	2.07	0.79
7	I can confidently and correctly set up the apparatus for acid-base titration.	19 (34.55)	19 (34.55)	17 (30.91)	2.04	0.81
8	I can manage my time effectively during titration experiments.	21 (38.18)	21 (38.18)	13 (23.64)	2.15	0.80
9	I can accurately measure and handle liquids during the titration experiment.	16 (29.09)	20 (36.36)	19 (34.55)	1.95	0.81
10	I can identify and minimize errors effectively during the acid-base titration experiment.	20 (36.36)	18 (32.73)	17 (30.91)	2.10	0.82

Source: field data, 2025. * Percentages in parentheses.

Table 5 presents the control group students' perceived difficulties in acid–base titration and neutralisation prior to the instructional intervention. The results indicate moderate levels of understanding across most conceptual and procedural aspects, although notable gaps remain.

With regard to conceptual understanding, Item 1 examined students' comprehension of the equivalence point. Only 32.73% agreed that they clearly understood the concept, while 30.91% disagreed (Mean = 2.02, SD = 0.80). The near balance between agreement and disagreement suggests uncertainty and incomplete conceptual clarity. The equivalence point is fundamental to accurate titration calculations and difficulty in understanding it may stem from challenges in linking stoichiometric principles to observable laboratory outcomes. This aligns with Johnstone's (2000) assertion that students often struggle to integrate symbolic calculations with conceptual chemical processes.

Similarly, Item 2 assessed understanding of neutralisation reactions. Although a relatively higher proportion (45.45%) agreed that they understood how acids and bases neutralise each other (Mean = 2.24, SD = 0.79), 54.55% of the students were either neutral or disagreed. This suggests that while some foundational knowledge exists, conceptual mastery is not widespread. As noted by Kind (2004), students may memorise definitions of neutralisation without fully grasping the reaction dynamics occurring during titration.

The ability to relate theoretical concepts to practical experiments (Item 3) also showed moderate confidence, with 41.82% agreeing (Mean = 2.16, SD = 0.78). However, the presence of 34.55% neutral responses indicates hesitation in applying theory to laboratory practice. This supports Johnstone's (1991) chemistry triad model, which explains students' difficulty in transitioning between macroscopic laboratory observations and abstract theoretical representations.

Procedural skills revealed additional challenges. Determining the endpoint (Item 4) recorded a relatively low mean (1.95, SD = 0.75), with only 25.45% agreeing they could easily identify it. Since endpoint detection requires careful observation of colour change and precision in titrant addition, the findings suggest limited practical confidence. Likewise, selecting the correct indicator (Item 5) showed one of the lowest mean scores (Mean = 1.89, SD = 0.78), with 36.36% disagreeing. This indicates difficulty in understanding the relationship between indicator properties and the nature of the acid–base reaction, a concern also highlighted by Hofstein and Lunetta (2004), who emphasised the importance of guided laboratory practice in developing procedural competence.

Understanding colour change patterns (Item 6) yielded a moderate mean of 2.07 (SD = 0.79), but with more than one-third of students neutral. This suggests partial familiarity without strong confidence. Similarly, apparatus setup (Item 7) and time management (Item 8) showed moderate means (2.04 and 2.15 respectively), yet a substantial proportion of neutral responses indicates uncertainty in independent laboratory performance.

Accuracy in measuring and handling liquids (Item 9) recorded a mean of 1.95 (SD = 0.81), with 34.55% disagreeing. This highlights concerns about volumetric precision, which is critical in titration experiments. In addition, the ability to identify and minimise errors (Item 10) showed only 36.36% agreement (Mean = 2.10, SD = 0.82), suggesting that metacognitive and reflective laboratory skills were not strongly developed.

Overall, the mean scores (ranging from 1.89 to 2.24) indicate moderate but not robust competence among control group students prior to intervention. While some students demonstrated conceptual and procedural familiarity, significant proportions expressed uncertainty or disagreement across key aspects of titration and neutralisation. These findings reinforce the need for instructional strategies that strengthen both theoretical understanding and hands-on laboratory skills to enhance students' confidence and accuracy in acid–base titration.

4.1.2 Research question 2: What is the effect of laboratory-based instructional activities on students' academic performance in acid-base titration and neutralisation as compared to conventional teaching methods?

This research question was sought to determine the effect of the teaching method (laboratory-based versus conventional) on students' (post-test) academic performance in acid-base titration and neutralisation in chemistry. To assess this, a general test was administered to both the experimental and control groups before and after the intervention to evaluate their understanding and application of the concept. The data from the pre-test and post-test were used to determine the effect of the intervention on the academic performance of the experimental group. To statistically assess the impact of the instructional approach while controlling for initial differences in students' prior knowledge, Analysis of Covariance (ANCOVA) was employed to establish any statistically significant difference between the experimental group and the control group after the intervention. This technique was chosen for its ability to adjust for baseline disparities and isolate the true effect of the intervention on post-test performance (Tabachnick & Fidell, 2013).

Table 6 compares the percentage frequency distribution of test scores obtained by students in the experimental and control groups before and after the intervention. The table presents students' performance across the full range of possible marks, highlighting changes in score distributions from the pre-test to the post-test. In addition, the table reports the mean scores and standard deviations for each group, providing an overall summary of performance and score variability before and after the intervention.

