AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

MPHIL THESIS

PROBLEM-BASED LEARNING: AN ESSENTIAL PEDAGOGY FOR ENHANCING SENIOR HIGH SCHOOL CHEMISTRY STUDENTS' CONCEPTUAL UNDERSTANDING OF SELECTED ORGANIC CHEMISTRY CONCEPTS

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JULY, 2024

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JULY, 2024

DECLARATION

Candidate's Declaration

I hereby declare that this dissertation is the result of my own original work and that no part of it has been presented for another degree at this university or elsewhere.

Evelyn Owusu-Dentaah

Signature: ………………………… Date: …………………………...

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

Dr. Eric Appiah-Twumasi (Principal Supervisor)

Signature:………………………………... **Date:**………………………………..

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Signature:…………………………........... **Date:**……………………………......

ABSTRACT

This research investigates students' understanding of organic chemistry and evaluate the effectiveness of Problem-Based Learning (PBL) as an essential pedagogy to enhance their grasp of specific organic chemistry concepts. The study involved 100 third-year Senior High School (SHS) chemistry students from two intact classes in the Kwabre East Municipality. A mixed-methods approach, employing the sequential explanatory design, was utilised. It commenced with pre-intervention assessment using a Three Tier Organic Chemistry Concept Test (TTOCCT) to measure students' understanding before the introduction of PBL. Post-intervention assessment, using the TTOCCT and interview guide, were conducted to assess the intervention's impact on the students' understanding. Quantitative data revealed a higher average participant percentage (66.19%) in 'full understanding' category compared to pre-intervention (8.06%). However, in 'partial understanding', 'misconception' and 'no understanding' categories, there were relatively higher average participant percentage before the intervention than after the intervention. Students' perceptions from the interview underscored the effectiveness of PBL in enhancing students' engagement, fostering collaborative and communication skills, nurturing critical thinking abilities, bolstering problem-solving confidence, as well as reinforcing the application of knowledge. In conclusion, the findings advocate for the integration of PBL as a promising pedagogical strategy to enhance students' understanding of organic chemistry within the Kwabre East Municipality. Consequently, chemistry educators in the Municipality are encouraged to incorporate PBL into their organic chemistry lessons to enhance students' understanding of this challenging subject.

DEDICATION

I dedicate this work to my dear husband, Mr. Simms Ofosu, our children (the Ofosu siblings), Rocklyn, Simms Jnr. and Evelyn Lois, and lastly to my late brother Kingsley Owusu Boadi.

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This work has seen the light of the day due to the dedication of these distinguished personalities: my supervisors, Dr. Eric Appiah-Twumasi and Professor Kofi Sarpong, whose help and prompts have helped me to complete this work. It will also be ungrateful on my part not to recognise immense help of Mr. Kenneth Darko Ateko. He guided and supported me throughout this work. God bless you, Kenneth.

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CHAPTER ONE

INTRODUCTION

1.0 Overview

In this introductory chapter, the groundwork for the research is laid out, beginning with a comprehensive exploration of the context and background of the study. The central problem is also delineated, leading to the statement of the study's overarching purpose and specific objectives. The research questions that were formulated to guide the study are also included in this chapter. The justification and significance of the study are highlighted, including the delimitations and limitations of the study. Also, included in this chapter are key terms that are operationally defined to ensure clarity of communication. Finally, an overview of the organisation of the thesis is provided, offering readers a roadmap for navigating the subsequent chapters.

1.1 Background to the Study

Nearly all nations now place a high premium on the development of science education, which has emerged as a key concern. Science cannot be fully understood without the study of Chemistry. Therefore, according to (Abimbade et al., 2018) secondary schools teach science courses like chemistry to lay the groundwork for important advancements in science and technology.

Chemistry explores both the use of natural materials and the creation of synthetic ones. The overall enabling infrastructure that produces the food, tools, and materials that are the trademarks of contemporary living is made possible by the strength of chemical chemistry (Samuel & Ikwuka, 2017). Chemistry is a scientific discipline that examines the properties, composition, and structure of substances, defined as elements and compounds. It also explores the transformations these substances undergo and the energy changes that occur during these processes. Chemistry, according to Ministry of Education (2010) is necessary for the creation of everyday products like soap, plastics, books, radio, TV, video, and computers. Therefore, we may use chemistry to comprehend, explain, manage, and prevent occurrences like bushfires, industrial pollution, metal corrosion, and ozone layer depletion. Chemistry is therefore a subject of vital importance for life, as a result it is very vital that we study it in school.

Since its principles are used in our daily lives, organic chemistry is a required course in senior high school (SHS) chemistry (Ministry of Educaton, 2010). Organic chemistry is the study of carbon compounds and their derivatives (Ajayi et al., 2020). According to Anim-Eduful and Adu-Gyamfi (2021), our daily lives are anchored in fundamental organic chemical processes, including the food we eat, hair dyes we use and medicines we take to treat illnesses. Hanson (2017) also explains that many graduate and professional programs in human care require a sufficient understanding of organic chemistry. That is, organic chemistry is essential to the creation of new products for the market as well as the enhancement of several others on which we have grown reliant. It serves as the raw material for the manufacture of plastics, apparel, automobile tires, cement, fuel, medications, and household cleansers. Organic chemistry is crucial for security and investigative agencies as well. Due to these uses of organic chemistry in daily life and the requirement for scientific advancement, organic chemistry education must always be given priority.

In spite of the above importance, SHS students have been reported to demonstrate difficulties in organic chemistry. For instance, Davis (2016) and O'Dwyer & Childs (2017) also reported that aromatic hydrocarbons, as well as reaction mechanisms were perceived as difficult aspects of organic chemistry to understand by greater percentages of students. Chemistry students within the Ghanaian context are not exempted in the demonstration of these lack of understanding in organic chemistry. As an instance, chemistry students, according to Donkoh (2017) found reactivity of organic compounds, petroleum, benzene, alkanoic acids and their derivatives, amino acid functional groups, natural and synthetic polymers as difficult topics to understand. Also, Adu-Gyamfi et al. (2017) found out that majority of students had difficulties in naming structural formulae of branched- and substituted-chains of alkanes and alkenes, geometrical isomers, dienes, unbranched alkynes, primary and tertiary alkanols, diols, alkanoic acids, and alkyl alkanoates.

Students' difficulties in understanding organic chemistry concepts are reflected in their weaknesses in their external examination as indicated by the chief examiners from the West African Examination Council (WAEC). A read-through of the chief examiners' reports from the West African Examination Council (WAEC) identified "candidates' inadequate knowledge of organic chemistry concepts, inability to explain simple scientific terms, including organic chemistry", as some of the leading causes of candidates' general "woeful" performance in Chemistry (WAEC, 2017, 2018, 2020, 2021). For instance, in 2017, the chief examiners reported that "candidates were unable to draw and name the isomers of methane (C_4H_8), draw the appropriate diagram to indicate how the C=C double bond in alkene is formed" (WAEC, 2017). Also, in 2018, it was identified by the chief examiner that candidates did not exhibit adequate knowledge of organic chemistry concepts (WAEC, 2018). Again, in 2020, according to the chief examiner, majority of candidates were able to arrange ethanol, ethane and butane in the correct order of increasing boiling points, but could not explain or give reasons for their answers (WAEC, 2020); and inability of candidates to select organic compound that could be cracked, undergo substitution reactions from a list of compounds (WAEC, 2021).