Table 6: Percentage frequencies of experimental group and control group pre-intervention and post-intervention test scores

Marks	Experimental Pre-Test	Control Pre-Test	Experimental Post-Test	Control Post-Test
0	2 (3.64%)	1 (1.82%)	0 (0.00%)	0 (0.00%)
1	3 (5.45%)	3 (5.45%)	0 (0.00%)	0 (0.00%)
2	8 (14.55%)	5 (9.09%)	0 (0.00%)	0 (0.00%)
3	10 (18.18%)	8 (14.55%)	0 (0.00%)	0 (0.00%)
4	12 (21.82%)	10 (18.18%)	0 (0.00%)	0 (0.00%)
5	6 (10.91%)	11 (20.00%)	0 (0.00%)	0 (0.00%)
6	5 (9.09%)	9 (16.36%)	0 (0.00%)	0 (0.00%)
7	0 (0.00%)	5 (9.09%)	0 (0.00%)	0 (0.00%)
8	0 (0.00%)	3 (5.45%)	0 (0.00%)	0 (0.00%)
9	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
10	0 (0.00%)	0 (0.00%)	1 (1.82%)	1 (1.82%)
11	3 (5.45%)	4 (7.27%)	0 (0.00%)	0 (0.00%)
12	4 (7.27%)	3 (5.45%)	1 (1.82%)	1 (1.82%)
13	3 (5.45%)	4 (7.27%)	0 (0.00%)	1 (1.82%)
14	4 (7.27%)	3 (5.45%)	1 (1.82%)	0 (0.00%)
15	3 (5.45%)	4 (7.27%)	0 (0.00%)	0 (0.00%)
16	3 (5.45%)	3 (5.45%)	1 (1.82%)	0 (0.00%)
17	4 (7.27%)	3 (5.45%)	0 (0.00%)	1 (1.82%)
18	4 (7.27%)	4 (7.27%)	1 (1.82%)	1 (1.82%)
19	2 (3.64%)	2 (3.64%)	0 (0.00%)	0 (0.00%)
20	1 (1.82%)	1 (1.82%)	0 (0.00%)	0 (0.00%)
21	4 (7.27%)	5 (9.09%)	1 (1.82%)	2 (3.64%)
22	4 (7.27%)	5 (9.09%)	1 (1.82%)	1 (1.82%)
23	3 (5.45%)	5 (9.09%)	2 (3.64%)	2 (3.64%)
24	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

Marks	Experimental Pre-Test	Control Pre-Test	Experimental Post-Test	Control Post-Test
25	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
26	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
27	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
28	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
29	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
30	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
31	0 (0.00%)	0 (0.00%)	5 (9.09%)	6 (10.91%)
32	0 (0.00%)	0 (0.00%)	6 (10.91%)	7 (12.73%)
33	0 (0.00%)	0 (0.00%)	4 (7.27%)	5 (9.09%)
34	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
35	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
36	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
37	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
38	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
39	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
40	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
41	0 (0.00%)	0 (0.00%)	8 (14.55%)	10 (18.18%)
42	0 (0.00%)	0 (0.00%)	12 (21.82%)	11 (20.00%)
43	0 (0.00%)	0 (0.00%)	15 (27.27%)	10 (18.18%)
44	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
45	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
46	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
47	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
48	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
49	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
50	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Total	**55**	**55**	**55**	**55**
Mean	**14.64**	**16.09**	**40.27**	**39.36**
SD	**6.60**	**6.52**	**7.10**	**7.33**

Source: Field data, 2025

Table 6 presents the frequency distribution of scores for both the experimental and control groups before and after the intervention. The results reveal a marked difference in performance patterns across the two groups.

Before the intervention, both groups recorded generally low scores, with several students clustered at the lowest levels of achievement. The experimental group recorded a minimum score of 0, attained by two students (3.64%), while the control group also had one student (1.82%) scoring zero. The maximum scores reached by both groups fell within the narrow range of 21–23 marks out of 50, achieved by only 3–5 students (5–9%). This shows that although a few students demonstrated partial understanding, the majority struggled with fundamental concepts of titration and neutralisation prior to intervention. The mean score for the experimental group was 14.64 (SD = 6.60) and that of the control group was slightly higher at 16.09 (SD = 6.52). These variations in means scores suggest not only low performance but also considerable variation in ability levels within each group.

After the intervention, the score obtained by the stdents shifted substantially upward for both groups. In the experimental group, scores ranged from 10 to 43, while the control group also recorded a minimum of 10 and a maximum of 43. Notably, very few students remained at the lowest end, as only one student (1.82%) in each group scored 10 marks. At the upper end, however, the gains were more striking: 15 students (27.27%) in the experimental group achieved the highest observed score of 43 marks compared with 10 students (18.18%) in the control group. This indicates that a larger proportion of experimental students attained mastery-level performance.

The improvement is further reflected in the mean scores. The experimental group mean rose from 14.64 to 40.27, representing a gain of about 25.6 marks, while the control group mean increased from 16.09 to 39.36, an improvement of 23.3 marks. Although both groups benefitted from the teaching interventions, the experimental group outperformed the control group in terms of average score and the proportion of students reaching the maximum score. The results highlight two important observations. First, both traditional and laboratory-based instructional strategies contributed to substantial learning gains, as evidenced by the upward shift in mean scores and the reduction of extremely low marks. Second, the experimental group benefitted more from the laboratory-based instructional strategy. More students in this group reached mastery-level scores, and the mean score improvement was slightly greater than that of the control group.

These results suggest that experiential, hands-on learning environments not only enhance conceptual understanding but also improve students' confidence and accuracy in performing titration experiments. By actively engaging with apparatus, indicators, and procedures, learners in the experimental group were able to consolidate theoretical knowledge and apply it more effectively. This aligns with constructivist learning principles, which emphasise that active participation and problem-solving in authentic contexts foster deeper learning and improved performance. An analysis of covariance (ANCOVA) was also conducted on the mean scores of the experimental and the control group to determine any significance between them. The results are presented in Table 7.