According to Holme et al. (2015), one of the primary causes of students' difficulties in solving organic chemistry problems is their inability to grasp fundamental chemical concepts, which Adu-Gyamfi et al. (2017) argue, stems from the abstractness of the concept of organic chemistry. This leaves students resorting to memorising of scientific facts and principles without much understanding (Adu-Gyamfi & Asaki, 2023; Konicek-Moran & Keeley, 2015; Nartey & Hanson, 2021). However, the fact that the concept is abstract does not mean its understanding should not be unraveled. Therefore, Konicek-Moran and Keeley (2015) assert that one of the main goals of science educations is to teach for conceptual understanding. Consequently, it tends to suggest that educators have a massive responsibility in addressing the challenges and difficulties exhibited by students in the teaching and learning of organic chemistry for better understanding. Thus, Adu-Gyamfi and Asaki (2022) subscribe to the view that educators are in charge of the classroom. As such, they set the tone for the classroom and mentor students according to their understanding, knowledge, and analysis of the curriculum’s goals, content, theory, and recommended pedagogical method.

Also, teaching organic chemistry for understanding can be hampered by the way it is sometimes given, which according to researchers such as Konicek-Moran & Keeley

(2015), Appiah-Twumasi (2020), as well as Nartey and Hanson (2021) involves direct instruction and the teacher imparting knowledge to the student through methods like lectures that allow for little to no student interaction with the subject matter. Thus, although gaining content knowledge is always the main objective, (Holme et al., 2015) opine that there can be differences in the specifics of the content and the level of understanding required for each topic.

Banda and Nzabahimana (2021) posit that for learners to demonstrate conceptual understanding, they must be able to reason in situations where the application of concepts, descriptions, relationships, or representations must be done carefully. This means that improved conceptual understanding can assist students in making connections between concepts in various contexts, preventing the isolation of methods and facts. Additionally, conceptual knowledge is necessary for students to develop metacognition, which involves they applying the facts to the overall explanatory frameworks, testing the frameworks against the facts, and connecting the content and facts to their understanding of the topic. Also, conceptual understanding is important for students to effectively apply their knowledge to novel settings (McTighe et al., 2004). Thus, once a concept is understood by students, they can apply it in different contexts, formulate it in their own terms, come up with analogies or metaphors, or construct a physical or mental model of it. Put another way, the learners have adapted the idea to suit them (Holme et al., 2015; Konicek-Moran & Keeley, 2015).

Aligning with the importance of teaching chemistry, as highlighted above, the Ghanaian senior high school (SHS) have outlined a number of aims of teaching chemistry, and for that matter organic chemistry, in the Ghanaian context. Among these aims include using facts, concepts, patterns, and principles to solve individual, societal and environmental problems as well as promoting an investigative approach to chemistry education and making chemistry lessons primarily problem-solving oriented (Ministry of Education, 2010a). Problem-Based Learning (PBL) appears to be a good fit for these needs, as it helps students to understand concepts and solve problems, which ultimately improves performance (Tan, 2003).

PBL is a student-centered teaching method that allows learners to explore, integrate theory with practice, and apply their knowledge and skills to develop practical solutions to specific problems (Savery, 2006). According to Jonassen and Hung (2008), through the process of finding solution to the given problem, learners develop the abilities of self-directed learning, and monitoring comprehension via learning to modify learning strategies. Jonassen and Hung (2008) further add that collaboratively, learners assume responsibility for developing learning difficulties and procedures through self-appraisal. The choice of unstructured problems—which are frequently interdisciplinary—and a tutor who facilitates learning and leads a comprehensive debriefing at the end of the session are essential to the approach's effectiveness (De Graaff & Kolmos, 2003).

Tan (2003) echoes that majority of students benefit from PBL, which makes its techniques fit for classrooms with a variety of skill levels where students may pool their strengths and work together to find a solution. These methods also lend themselves to an interdisciplinary approach because solving an issue sometimes necessitates knowledge from multiple academic fields (Tawfik et al., 2021). The consequence is that learners may absorb more knowledge, comprehend concepts, and take pleasure in learning more (Yew & Goh, 2016). Recently, researchers including Anyafulude (2014), Aidoo et al. (2016), Günter and Alpat (2017), Chuks et al. (2020) and Okebanama et al. (2023) have found PBL to enhance students' performance in chemistry concepts. However, there is apparently limited research on how PBL can be used to enhance students' understanding in organic chemistry, especially in Ghana.

Based on the above background, this study has taken a further step to determine experimentally, the effect of PBL on chemistry students' understanding in organic chemistry.

1.2 Statement of the Problem

Chemistry students in both international studies (Eticha & Ochonogor, 2015; O'Dwyer & Childs, 2017) and local studies (Adu-Gyamfi et al., 2017; Anim-Eduful & Adu-Gyamfi, 2022a; Nartey & Hanson, 2021) have consistently found evidence suggesting students' difficulties in understanding organic chemistry concepts. For instance, in Ireland, the study of O'Dwyer and Childs (2017) found reaction types, mechanisms and synthesis as areas in organic chemistry where students find most challenging to understand. Similarly, within the American context, it was reported that organic chemistry mechanisms, nucleophiles and electrophiles, and stereochemistry were organic chemistry concepts students struggled to understand (Salame et al., 2020).

In the African setting, Eticha and Ochonogor (2015) in Ethiopia found that students' lack of understanding in organic chemistry was demonstrated in areas such as functional groups, stereochemistry, organic reactions and mechanisms, among others. Also, in Ghana, Adu-Gyamfi et al. (2017), Donkoh (2017), and Nartey and Hanson

(2021) have all documented diverse forms of difficulties students demonstrate when solving organic chemistry problems, among which include difficulties in naming structural formulae of branched- and substituted-chains of alkanes and alkenes, geometrical isomers, dienes, unbranched alkynes, primary and tertiary alkanols, diols, alkanoic acids, and alkyl alkanoates.

These difficulties exhibited by students have been echoed in the reports of WAEC chief examiners from 2017 to 2021, where the chief examiners reported, amongst others, candidates' inability to draw isomers of some organic compounds (WAEC, 2017), inability to give reasons for arranging some organic compounds in increasing order of their boiling points (WAEC, 2020), and to select organic compound that could be cracked, undergo substitution reactions from a list of compounds (WAEC, 2021).