Table 7: Results of analysis of covariance (ANCOVA) on the effect of teaching method on student's post-test scores

Source	Type III SS	df	Mean Square	F	Sig.	Partial Eta²
Intercept	9853.497	1	9853.497	1250.747	.000	.922
Pre-Test (Covariate)	6355.145	1	6355.145	806.686	.000	.884
Group(teaching method)	30.398	1	30.398	3.858	.052	.035
Group * Pre-Test	0.060	1	0.060	0.008	.931	.000
Error	835.078	106	7.878			

*df=degree of freedom. Source field data, 2025

The results indicate that pre-test scores (covariate) had a statistically significant effect on post-test scores, F(1, 106) = 806.686, p < .000, Partial Eta² = .884. This very large effect size suggests that prior knowledge accounted for a substantial proportion of the variance in post-test performance. In practical terms, students who performed well in the pre-test were highly likely to perform well in the post-test. This finding supports the view that prior knowledge is a powerful predictor of academic achievement (Chatterji, 2003). It is also consistent with constructivist learning theory, which posits that new knowledge is built upon existing cognitive structures (Bransford, Brown, & Cocking, 2000). In chemistry education specifically, prior conceptual understanding significantly influences students' ability to grasp abstract topics such as stoichiometry and acid–base reactions (Johnstone, 2000). The magnitude of the effect observed in this study underscores the central role of foundational knowledge in mastering acid–base titration.

With respect to the main effect of teaching method (Group), the results show F(1, 106) = 3.858, p = .052, Partial Eta² = .035. Although the p-value (.052) is slightly above the conventional alpha level of .05, indicating that the effect is not statistically significant, it is very close to the threshold, suggesting a marginal trend toward significance. The partial eta squared value of .035 represents a small effect size. According to Cohen's (1988) benchmarks for interpreting effect sizes, this magnitude falls within the small range, yet small effects in educational research can still carry practical importance, particularly in authentic classroom contexts (Hattie, 2009).

The near-significant trend favouring laboratory-based instruction aligns with prior research emphasizing the value of practical work in science education. Hofstein and Lunetta (2004) argue that laboratory experiences enhance students' conceptual understanding and engagement when properly structured. Similarly, Prince and Felder (2006) contend that active, student-centred instructional approaches tend to yield better learning outcomes than traditional lecture-based methods. Although the present study did not reach statistical significance at the .05 level, the direction of the effect suggests that laboratory-based instruction may provide incremental benefits beyond conventional teaching.

The interaction between pre-test scores and teaching method was not statistically significant, F(1, 106) = 0.008, p = .931, Partial Eta² = .000. This confirms the assumption of homogeneity of regression slopes, meaning that the relationship between pre-test and post-test scores was consistent across both instructional groups. In other words, the effect of prior knowledge on post-test performance did not vary according to teaching method. This finding supports Field's (2018) assertion that ANCOVA assumptions must be satisfied to ensure valid interpretation of group effects. The absence of interaction also suggests that the instructional method did not differentially benefit students based on their initial achievement levels.

Overall, the findings demonstrate that pre-test performance was the dominant predictor of post-test achievement, while the teaching method did not produce a statistically significant difference at the 0.05 level. However, the near-significant p-value and small effect size indicate a possible instructional influence that may become statistically meaningful with a larger sample size or longer intervention period. This interpretation is consistent with Millar (2010), who notes that the effectiveness of laboratory activities depends on duration, structure, and the extent to which students actively engage in inquiry rather than procedural imitation.

In summary, while prior knowledge significantly influenced students' learning outcomes in acid–base titration and neutralisation, the laboratory-based instructional approach showed a promising but inconclusive effect. These findings reinforce existing literature that highlights both the importance of foundational knowledge and the potential value of well-designed practical activities in improving chemistry achievement.

4.1.3 Research question 3: What are students' perceptions about laboratory activities in teaching and learning acid-base titration and neutralisation?

The purpose of this research question was to explore and understand students' perceptions regarding the use of laboratory-based instruction in teaching the concept of acid-base titration and neutralization. Specifically, it aimed to determine whether students perceived these practical activities as beneficial in enhancing their understanding, engagement and ability to apply the concepts in real-life or academic contexts. A five-point Likert type scale questionnaire was administered to both the experimental group.

Table 8 summarises the percentage frequency distribution of students’ responses in the experimental group regarding to their perceptions of acid–base titration and neutralisation following exposure to laboratory-based instruction.

Table 8: Percentage frequency distribution of student's responses on their perception with acid-base titration and neutralization (Experimental Group, N=55)

S/N	Statement	Percentage frequency Responses				
		Agree	Neutral	Disagree	Mean	SD
1	Performing titration in the laboratory helps me retain the concept longer.	29 (26.36)	25 (22.73)	56 (50.91)	2.60	1.34
2	I believe laboratory activities are good ways to learn about acid-base reactions.	69 (62.73)	19 (17.27)	22 (20.00)	3.68	1.29
3	I understand neutralisation better when it is taught through laboratory activities.	67 (60.91)	26 (23.64)	17 (15.45)	3.64	1.18
4	I can now confidently and independently perform titration experiment after going through laboratory activities.	66 (60.00)	15 (23.64)	29 (26.36)	3.46	1.36
5	Doing practical experiments increases my interest in learning chemistry.	61 (55.45)	29 (26.36)	20 (18.18)	3.61	1.25
6	Laboratory activities enable me value titration beyond the classroom.	31 (28.18)	22 (20.00)	57 (51.82)	2.59	1.35
7	Through laboratory activities, titration is an important skill for my future science-related careers.	35 (31.82)	21 (19.09)	54 (49.09)	2.62	1.36
8	The concept of acid-base neutralization is useful in real-life situations.	67 (60.91)	22 (20.00)	21 (19.09)	3.71	1.26
9	Learning about titration will help me see how chemistry works outside the classroom.	62 (56.36)	26 (23.64)	22 (20.00)	3.61	1.24
10	Acid-base titration and neutralization can help me understand chemical reactions.	66 (60.00)	24 (21.82)	20 (18.18)	3.71	1.25

*Percentages in parentheses.