A preliminary investigation by the researcher in the Kwabre East Municipality revealed that majority of SHS chemistry students had negative perceptions about organic chemistry as a topic. For instance, one student stated: "*I do not like organic chemistry. I hate it so much, especially the structures and the naming. I only memorise but easily forget*." Another student also lamented that: "*Since I came to SHS 3, the topic I am struggling most to understand is organic chemistry. I have never seen the compounds we hear in class. I do not even know what I will use organic chemistry for after my final examination*". Also, one chemistry student expressed their challenge in understanding organic chemistry. According to the student, "*My teacher always mentions reagent in organic chemistry reactions but I have never seen such reagent and even how they work in the reactions. This means that I am only doing chew and pour. I do not understand most of the things we learn in organic chemistry*".

To improve students' understanding in organic chemistry, the use of student-centred pedagogical approaches (Byusa et al., 2022) which will engage students in the teaching and learning process, and unmasking the reality of the content, have been advocated by researchers. One of such approaches is PBL (Chuks et al., 2020; Okebanama et al., 2023). This is because, the pedagogical attributes of PBL, including small-group instruction, ill-structured, interdisciplinary, and intricate real-world problems, offer a setting conducive to the social exchanges necessary for students to jointly construct their own knowledge which helps to understand concepts better (Savery, 2006). The interactions, debates, ideas, cultural exchanges, and social negotiations that occur throughout these social encounters are necessary in building students' knowledge and skills (Hmelo-Silver, 2004). However, there apparently exists little knowledge on the effect of PBL in enhancing students' understanding of organic chemistry, especially in the Ghanaian context. Therefore, this study sought to enhance the understanding of SHS chemistry students in organic chemistry.

1.3 Purpose of the Study

The purpose of the study was to determine the effect of Problem-Based Learning as an essential pedagogy for enhancing SHS chemistry students' understanding of selected organic chemistry concepts.

1.4 Objectives of the Study

The study specifically sought to determine:

1. SHS chemistry students' level of understanding in selected organic chemistry concepts (nomenclature, structure, properties and reactions of organic compounds) before the use of PBL.

2. the extent to which the use of PBL as a pedagogical approach enhances SHS chemistry students' understanding in selected organic chemistry concepts (nomenclature, structure, properties and reactions of organic compounds).
3. SHS chemistry students' perceptions towards the use of PBL as a pedagogical approach in the teaching and learning of organic chemistry.

1.5 Research Questions

The following are the specific research questions that guided the study.

1. What are SHS chemistry students' level of understanding in selected organic chemistry concepts (nomenclature, structure, properties and reactions of organic compounds)?
2. To what extent does the use of PBL as a pedagogical approach enhance SHS chemistry students' understanding of selected organic chemistry concepts (nomenclature, structure, properties and reactions of organic compounds)?
3. What are the perceptions of SHS chemistry students on the use of PBL as a pedagogical approach in the teaching and learning of organic chemistry?

1.6 Justification of the Study

The study's justification lies in the fact that within the Ghanaian context, especially in the teaching and learning of organic chemistry, literature appears to be silent on using PBL as a pedagogical approach to enhance SHS Chemistry students' understanding in organic chemistry.

1.7 Significance of the Study

This study is relevant because it will help SHS chemistry students within the Kwabre East Municipality to develop various skills and strategies to solve organic chemistry problems as they learn through PBL. This will ultimately improve their understanding in organic chemistry. Also, SHS chemistry teachers within the Kwabre East Municipality will benefit from this study, as it will help them to assist chemistry students to develop their problem-solving skills through the presentation of real-life problems. This will in turn help students to tackle any question they face in organic chemistry, thereby improving their academic performances.

1.8 Delimitations of the Study

This study has some delimitations. In that, not all concepts in organic chemistry were considered. The concepts considered were nomenclature, reactions, structure and properties of organic compounds. These concepts were selected based on the accounts provided by researchers where students demonstrate lack of understanding. Also, three tier-test was used to assess students' conceptual understanding of organic chemistry. This was done in order to determine the different levels of understanding, by including a confidence tier in the test. Again, students were put in intact classes, as a result individual participants were not randomly selected to participate in this study. Moreover, the study focused on SHS 3 chemistry students because as outlined in the Ghanaian chemistry syllabus, organic chemistry was taught in year 3 at the SHS level.

1.9 Limitations of the Study

A major limitation in this study was that since random assignment of participants was possible, drawing conclusions about causal relationship between the intervention and the outcome was made with extreme caution. Also, with the absence of control group in this study, some unmeasured extraneous variables might have affected the results of the study. As a result, drawing conclusions were made with care.

1.10 Operational Definition of Terms

Problem-Based Learning – an instructional approach where students begin self-directed, small-group learning with ill-structured, real-life problems, and are assisted by an instructor who serves as a facilitator of the instructional process, rather than a source of knowledge.

Understanding - grasping fundamental principles of a concept, its relationships, and applications in a way that allows for meaningful explanation, prediction, and problem-solving within the context of a concept.

Organic Chemistry - the branch of chemistry that focuses on the study of carbon-containing compounds, which are fundamental to life and form the basis of many substances found in living organisms.

Organic compound – a compound of carbon atoms bound to one another and other atoms by covalent bonds (single, double or triple bonds), which are found in living organisms.

1.11 Organisation of the Study

This study is structured into five chapters, each focusing on a different aspect of the research. Chapter one covers the background, statement of the problem, the study’s main purpose, and specific objectives, as well as research questions, significance, delimitations, limitations, and definitions of terms. Chapter two reviews relevant literature, including conceptual, theoretical, and empirical studies. Chapter three details the research design, population, sampling methods, data collection instruments, procedures for collecting data, data processing and analysis, and ethical considerations. Chapter four presents and discusses the results. Finally, chapter five summarises the findings, draws conclusions, offers recommendations, and suggests areas for further research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter presents the reviewed literature based on which the study was conducted. The literature review is categorised into three major sections, with each major section having sub-sections. The major sections were the conceptual review – which explains the various variables (Problem-Based Learning, the concept of understanding, and the concept of organic chemistry), the theoretical review – which highlights the theoretical underpinnings of this study, and the conceptual framework – which shows the relationship between the various variables considered in this study. Also, the empirical review as well as summary of the literature review are captured in this chapter.

2.1 Conceptual Review of the Study

This section presents a review of the various conceptual variables used in this study. These concepts include Problem-Based Learning, understanding, and organic chemistry.

2.1.1 Origin of Problem-Based Learning

The 1950s saw the development of Problem-Based Learning in medical education. The work of medical educators at McMasters University in Canada throughout the 1950s is widely acknowledged as being responsible for the birth of PBL (De Graaff & Kolmos, 2003). The same period, according to De Graaff and Kolmos (2003) saw the development of Problem-Based Learning curricula at other medical schools across the globe, including Newcastle University in Australia, Maastricht University in the Netherlands, and Michigan State University in the United States.

However, Hung et al. (2008) assert that PBL was created and implemented as a solution to inadequate clinical performance among students, which was attributed to traditional health science education's focus on memorising isolated pieces of scientific knowledge. The General Professional Education of the Physician and College Preparation for Medicine (GPEP/CPM) report, which was funded by the Association of American Medical Colleges, expedited the expansion of PBL in the United States throughout the 1980s (Hung et al., 2008). It was titled "Report of the Panel on the General Professional Education of the Physician and College Preparation for Medicine" (Hung et al., 2008). This paper offered suggestions for modifications to medical education, including encouraging self-directed learning and problem-solving, cutting back on lecture hours, shortening scheduled times, and testing self-directed learning capacity (Hmelo-Silver, 2004).