The data in Table 8 indicate that students in the experimental group generally held a positive perception of the laboratory based pedagogy employed in teaching acid base titration and neutralisation. Mean scores for perception items ranged from 2.59 to 3.71. Following Kale et al. (2015), scores above 3.00 indicate positive perception, scores of 3.00 reflect neutrality, and scores below 3.00 suggest negative perception. Using this framework, the majority of items (Items 2, 3, 4, 5, 9, and 10) fall within the positive perception range, indicating that students valued hands on laboratory experiences, although some items reveal areas for further pedagogical attention.

A closer examination shows that six of ten items recorded mean scores above 3.00, reflecting generally positive perceptions. For instance, Item 2, assessing students' views on the effectiveness of laboratory activities for learning acid base reactions, recorded a mean of 3.68, with approximately 62.7% of students in agreement. Similarly, Item 3, which probed whether neutralisation concepts are better understood through experiments, yielded a mean of 3.64 (60.91% agreement). The highest rated item, Item 10, assessing whether laboratory activities facilitated understanding of chemical reactions, achieved a mean of 3.71, with 60.00% agreement. These findings suggest that students recognised the cognitive benefits of experiential learning, consistent with constructivist theory, which posits that learners build deeper understanding when actively engaged in real world tasks (Piaget, 1952; Vygotsky, 1978).

Positive perceptions were also evident in motivation and relevance to learning. Item 5, measuring students' interest in chemistry as influenced by practical work, and Item 9, evaluating the perceived connection between titration and real world experiences, both recorded means of 3.61, with over 55% agreement. Item 4, concerning students' confidence in conducting titrations independently, achieved a mean of 3.46, indicating that structured laboratory activities supported procedural confidence. These findings align with Hofstein and Lunetta (2004), who emphasised that hands on laboratory instruction not only reinforces conceptual understanding but also enhances learner engagement and self-efficacy in scientific practice.

However, not all responses were positive, suggesting a nuanced perception. Item 1, examining students' views on long term retention of concepts through laboratory work, had a mean of 2.60, with only 26.36% agreement and over 50% disagreement. Similarly, Item 6, exploring the relevance of titration outside the classroom, recorded the lowest mean (2.59), with just 28.18% agreement. Item 7, assessing the perceived importance of titration for future science related careers, also scored low (mean = 2.62), with 49.09% disagreement. These findings suggest that while students enjoyed and engaged with practical activities, they were less certain about the enduring conceptual benefits or broader applicability of the skills acquired. This aligns with observations by Kale et al. (2015) and Millar (2010), who reported that students often perceive laboratory tasks as enjoyable but struggle to connect them to long term learning outcomes or real world contexts without explicit guidance.

The variability in responses, reflected in standard deviations ranging from 1.19 to 1.37 and notable neutral responses (13.64–26.36%), may be attributed to factors such as previous exposure to laboratory work, differential instruction quality, access to materials, or limited understanding of real life applications. These findings highlight the importance of instructional strategies that not only involve students in laboratory activities but also explicitly link these experiences to theoretical principles and professional contexts, thereby strengthening both retention and perceived relevance.

Overall, the data suggest that students in the experimental group held generally positive perceptions of laboratory based instruction, with seven out of ten items exceeding the neutral benchmark of 3.00. Students particularly valued the enhancement of conceptual understanding, engagement, and interest in chemistry through hands on activities. However, areas of concern, including long term retention, real world relevance, and career applicability, indicate that further scaffolding and explicit connections between laboratory practice and broader scientific contexts are necessary. These results corroborate prior research advocating for constructivist, inquiry driven laboratory instruction to foster not only engagement and motivation but also meaningful learning and skill transfer (Hofstein & Lunetta, 2004; Millar, 2010; Kale et al., 2015).

4.2 Summary of Findings

The findings from the study revealed that:

1. Prior to the intervention, students demonstrated considerable conceptual and procedural challenges in understanding acid–base titration and neutralisation. In the experimental group (Table 3), mean scores for all ten items fell within a narrow range of 1.76 to 1.87. Levels of agreement were generally low (≤22%), indicating limited grasp of essential concepts such as identifying the equivalence point, describing the process of neutralisation, and linking theoretical principles to practical applications. Difficulties were also evident in laboratory skills, including detecting endpoints, selecting and interpreting indicators, setting up apparatus correctly, handling solutions accurately, managing time efficiently, and reducing experimental errors.

   The control group (Table 5) showed slightly higher mean scores (1.89–2.24), yet responses still reflected modest understanding, with many students remaining neutral or disagreeing on several items. In comparism, the results suggest that both groups encountered substantial learning difficulties, though the experimental group reported greater challenges on nearly all items.

2. Both groups showed substantial improvement from the pre-test to the post-test (Table 6). In the experimental group, mean scores rose from 14.64 (SD = 6.60) at pre-test to 40.27 (SD = 7.10) at post-test, while the control group improved from 16.09 (SD = 6.52) to 39.36 (SD = 7.33). The minimum pre-test score was 0 marks in both groups. A total of 15 students in the experimental group achieved the maximum score of 43 marks compared to 10 students in the control group, thereby suggesting a slight performance advantage for the laboratory-based approach. Also, ANCOVA results (Table 7) showed that students' prior knowledge was the strongest factor influencing post-test performance, $F(1,106) = 806.686$, $p < .001$, partial $\eta^2 = .884$. This means that students who scored higher in the pre-test generally maintained that advantage after the intervention. The type of teaching method did not reach statistical significance at the 0.05 level, $F(1,106) = 3.858$, $p = .052$, although the small effect size (partial $\eta^2 = .035$) suggested a modest benefit for the laboratory-based group.
3. Perception data revealed that students generally held positive views toward laboratory activities. In the experimental group (Table 8), mean scores ranged from 2.59 to 3.71. Concepts such as acid–base reactions, understanding neutralisation through experiments, heightened interest, and perceived real-world applications (Items 2, 3, 5, 9, and 10) each recorded mean scores above 3.00, reflecting favourable perceptions. However, some reservations were noted regarding long-term retention, the value of laboratory activities beyond the classroom, and their relevance to career aspirations (Items 1, 6, and 7), which all recorded mean scores below 3.00.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Overview

This chapter presents a summary of the key findings that arouse from the study. The chapter also contains the conclusions and recommendations that were made based on the findings of the study. It again suggests areas for further research.

5.1 Summary

The purpose of this research was to examine the effect of laboratory-based instructional activities on students’ academic performance in acid–base titration and neutralisation at St. Rose’s Senior High School. Specifically, the study aimed at examining: the difficulties and perception students encounter during theory and practical lessons on acid-base titration and the effect of students’ academic performance on acid-base titration and neutralisation. The study adopted a quasi-experimental design using action research approach. The study targeted all form three science students in St. Rose’s Senior High School during the 2024/2025 academic year. This study adopted purposive sampling technique type to select two intact classes of 110 form three science students, 55 students per class. The instruments used to collect data for this study were tests (pre-test and post-test), questionnaires and an observation checklist.

Descriptive statistics were used to organize the sample test scores into mean scores and deviations. Similarly, sample response to the questionnaire items were organized into frequency counts and converted into percentages. Inferential statistics specifically, Analysis of Covariance (ANCOVA) was conducted to compare post-test scores of the laboratory-based and conventional groups while controlling for pre-test differences.

Levels of statistical significance (p-values) and effect sizes (Partial Eta²) were reported to evaluate the magnitude and reliability of the observed effects

5.2 Key findings

The following findings emerged from the study.

5.2.1 Students' Difficulties with in acid–base titration and neutralisation (Experimental group)

From Table 3, prior to the intervention, students in the experimental group exhibited substantial difficulties in both conceptual understanding and practical execution of acid–base titration and neutralisation. Mean scores across all ten perception items ranged narrowly from 1.76 to 1.87, reflecting generally low confidence and competence. Conceptually, fewer than one-quarter of students demonstrated understanding of foundational principles such as the equivalence point, the process of neutralisation, and the ability to link theoretical knowledge to practical application.

Essential laboratory skills, including endpoint detection, selection and interpretation of appropriate indicators, apparatus setup, liquid handling, time management, and error minimization were similarly underdeveloped, with agreement rates below 22%. The majority of students (about 78%) responded "neutral" or "disagree" to key items, signaling uncertainty or lack of skill.

Overall, the results reveal a pronounced gap between theoretical instruction and practical mastery, underscoring the need for targeted, hands-on laboratory activities to strengthen both conceptual clarity and procedural accuracy in titration-related tasks.

5.2.2 Students' Difficulties with in acid–base titration and neutralisation (Control group)

Prior to the instructional intervention, students in the control group exhibited considerable conceptual and procedural weaknesses in acid–base titration and neutralisation. While a moderate proportion demonstrated understanding of concepts such as the equivalence point (32.73%) and neutralisation reactions (45.45%), the majority expressed uncertainty or disagreement, indicating shallow comprehension. The ability to connect theoretical knowledge to practical application was also limited, with about 50% of the students unable to confidently transfer learned concepts into laboratory practice.

Practical competencies were notably underdeveloped. Skills such as endpoint detection, correct indicator selection, understanding of indicator colour changes, apparatus setup, liquid handling, time management, and error minimisation all recorded low agreement rates, generally below 40%. These deficiencies point to insufficient hands-on exposure and limited opportunities for active laboratory engagement, aligning with literature that highlights the inadequacy of observation-based learning in fostering practical skills.

Overall, the control group's difficulties underscore the shortcomings of traditional, theory-focused instructional methods in preparing students for practical chemistry tasks. The findings emphasise the need for more experiential, inquiry-based, and scaffolded approaches that explicitly connect conceptual learning with procedural competence in titration.

5.2.3 Effect of laboratory-based instructional activities on students' academic performance in acid-base titration as compared to conventional teaching methods

From Table 6, both groups improved in post-test scores. However, the experimental group recorded a sharper improvement. No student attained the highest score range (41–50 marks) in the pre-test. However, after the intervention, 63.64% of the students achieved this top rang in the post-test. Similarly, the percentage of students in the lowest ranges (0–10 and 11–20 marks) dropped drastically from 23.64% and 56.36%, respectively, in the pre-test to 0% and 1.82% in the post-test.

In the control group, 56.36% of the students attains the highest scores range (41–50 marks) in the post-test as compared to 0.00% in the pre-test. However, the improvement was less significant compared to the experimental group, as a noticeable percentage of students (1.82% and 9.09%) continued to score within the lower marks range (11–20 and 21–30) respectively, in the post-test.