These suggestions, according to Hung et al. (2008), provided compelling evidence in favor of using PBL in medical education. Around this time, a few medical schools also started creating other, parallel, problem-based curricula for a portion of their student body (Hmelo-Silver et al., 2019). Examples of these curricula are the Harvard University Medical School's New Pathways Program and the University of New Mexico's Primary Care Curriculum. Later, a number of medical schools took on the more difficult challenge of switching their entire curriculum to Problem-Based Learning, including the University of Hawaii, Harvard University, and the University of Sherbrooke in Canada (Hung et al., 2008). Many other medical institutions, including

Southern Illinois University, Rush, Bowman Gray, and Tufts, began using PBL as their main teaching strategy in the 1990s (Thorndahl & Stentoft, 2020).

Throughout the 1990s, PBL was progressively adopted in primary and high school settings as well as in higher education outside of the medical area (Savery, 2006). Since it was originally used several decades ago, PBL has been a well-known teaching strategy in medical schools and health-related programs all over the world, including North America, The Netherlands, England, Germany, Australia, New Zealand, and India (Thorndahl & Stentoft, 2020). According to Hung et al. (2008), PBL has been used all over the world in a range of professional schools and subjects including science courses, physics, art, history, biology, biochemistry, calculus, chemistry, economics, geology, psychology, leadership education, criminal justice, nutrition and dietetics, and other post-secondary education areas.

2.1.1.1 Problem-Based Learning as an Instructional Approach

As an instructional approach, problem-based learning (PBL) allows students to actively participate in the process of learning through the solution of real-world problems while they are learning. In this way, Yew and Goh (2016) argue that students can work together to solve problems, develop mental models for learning, and develop the habits of self-directed learning via practice and reflection. In an attempt to expand on the concept of PBL as an instructional approach, Tan (2003) links PBL to a scenario where the student being faced with a task when the means (the knowledge, procedure, and activities to be performed) are unfamiliar or new to them.

Balac and Ozogul (2023) also explain that PBL usually consists of a small group of self-directed students that work together to solve real-world problems while developing their critical thinking abilities, content understanding, and collaborative learning skills. In this way, PBL lends a hand in making visible or making explicit, the thinking process and the complexity of the cognitive organizing and processes involved. However, according to Balac and Ozogul (2023), PBL aims to foster in students not only the ability to learn independently, but also the responsibility for lifelong learning and ongoing professional development. This means that PBL places emphasis on active learning as an important classroom feature. Thus, students are urged to investigate, inquire, and come to their own understanding rather than memorizing information or procedures (Trullàs et al., 2022). In order to solve the problem, learners must determine what they must study (Smith et al., 2022), which encourages a sense of ownership over their education. This method not only helps students retain the material better (Da Silva et al., 2017), but it also gives them the problem-solving, communication, and teamwork skills they will need in the workplace (Smith et al., 2022). Because of this, learners can demonstrate some degree of control over the material.

Also, PBL is an instructional strategy that centers the learning process around real-world problems, challenging the conventional educational model. That instance, in line with Smith et al.'s (2022) assertion, in PBL, students are given complicated, open-ended issues that call for critical thinking, teamwork, and research to answer rather than passively absorbing material from a teacher through lectures or readings, as is commonly seen in the traditional classroom. This makes the learning process genuine and interesting by the fact that these problems are frequently created to resemble the kinds of difficulties that experts in the field would face.

According to Hmelo-Silver (2004), PBL was designed with some vital goals. These include building a broad and adaptable knowledge base, improving problem-solving abilities, cultivating a self-directed, lifelong learning style, being a productive team player, and developing an innate desire to learn. Creating a broad and flexible knowledge base involves integrating information from several disciplines and flexibly conditionalizing it so that it may be readily retrieved and applied in a variety of suitable contexts (Hmelo-Silver, 2004). In enhancing problem-solving skills, students need to be able to make informed decisions by analyzing information and evaluating evidence (Kolmos et al., 2008). They gain the ability to critically evaluate the reliability of sources, the applicability of knowledge, and the possible ramifications of various courses of action. This improves their capability to take on new difficulties with a deliberate and analytical perspective in addition to strengthening their ability to solve the particular situation at hand (Tan, 2003). This can be achieved through laboratory experiments or classroom-based research (Djou et al., 2022). However, Tan (2003) posits that prior to investigating problems, discussing problems in a PBL group helps students activate pertinent prior knowledge and assimilate new information more easily. This way, students can draw on relevant prior knowledge and digest new material more easily.

Self-directed learning is a learning process where the learner takes responsibility for their own learning which does not depend on a formal instructor or formal classroom (Robinson & Persky, 2020). When these skills are developed and enhanced, the student's metacognitive skills, which also play crucial role in self-directed learning, are also enhanced (Leary et al., 2019). Thus, one can say that the skills that support self-directed learning are those of lifelong learning. According to Ayyildiz and Tarhan

(2015) self-directed learning involves a number of subskills. That is, learners must first be aware of their own metacognitive gaps in understanding. Secondly, they should be able to create learning objectives by determining what they still need to learn in order to complete the work at hand. Thirdly, learners need to be able to organize their education and choose the best learning techniques. That is, they need to choose a path of action or courses of action in order to attain their learning objectives. Lastly, learners need to be able to track and assess their progress toward their goals as they carry out their plan.

Another goal of PBL, according to Hmelo-Silver (2004), is being a good collaborator. This means being able to work successfully in a team. This includes reaching consensus, finding common ground, settling disagreements, and negotiating the course of action that a group will pursue (Hmelo-Silver, 2004). This kind of work necessitates an honest discussion among all group members and active participation. In this view, students must collaborate in groups, exchanging ideas, talking about approaches, and debating solutions because many problems are too complicated for one person to handle alone. Students learn the value of varied viewpoints and the significance of efficient communication in achieving a common goal via this collaborative element (Yew & Goh, 2016), which also simulates real-world professional settings (Fukuzawa et al., 2017). Assisting learners in developing intrinsic motivation is another goal of PBL (Hmelo-Silver, 2004). When students work on a task because it fulfills them or because it presents challenges or intrigues them, they are working with intrinsic motivation (Serin, 2018). Therefore, problems that give learners the immediate, measurable aim of using what they have learned to address an actual problem are intrinsically motivating.

2.1.2 The Concept of Understanding

Understanding is an educational goal that according to McTighe et al. (2004), should be worth attending to as educators. In providing a framework for classifying educational goals and objectives, Benjamin Bloom and his associates categorised learning into three domains which are the cognitive, affective and psychomotor domains (Bloom et al., 1973). This framework has been adopted by curriculum planners in most countries including Ghana (Ministry of Education, 2010) as standard for assessing teaching and learning. In Bloom's cognitive domain there are six levels of behavioural classes which include remembering, understanding, application, analysis, synthesis and evaluation (Bloom et al., 1973). Therefore, since understanding is a very important aspect in assessing teaching and learning, it is appropriate to provide a fitting definition for it.