Analysis of Covariance (ANCOVA) results in Table 7 also indicated that, pre-test scores were a strong, significant predictor of post-test results ($p < .001$, partial $\eta^2 = .884$). The main effect of teaching method was not statistically significant ($p = .052$**)**, though the small effect size (partial $\eta^2 = .035$) favoured laboratory-based instruction and there was no significant interaction between pre-test scores and teaching method.

5.2.4 Students' Perceptions with in acid–base titration and neutralisation (Experimental group)

From Table 8, mean scores for perception items ranged from 2.59 to 3.71, suggesting generally positive attitudes toward acid–base titration and neutralisation. Most students expressed favourable views regarding the relevance and clarity of the concept of acid-base titration as well as the usefulness of practical activities. However, a few areas reflected negative perceptions, with three of the ten items (Items 1, 6, and 7) showing less favourable views regarding titration's role in helping students retain concepts over time, its value beyond the classroom, and its importance as a skill for future science-related careers.

5.3 Conclusions

The study was to investigate the effects of laboratory activities on students' academic performance in acid–base titration and neutralisation at St. Rose's Senior High School. Based on the findings from both quantitative and qualitative analyses, several key conclusions were made:

1. The study revealed that, prior to the intervention, science students in both the experimental and control groups demonstrated significant gaps in their understanding of fundamental concepts such as the equivalence point, neutralisation reactions, and the integration of theory into laboratory practice. Their procedural skills including endpoint detection, appropriate indicator selection, apparatus setup, and accurate measurement were also underdeveloped. These deficiencies limited their ability to perform titration and neutralisation tasks effectively, underscoring the importance of strengthening both conceptual knowledge and laboratory competence.

2. The ANCOVA results revealed that the choice of instructional method did not yield a statistically significant difference in post-test performance at the 0.05 level [$F(1, 106) = 3.858$, $p = .052$]. This finding suggests that, after controlling for prior knowledge, both laboratory-based and conventional teaching approaches were comparably effective in enhancing students' academic achievement in acid–base titration. However, the small effect size (partial $\eta^2 = .035$) slightly favoured the laboratory-based method, indicating that students exposed to hands-on activities

enjoyed a modest performance advantage of about 3.5%. Both groups improved substantially from pre-test to post-test, but the laboratory-based group recorded a marginally higher mean score and a greater proportion of learners reaching mastery.

3. Students' perceptions of laboratory activities were generally positive. They highlighted the role of practical work in improving conceptual understanding, promoting engagement, and establishing connections between classroom knowledge and real-world contexts. Nonetheless, there were mixed views concerning the long-term retention of knowledge, the transferability of skills beyond the classroom, and the career relevance of the activities. These perspectives point to the need for stronger integration of laboratory tasks with authentic applications, so as to reinforce the durability and perceived utility of learning outcomes.

4. Overall, the study demonstrates that while both conventional and laboratory-based methods can enhance students' learning of acid–base titration and neutralisation, laboratory activities provide a slight but meaningful advantage in performance and student engagement. The positive perceptions expressed by learners suggest that practical work has the potential to deepen conceptual understanding and foster greater interest in science when explicitly linked to authentic, real-world applications. Strengthening the alignment between theory, laboratory practice, and practical relevance will therefore be key to achieving lasting learning outcomes.

5.4 Recommendations

Considering the findings and conclusions drawn from the study, the following recommendations have been made for consideration:

1. From research question one, it emerged that science students used in this study at St. Rose's Senior High School in both the experimental and control groups exhibited conceptual and procedural difficulties in acid-base titration and neutralisation. Hence school authorities should ensure that teachers to structure their lessons to explicitly connect theoretical explanations with corresponding laboratory demonstrations and exercises, ensuring that concepts are reinforced through direct practical application.
2. The findings on research question two are sobering, as the teaching method did not produce a statistically significant difference in students' post-test scores. This suggests that, within the context of this study, the type of instructional method did not significantly influence students' academic performance in acid–base titration and neutralisation. Nevertheless, the small effect size observed slightly favoured the laboratory-based approach. Although not statistically significant, this indicates that teachers should still consider exposing students to hands-on activities. At the same time, teachers must be cautious not to assume that practical work alone guarantees improved academic performance, particularly when it is not reinforced with conceptual understanding and aligned with targeted assessment strategies. School administrators and heads of science departments should support teachers by ensuring adequate time, resources, and instructional guidance for the effective integration of laboratory work with theory. Additionally, curriculum implementers and teacher educators should emphasise balanced instructional approaches during

in-service training and pre-service teacher preparation, highlighting the need to align practical work with clear learning objectives and assessment strategies.

3. The findings related to the third research question highlight the need for teachers to connect concepts of titration and neutralisation to real-life applications in health, environmental management, agriculture, and industry, thereby making learning more meaningful and career-relevant. Chemistry teachers should ensure that laboratory activities are consistently followed by guided discussions, assessments, and reflective exercises that explicitly link experimental outcomes with theoretical principles, to enhance long-term retention and deepen conceptual understanding. Furthermore, teachers should scaffold practical tasks, gradually increasing complexity to build students' confidence, independence, and self-monitoring abilities, while simultaneously fostering problem-solving and critical thinking skills. School administrators and curriculum coordinators should support this approach by providing necessary laboratory resources, allocating sufficient instructional time, and encouraging professional development that emphasizes connecting practical work with real-life contexts and cognitive skill development.