In their work, Bloom et al. (1973) define understanding as "constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarising, inferring, comparing, and explaining" (P. 45). Therefore, understanding involves a student's ability to explain and articulate a concept, provide examples and illustrations, and offer a more imaginative explanation using words or symbols (Kholid et al., 2021). This means that the ability of a student to demonstrate understanding of concepts means being able to interpret an idea accurately without altering its original meaning. According to McTighe et al. (2004), for a student to fully understand a concept, there are six facets of knowledge which the student must demonstrate. First, the student should be able to explain concepts, principles and processes by paraphrasing, impart it to others, provide evidence for their responses, and demonstrate their thinking. Second, the student should be capable of interpreting data, text, and experiences by making sense of them through the use of images, analogies, stories, and models. Third, in novel and complicated situations, the learner should be able to apply what they have learned by skillfully utilising and adjusting it. Fourth, the student should be able to display perspective by considering the larger picture and identifying other points of view. Fifth, the student should be able to demonstrate empathy by feeling for others and putting themselves in their shoes. Lastly, the student should be able to demonstrate self-knowledge through metacognitive awareness and reflection on the significance of the experience and learning. From the foregoing, it can be concluded that, understanding goes beyond just a mere collection of facts and principles.

In the context of chemistry, Holme et al. (2015), using a sample of 1395 general chemistry lecturers in a national survey across varying levels of education, developed a five-component definition of understanding a concept. In their study, Holme et al. (2015) concluded that for a chemistry student to demonstrate understanding in a concept, the student must be able to demonstrate transfer of concepts – that is applying fundamental concepts of chemistry to unfamiliar chemical circumstances for the learner. Second, the student must be able to demonstrate an in-depth knowledge of the concept – that is thinking critically about fundamental concepts in chemistry utilizing abilities that go beyond simple rote learning or algorithmic problem solving. Third, the learner must be able to predict – that is broaden situational knowledge to elucidate how chemical systems behave. Fourth, the learner must be able to demonstrate problem-solving skills – that is demonstrate the use of reasoning and critical thinking in solving problems. Lastly, Holme et al. (2015) assert that for a learner to demonstrate understanding of a concept, the learner must be able to translate across scales and representations.

Given these definitions, it can therefore be said that educators' assessment of conceptual understanding should exhibit at least one of these components in test items as well as students' responses to the items.

2.1.2.1 Levels of Students' Understanding

It can be drawn from the preceding section (section 2.1.2) that understanding transcends mere memorisation (Holme et al., 2015; McTighe et al., 2004), venturing into varying levels as Holme et al. (2015) assert. These levels have been unraveled by researchers. For instance, Milenković et al. (2016) and Japashov et al. (2024) classified students' understanding as scientific knowledge, lucky guess, lack of knowledge, and misconception. Nuzulia et al. (2018) also categorised students' level of understanding in thermochemistry as high, and low levels. According to Nuzulia et al. (2018), students had high conceptual understanding if they obtained a score of 40-100 and low conceptual understanding if they obtained a score of 0-39. However, it can be argued that based on the definitions of Bloom et al. (1973), McTighe et al. (2004) and Holme et al., (2015) that using overall scores to determine conceptual understanding of students may not reveal the true understanding or conception of the student to classify their understanding as high or low.

Anim-Eduful and Adu-Gyamfi (2022a) classified students' understanding into "full scientific understanding", "partial scientific understanding" and "no scientific understanding". Meiliyadi et al. (2023) in their study also categorised students' levels of understanding as "full understanding", "partial understanding", "misconception" and no "understanding". Hanson et al. (2016) also categorized students' level of understanding into sound conception (when students' responses included all elements of the validated responses), partial conception (in cases where students' answers contained some, but not all, of the elements of the validated response) and alternative conception (when students' answer space was blank or contained illogical, inaccurate, irrelevant, or confusing answers). It can therefore be said from the above, that by classifying students' answers into the mentioned categories, much insight can be gained into students' conceptual understanding about the concept.

2.1.3 The Concept of Organic Chemistry

Organic chemistry is the branch of chemistry that focuses on the study of carbon-based compounds, which are the building blocks of life (McMurry, 2013). Carbon is a unique element because of its ability to form long chains and complex structures through bonding with other elements, particularly hydrogen, oxygen, nitrogen, sulfur, and phosphorus. These compounds are the foundation of all living organisms, from the simplest bacteria to the most complex human beings (Petrucci et al., 2011). Understanding organic chemistry is crucial for comprehending the molecules and processes that govern life.

One of the key aspects of organic chemistry is the study of hydrocarbons, which are compounds made up of only hydrogen and carbon atoms (Petrucci et al., 2011). These hydrocarbons come in various forms, including alkanes, alkenes, and alkynes, each distinguished by the type of carbon-carbon bonds they possess. For example, alkanes have single bonds between carbon atoms, alkenes have double bonds, and alkynes have triple bonds (Wade, 2013). This variety of structures, according to Wade (2013), leads to a vast array of organic molecules with different properties and functions. Functional groups are another fundamental concept in organic chemistry. These are specific arrangements of atoms within a molecule that determine its chemical reactivity and properties (McMurry, 2013). Common functional groups include hydroxyl (-OH), carbonyl (C=O), carboxyl (-COOH), and amino (-NH2) groups, among many others (Petrucci et al., 2011). By understanding how these functional groups behave and interact, chemists can predict the behavior of organic compounds in various reactions (Adu-Gyamfi & Asaki, 2023).

Organic reactions are at the core of organic chemistry, where molecules undergo transformations through the breaking and forming of bonds. These reactions follow specific mechanisms and pathways, which can be understood through detailed study and experimentation (Anim-Eduful & Adu-Gyamfi, 2022a). Some reactions involve adding functional groups to a molecule, while others involve rearranging existing atoms within the compound. The study of reaction mechanisms allows chemists to design and synthesize new organic molecules for applications in medicine, materials science, agriculture, and more (Yaayin et al., 2022).

In general, organic chemistry plays a crucial role in everyday life. It is central to the development of pharmaceuticals, as many drugs are organic compounds designed to interact with specific biological targets in the body. The field also contributes to the creation of new materials, such as plastics, fibers, and coatings (Adu-Gyamfi et al., 2017). Understanding organic chemistry helps us make sense of the foods we eat, the medicines we take, and the materials we use (Anim-Eduful & Adu-Gyamfi, 2022b), highlighting its importance in both scientific research and practical applications in our daily lives.