5.5 Suggestions for Further Research

Here are some suggestions for future studies based on the study's findings and limitations:

1. Future studies should not only measure students' immediate performance gains but also assess whether the knowledge and skills developed through laboratory-based instruction are retained over time. In addition, researchers could explore strategies that highlight the practical importance of titration and neutralisation in everyday contexts such as medicine, agriculture, food production, and

environmental monitoring. This would help address the weak perceptions of real-world applicability observed in the current study.

2. Further investigations could extend to schools of different categories and regions to make the findings more generalisable. Such studies may also consider learner characteristics, including gender, previous academic achievement, and preferred learning styles, in order to understand how these variables, interact with laboratory-based teaching methods and influence students' performance and attitudes.3.
3. Additional research is needed to examine how variations in teaching style, scaffolding, and teacher support shape both conceptual and practical learning outcomes in titration.

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APPENDICES

APPENDIX A

INSTITUTION: ST. ROSE'S SENIOR HIGH SCHOOL

ACID-BASE TITRATION AND NEUTRALISATION

(PRE-TEST)

The purpose of this test is to gather data on St. Rose's SHS chemistry students so that the researcher can forecast how laboratory exercises will affect the students' academic performance in acid-base titration and neutralization. The researcher will be better able to draw conclusions on how laboratory activities affect students' academic performance in acid-base titration and neutralisation if you answer these questions honestly. Please be aware that the information you provide will be kept confidential.

BIO-DATA

Kindly tick (√) *appropriately.*

Sex: *Male [ ] Female [ ]*

Class*: Chemistry – Science student [ ]   Chemistry – Home economic student [ ]*

Duration*: 60 minutes*   *Answer all questions.*

Some terminologies associated with acid-base titration and nuetralisation.

SECTION A

1. Explain the term neutralisation reaction.

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………………………**[2mark]**

2. What is titration?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………**[2marks]**

3. Give two (2) examples of acid-base titrations

………………………………………………………………………………………

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………………………………………………………………………………………..................................

..............................**[2 marks]**

SECTION B

4. Which indicator is best suited for a weak acid-strong base titration?

(a) Phenolphthalein (b) Methyl orange (c) Bromophenol blue (d) Litmus

5. What is the pH range for methyl orange to change color?

(a) 3.1–4.4 (b) 6.0–7.6 (c) 8.3–10.0 (d) 4.0–6.5

6. Which of the following indicators changes from yellow in acid to blue in base?

(a) Bromothymol blue (b) Phenolphthalein (c) Methyl orange (d) Universal indicator

7. What determines the choice of an indicator for a titration?

(a) The color of the solution (b) The pH at the equivalence point

(c) The strength of the acid only (d) The volume of titrant used

8. What is the color of phenolphthalein in an acidic solution?

(a) Pink (b) Yellow (c) Colorless (d) Blue

SECTION C

9. State **three** sources of errors that may occur during acid-base titration and neutralization.

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....**[3 marks]**

10. In an *acid-base* titration, which of the substances is usually put in the:

(i). pipette……………………………………………………………………………...**[2mark]**

(ii). burette………………………………………………………………………………**[2 mark]**

SECTION D

11. Complete and balance the following chemical equations

(α). Na_2CO_3 + HCl →……………………………… ……………(3 marks)

(β). NaOH + H_2SO_4→ …………………………… ………………(3 marks)

(γ). NaOH + HCl →…………………………………………….. (3 marks)

SECTION E

12. The following table gives the burette reading when 20.00cm^3 portion of 0.100moldm^{-3} solution of sodium hydrogen trioxocarbonate (IV), $NaHCO_3$ were titrated against dilute trioxonitrate (V) acid, HNO_3 using methyl orange as indicator.

The equation for the reaction is $NaHCO_{3(aq)} + HNO_{3(aq)} \rightarrow NaNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$

Burette readings/ cm^3	1st titration	2nd titration	3rd titration
Final burette readings/cm^3	27.50	27.20	27.10
Initial burette readings/cm^3	0.00	0.00	0.00
Volume of acid used/cm^3			

(α) Copy and complete the table. **[3 marks]**

(β) Calculate the average titre. ………………………………………..**[2marks]**

(γ) Determine the concentration of the acid in *moldm*$^{-3}$.

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…………………………………………………………………….**[5marks]**

APPENDIX B

MARKING SCHEME/RUBRICS FOR BOTH PRE-INTERVENTION TEST AND POST INTERVENTION TEST ON ACID-BASE TITRATION.

(PRE-INTERVENTION TEST)

SECTION B

1. **Neutralisation** is reaction between acid and base to form salt and water only – **2 marks**
2. **Titration** is a technique used to determine concentration of a solution using a reaction with known concentration – **2 marks**
3. **Two examples of acid-base titrations**: HCl vs NaOH, CH_3COOH vs NaOH – **1 mark each**

SECTION B

4. Best indicator for weak acid-strong base – **(a) Phenolphthalein**

5. pH range for methyl orange – **(a) 3.1–4.4**

6. Indicator changing yellow in acid to blue in base – **(a) Bromothymol blue**

7. Indicator choice depends on – **(b) The pH at the equivalence point**

8. Colour of phenolphthalein in acid – **(c) Colorless**

SECTION C

Three sources of error in measurement: parallax error, improper mixing, not reading meniscus-1 mark for each correct source

9. **(i) Substance in pipette:** Base or solution of known volume. – **2 marks**

   (ii) Substance in burette: Acid or solution of known concentration. – **2 marks**

SECTION D

11. Balanced Equations:

(α) $Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$

(β) $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

(γ) $NaOH + HCl \rightarrow NaCl + H_2O$ **[3 mark each]**

SECTION E

12. Completed titration table.

Burette readings/ cm^3	1st titration	2nd titration	3rd titration
Final burette readings/cm^3	27.50	27.20	27.10
Initial burette readings/cm^3	0.00	0.00	0.00
Volume of acid used/cm^3	**27.50**	**27.20**	**27.10**