2.2 Theoretical Review of the Study

As a pedagogical technique, PBL has its root from the constructivist theory (Tan, 2003). The core principle of constructivism is that learning is an active process where individuals construct new ideas or concepts based on their current knowledge and past experiences (Bada, 2015). Developed by scholars such as Jean Piaget and Lev Vygotsky, constructivism emphasizes the importance of learners' mental models and their interactions with the environment (Amineh & Asl, 2015). This theory suggests that learners actively engage in sense-making activities (Krahenbuhl, 2016), where they reconcile new information with existing cognitive structures, ultimately fostering deeper understanding and knowledge acquisition.

At the heart of constructivism lies the concept of schema, which refers to mental frameworks that individuals use to organize and interpret information (Piaget, 1976). According to Piaget (1976), individuals constantly adapt their schemas through processes of assimilation and accommodation. Assimilation involves incorporating new information into existing schemas, while accommodation requires modifying existing schemas to incorporate new information. This dynamic interplay between assimilation and accommodation allows individuals to gradually build more complex and accurate mental representations of the world around them (Devi, 2019).

Vygotsky, on the other hand, introduced the idea of the Zone Of Proximal Development (ZPD), which refers to the gap between what a learner can achieve independently and what they can achieve with guidance and support from others (Mugambi, 2018). Vygotsky (1994) emphasised the importance of social interaction and cultural context in learning, arguing that meaningful learning occurs within the ZPD through collaborative activities and scaffolded support provided by more knowledgeable others, such as teachers, peers, or mentors. This socio-cultural perspective highlights the role of language, social cues, and cultural tools in shaping individuals' cognitive development. Vygotsky's notion of the ZPD highlights the idea that learning is not solely an individual endeavor but a collaborative and socially mediated process (Eun, 2019). In classroom settings, collaborative learning activities, such as group projects, peer teaching, and cooperative problem-solving tasks, create opportunities for students to interact, share perspectives, and negotiate meaning together (Tan, 2003). These social interactions, according to Tan (2003), not only facilitate knowledge construction, but also promote the development of communication skills, empathy, and a sense of community among learners.

Mugambi (2018) asserts that constructivist approaches to education prioritise student-centered, inquiry-based learning environments where learners actively participate in constructing their own understanding. In this context, teachers serve as facilitators and guides rather than lecturers, fostering opportunities for exploration, discovery, and reflection (Juvova et al., 2015). These environments often incorporate hands-on activities, group discussions, and real-world problem-solving tasks (Efgivia et al., 2021) to engage learners in authentic learning experiences that promote critical thinking, creativity, and metacognition (Mohammed & Kinyo, 2020; Poonam, 2017). Thus, one can say that constructivist principles underpin the development of learner-centered instructional strategies and educational technologies aimed at promoting active engagement and meaningful learning experiences. These approaches often incorporate scaffolding techniques, formative assessment, and authentic assessments to support learners' cognitive processes and monitor their progress (Darsih, 2018; Saleem et al., 2021). By aligning instruction with learners' prior knowledge, interests, and abilities, Krahenbuhl (2016) and Golder (2018) argue that educators can enhance motivation, retention, and transfer of learning. In conclusion, constructivist theory offers a powerful lens through which to understand the process of learning and the role of educators in facilitating meaningful educational experiences.

2.2.1 Relationship Between PBL and Constructivism

According to Tan (2003), the active role learners play in making meaning of concepts in a PBL environment makes the use of PBL fit into the constructivism principles. In PBL, students are presented with complex, real-world problems or challenges that require critical thinking, collaboration, and problem-solving skills to resolve. This approach encourages students to engage in inquiry, exploration, and discovery, which are key elements of constructivist learning. By working through these authentic problems, students not only acquire knowledge but also develop a deeper understanding of concepts and how they apply in practical contexts.

At the core of PBL is the idea that learning is most effective when it is contextualised and meaningful to the learner (Savery, 2006). Piaget (1976) believed that meaningful learning occurs when individuals connect new information to their existing knowledge and experiences. In a PBL setting, students grapple with ill-structured problems that resonate with real-life scenarios (De Graaff & Kolmos, 2003). This mirrors Piaget's notion of "schemata," which are mental structures individuals use to organize and interpret information (Piaget, 1976). When students engage in PBL, they are prompted to draw upon their existing mental schemes, adapting and restructuring them as needed to tackle the problem at hand (Tan, 2003). This process of assimilation and accommodation, central to Piaget’s theory, is evident as students grapple with new information, adjust their thinking, and arrive at solutions through their active engagement with the problem. This approach fosters deeper engagement and motivation, as students see the relevance of their learning to the world outside the classroom.

Moreover, PBL encourages the active construction of knowledge through collaboration and discussion. In Vygotsky's (1994) constructivist framework, social interaction plays a crucial role in cognitive development. Through interactions with peers, students are exposed to diverse perspectives, which challenge their existing ideas and schemas. In a PBL setting, students often work in groups, sharing their thoughts, strategies, and solutions (Hmelo-Silver, 2004). This collaborative process mirrors Vygotsky's (1994) idea of social constructivism, where knowledge is co-constructed through social interactions.

Also, PBL supports the idea of “scaffolding,” a concept often associated with Vygotsky's (1994) theory. Scaffolding involves providing support and guidance to learners as they work on tasks that are just beyond their current level of understanding (Joda, 2019). In PBL, educators act as facilitators, offering guidance, resources, and feedback to help students navigate complex problems. This gradual release of responsibility empowers students to take ownership of their learning while ensuring they have the necessary support to succeed. This process reflects Vygotsky's (1994) concept of the “Zone Of Proximal Development” (ZPD), which is the gap between what a learner can accomplish independently and what they can achieve with support from the instructor and/or more knowledgeable peers.

Finally, within PBL, students are not just passive recipients of information but active participants in constructing their knowledge. This aligns with both Piaget and Vygotsky's emphasis on the importance of active, hands-on experiences in learning. PBL tasks often require students to research, experiment, and apply their knowledge in practical ways (Tan, 2003), providing the kind of experiential learning Piaget (1976) and Vygotsky (1994) advocated. Through these experiences, students not only deepen their understanding of content but also develop problem-solving skills and meta-cognitive strategies, which are essential aspects of constructivism.

2.3 Conceptual Framework of the Study

Situated in the constructivist learning theory, the use of PBL ensures that learners actively engage the concepts of organic chemistry through collaborative and experiential learning activities. Through these activities, learners make meaning of the content by themselves, making them owners of their own knowledge. The resulting effect is that learners' understanding of organic chemistry is enhanced. This is conceptualised in Figure 2.1.

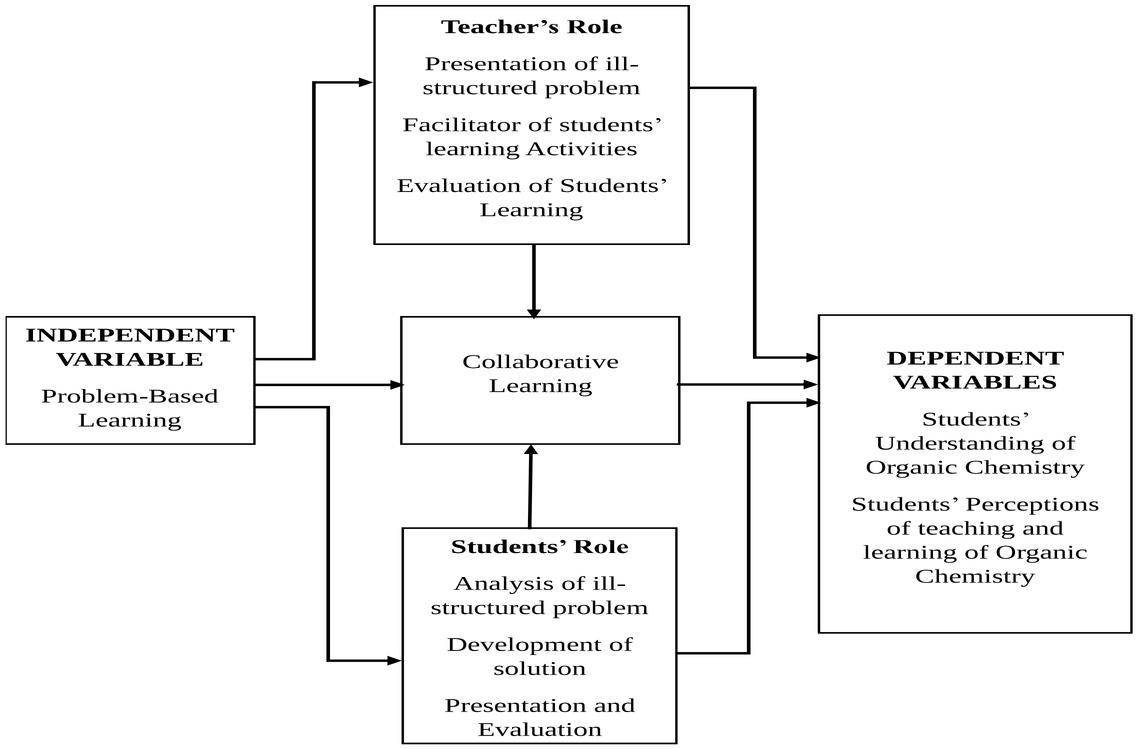

Figure 2. 1: Conceptual Framework of the Study

As shown in Figure 2.1, the independent variable is Problem-Based Learning. This variable is conceptualised as the variable causing a change in the dependent variables, which were students' understanding in organic chemistry as well as their perceptions in the use of PBL in the teaching and learning of organic chemistry. From Figure 2.1, the teacher plays a role as a facilitator who presents an ill-structured problem (a problem that lacks straightforward solution path) to the students, moderates the learning process as the learners analyse the problem, develop solution to the problem and present their solutions to the whole class for subsequent evaluation. In this way, the learner's role in Figure 2.1 is to actively perform activities assigned them. By so doing, the instructional methods are then able to influence students' understanding in organic chemistry.

2.3.1 Characteristics of Problem-Based Learning

There are certain activities that characterize a PBL environment. These activities include student-centeredness, ill-structured problem, the instructor's role and collaboration (De Graaff & Kolmos, 2003; Hmelo-Silver, 2004; Savery, 2006; Tan, 2003). These are briefly explained below.

Student-centeredness – In PBL, students are presented with complex, real-world problems to solve, often resembling the challenges they might encounter in their future careers. This approach, as Savery (2006) suggests, places the responsibility for learning squarely on the students' shoulders, as they must research, analyze, and develop solutions to these problems. Rather than passively receiving information from a teacher, students engage deeply with the material, often collaborating with peers to brainstorm ideas and strategies. In their view, Da Silva et al. (2017) highlight that this dynamic process fosters a sense of ownership over their education, allowing students to develop critical thinking, problem-solving, and teamwork skills in an organic and meaningful way.

The emphasis on ill-structured problem – Central to PBL is the use of authentic, ill-structured problems that mirror the challenges professionals face in their fields (Yew & Goh, 2016). Defining an ill-structured problem, Tan (2003) stated that ill-structured problems lack a straightforward answer or defined approach. These problems, according to Tan (2003), often mirror the messy, real-world scenarios that professionals encounter in their careers, requiring students to navigate uncertainty, conflicting information, and changing circumstances. Hmelo-Silver et al. (2019) add that these problems are often interdisciplinary, requiring students to draw upon knowledge from various subjects to develop solutions. This interdisciplinary nature encourages holistic thinking and helps students appreciate the interconnectedness of different areas of knowledge. The ill-structured problem also focuses on the process of inquiry and exploration rather than a predetermined outcome (Da Silva et al., 2017).

This process-oriented approach emphasizes the journey of learning, with students continually revising their understanding, testing hypotheses, and considering alternative perspectives (Ceker & Ozdamli, 2016). Through this iterative process, students develop essential skills such as problem-solving strategies, collaboration, communication, and adaptability – skills that are invaluable for success both in their academic pursuits and future careers (Da Silva et al., 2017). According to Kolmos et al (2008), the open-ended nature of ill-structured problems also fosters creativity and innovation, challenging students to think outside the box and develop novel solutions to complex, real-world challenges.

The role of the classroom teacher – Another hallmark of PBL is the role of the instructor as a facilitator rather than a lecturer (Hmelo-Silver, 2004). Instead of providing direct answers, instructors guide students through the problem-solving process, helping them develop skills in research, critical analysis, and decision-making (Da Silva et al., 2017). This can be achieved when the teacher creates an environment that fosters inquiry, critical thinking, collaboration, and problem-solving skills among students. This, according to Ceker and Ozdamli (2016), includes the design of meaningful problems, facilitation of learning processes including group discussions, modeling of inquiry and critical thinking, providing support and resources as needed, clarifying concepts, helping students navigate challenges they encounter along the way and assessment of students' learning outcomes. This shift in the instructor's role fosters a sense of autonomy and ownership among students, as they take responsibility for their learning journey.

Collaboration – Collaboration is also a fundamental aspect of PBL (Savery, 2006). Thus, in a PBL classroom, students often work in small groups to tackle problems, sharing their perspectives, ideas, and research findings. This collaborative environment mirrors real-world professional settings where teamwork and effective communication are essential for success. Through collaboration, students learn not only from their own investigations but also from the diverse insights and approaches of their peers.

2.3.2 Implementing Problem-Based Learning

Literature reveals diverse ways in which PBL is implemented in the classroom (Da Silva et al., 2017; De Graaff & Kolmos, 2003; Savery, 2006; Tan, 2003). However, a synthesis of these studies revealed four key steps in the PBL process, all of which are designed to lead students through an organized method of problem solving. These stages are presentation of ill-structured problem, analysis of the problem, solution development, as well as communication of solutions and evaluation. The various stages are briefly explained in the next sub-sections (2.3.2.1 to 2.3.2.4).

2.3.2.1 Presentation of Ill-Structured Problem

At this stage, the teacher introduces the problem to the students, provides the students with the necessary background information, context, and constraints, encourage questions and clarifies any misunderstandings. According to Da Silva et al. (2017) the problem should describe an actual situation that has to be resolved. Da Silva et al.