1x1 =3 mark

(27.10 + 27.20)/2 = 27.15 cm^3 – **2 marks**

Concentration of the acid

Step-by-step:

- Writing of balanced chemical equation – **1 mark**
- Use mole ratio (1:1) – **1 mark**
- Calculate moles of base: M × V = 0.100 × 0.020 = 0.002 mol – **1 mark**
- Use mole ratio to find moles of acid = 0.002 mol – **1 mark**
- Concentration = moles / volume in dm^3 → 0.002 / 0.02727 ≈ **0.0733 mol/dm^3**

  – 1 mark

Total: 50 marks

APPENDIX C

QUESTIONNAIRE

INSTITUTION: ST. ROSE'S SENIOR HIGH SCHOOL

The essence of this questionnaire is to collect data on student's difficulties in acid-base titration and neutralization concept. Your candid responses to the questions will go a long way to enable the researcher obtain valid information which will give insights on the issue being investigated. Kindly bear in mind that your anonymity and confidentiality of the information provided is assured.

Class: ……….. Age: …………… Sex: …………

Kindly read through each question and tick (√) the appropriate option that matches your view.

Strongly disagree (SD=1), disagree (D=2), neutral (N=3), agree (A=4) and strongly agree (SA=5).

STATEMENTS	SA	A	N	D	SD
1. I clearly understand the concept of equivalence point in acid-base titration					
2 I understand how acid and base neutralize each other in titration.					
3. I can easily relate the theoretical concepts of acid-base titration to the practical experiment.					
4. I can easily determine the endpoint during the titration process.					

5. I can accurately select the correct indicator for different acid-base titrations					
6. I understand the colour change patterns of indicators used in titration					
7. I can confidently and correctly set up the apparatus for acid-base titration.					
8. I can manage my time effectively during titration experiments					
9. I can accurately measure and handle liquids during the titration experiment.					
10. I can identify and minimize errors effectively during the acid-base titration experiment.					

The essence of this questionnaire is to collect data on student's perception about acid-base and neutralization. Your candid responses to the questions will go a long way to enable the researcher obtain valid information which will give insights on the issue being investigated. Kindly bear in mind that your anonymity and confidentiality of the information provided is assured.

Class: ………… Age: …………… Sex: …………

Kindly read through each question and tick (√) the appropriate option that matches your view. Strongly disagree (SD=1), disagree (D=2), neutral (N=3), agree (A=4) and strongly agree (SA=5).

S/N	Statement	SA	A	N	D	SD
1	Performing titration in the laboratory helps me retain the concept longer.					
2	I believe laboratory activities are good ways to help me learn about acid-base reactions.					
3	I understand neutralisation better when it is taught through laboratory activities.					
4	I can now confidently and independently perform titration experiment after going through laboratory activities.					
5	Doing practical experiments increases my interest in learning chemistry.					
6	I see the value of titration beyond the classroom.					
7	Titration is an important skill for future science-related careers.					
8	The concept of acid-base neutralization is useful in real-life situations.					
9	Learning about titration will help me see how chemistry works outside the classroom.					
10	Acid-base titration and neutralization can help me understand chemical reactions.					

APPENDIX D

CLASSROOM OBSERVATION CHECKLIST

Observation checklist for Assessing St. Rose's SHS Chemistry Students based on their ability to follow instructions, teamwork, problem-solving skills, and practical skills.

Indicator	Yes	No	Remarks
1. Follows laboratory safety rules and precautions			
2. Adheres to teacher's guidelines without repeated reminders.			
3. Student possesses the skill to measure accurately, the volume of acids and bases using burettes and pipettes.			
4. Identifies and analyzes problems in experiments			
5. Student is able to calculate accurately the concentration of the acid used by relating it to the concentration of the base used in titration			
6. Student is able to calculate the volume of base accurately used in performing practical work. i.e. determining titer values			
7. Student completes the practical task successfully.			
8. Records observations and tabulate results systematically			
9. Student is able to relate the color change (end point) to calculate the accurate volume of acid used in neutralizing the base and vice versa			
10. Student possesses the manipulative skills required for using laboratory apparatus (burettes, pipette, or cylinder) with precision and accuracy to measure the desired volume of acids and bases.			

APPENDIX E

CRONBACH ALPHA COEFFICIENT

Statistic	Value
Number of items (k)	10
Sum of item variances	0.9393
Variance of total scores	4.4651
Cronbach’s alpha	α =0.7906

APPENDIX F

TEST RE-TEST RELIABILITY

Statistic	Value
Number of Participants	20
Pearson’s *r*	0.87

APPENDIX G

INTRA-RATER RELIABILITY ON THE OBSERVATION CHECK LIST

Item	a	b	c	d	n	Po	Pe	Kappa values on each item (κ)
1	9	0	1	10	20	0.950	0.503	0.900
2	9	0	1	10	20	0.950	0.503	0.900
3	8	1	1	10	20	0.900	0.505	0.798
4	9	0	2	9	20	0.900	0.505	0.798
5	8	1	1	10	20	0.900	0.505	0.798
6	8	1	2	9	20	0.850	0.508	0.694
7	9	0	1	10	20	0.950	0.503	0.900
8	8	1	1	10	20	0.900	0.505	0.798
9	8	0	1	11	20	0.950	0.503	0.900
10	8	1	1	10	20	0.900	0.505	0.798
Mean κ								**0.753**