(2017) provided additional characteristics of the problem, where they stated that the problem should be straightforward and objective in order to prevent confusion when identifying the main goal; it should also be motivating for the student; it should include a description of the case that is impartial; it should be able to clarify the information needed to resolve it; it shouldn't include procedures for doing so; it should let students make their own decisions; it should concentrate on a small number of learning objectives; and it should contain elements that the students are already familiar with.

According to Tan (2003), while presenting the problem to the learners, the instructor should encourage students to brainstorm questions related to the problem. These questions will guide the students research and investigation. Also, the teacher can help students identify what they need to learn in order to solve the problem. This may involve clarifying concepts, exploring relevant theories, or acquiring specific skills. Savery (2006) further emphasized that learning is less driven and less involved in the process of developing a solution when a problem is well-structured. As a result, the problem should be stated in such a way that learners will be intrigued to design a course of action to find solution to the problem.

2.3.2.2 Analysis of the Problem

At this stage, students examine the problem scenario in small groups, consisting of eight to twelve members (De Graaff & Kolmos, 2003; Tan, 2003). Thus, this is the stage where the students assess what they know about the subject, consider it, analyse it, and share knowledge with colleagues and teachers in order to generate ideas, generate hypotheses, and find answers. Students are asked to develop their own learning issues and objectives based on the questions posed as they reflect on the topic, brainstorm, and discuss in groups. De Graaff and Kolmos (2003) provide seven steps which students can engage in analysing the problem. These include making the concepts more understandable, describing the problem, analysing the problem, coming up with an explanation, creating a learning objective, looking for more information, and reporting and testing new information. The instructor takes on the roles of mentor and facilitator, assisting the group's work and member interactions.

2.3.2.3 Development of Solution

In developing the solution to the problem, after the students have analysed and identified the various facets of the problem, they then split up the job so each of them can look for the information they need on their own (Tan, 2003). Students combine the knowledge they have acquired and evaluate it in light of the problem at hand. They then begin to formulate potential solutions or approaches. At this stage students engage in self-directed learning to explore the problem further (De Graaff & Kolmos, 2003). They conduct research, analyze data, and gather information from various sources such as books, journals, internet resources, and resource persons and to return with more knowledgeable responses to the problems raised (Tan, 2003).

2.3.2.4 Presentation and Evaluation

After conducting research and engaging in self-directed learning, students present their learning discoveries to their respective groups. Students come together to share the new knowledge they have each independently acquired during this peer-teaching phase. Students use inquiries and seeking out further information from one another to build group collaboration and communication skills. The PBL tutor quizzes students on the validity and reliability of the material they have learned while also assisting in making sure that important topics are not missed. In this way, the tutor assists students in resolving questions, identifying areas of knowledge deficiency, and clearing up misunderstandings or oversimplifications.

2.3.4 Students' Difficulties in Organic Chemistry

Students' difficulties in understanding organic chemistry concepts are well documented in literature. For instance, Eticha and Ochonogor (2015) employed quantitative and qualitative approaches using document analysis (on students' answered scripts) and interview to determine students' difficulties in solving organic chemistry problems. The authors reported that major areas of difficulties among students were functional groups, stereoisomerism and organic compounds reactions. In their study, O'Dwyer and Childs (2017) also reported that majority of high school and university learners deemed reactions of organic compounds, isomerism, mechanisms and syntheses of organic compounds as difficult to understand. In the same study, participants rated nomenclature of organic compounds as not difficult to understand, however, students' poorly answered questions relating nomenclature of organic compounds when a diagnostic test was used to test their understanding.

Also, Adu-Gyamfi et al. (2017) diagnosed SHS chemistry students' difficulties in IUPAC nomenclature of organic compounds using an achievement test and interview. Adu-Gyamfi et al. (2017) revealed that students had difficulties in naming structural formulae of branched and substituted-chains of alkanes and alkenes, geometrical isomers, dienes, unbranched alkynes, primary and tertiary alkanols, diols, alkanoic acids, and alkyl alkanoates. The demonstration of these difficulties, according to Adu-Gyamfi et al. (2017), stemmed from students' inability to identify the correct number of carbon atoms in the parent chain, and to identify a substituent or functional group, amongst others.

Using a semi-structured interview, Popova and Bretz (2018) assessed chemistry students on the factors that contribute to the stability and reactivity of organic compounds as far as unimolecular and bimolecular nucleophilic substitution and elimination reactions are concerned. Popova and Bretz (2018) found that in these reactions, the majority of students correctly identified the leaving groups and called them "good leaving groups." Less than half of the students, however, were able to describe the structural and electrical elements that support classifying a species as a "good leaving group". Almost one-third of the students who participated in the interviews were unable to explain in any detail why one leaving group was superior to another.

Balea (2021) also studied pre-service teachers' understanding in nomenclature of aliphatic hydrocarbons. In Balea's (2021) study where analysis was conducted item by item, (classified as alternative conception or correct conception) it was found that higher percentages of participants demonstrated alternative conceptions on all items while lower percentages of participants demonstrated correct conceptions. Examples of students' alternative conceptions were "alkane molecules can have double and triple bonds in their structures", "naming of alkane molecules is related to electronic configuration", "misunderstanding of identifying the parent chain in branched hydrocarbon" amongst others. A study conducted by Nartey and Hanson (2021) in Ghana revealed that 45% out of 100 participants considered preparation and chemical reactions of alkenes, preparation and chemical reactions of alkynes, structure and stability of benzene, reactions of benzene, comparison of reactions of benzene and alkenes, as the most organic chemistry concepts they find difficulty in understanding, while 48% did not find much difficulty in understanding these concepts.

In another study, Anim-Eduful and Adu-Gyamfi (2022a) reported that senior high school students demonstrated difficulties in organic qualitative analysis. In their study, the authors used a two-tier diagnostic test and found that the overall difficulty index for all the items was 0.35. Furthermore, in the two-tier diagnostic test with a total score of 44, the average mean score was 8.89(SD=7.218). Greater percentages of student exhibited difficulties in detection of functional groups in saturated and unsaturated carbon compounds. Also, greater percentages of students failed to draw the appropriate chemical structures of organic compounds undergoing chemical reactions. Furthermore, students demonstrated little or no knowledge about organic reagents required to test functional groups, as well as providing the appropriate reactants and observations in given reactions.

2.3.4.1 Psychometric Approaches to Assess Students' Understanding of Concepts

From Bloom's taxonomy of behavioral objectives, it can be inferred that if an individual's understanding in a topic is incomplete, their academic performance is also challenged (Bloom et al., 1973). Academic performance concerns how well students are doing in a subject as demonstrated by their grades, scores on tests or assignments, and overall achievements in that subject (Lamas, 2015). Understanding, on the other hand, refers to a deeper level of comprehension and mastery of the content (Bloom et al., 1973; Holme et al., 2015). Thus, understanding deals with students' ability to think critically, adapt to new challenges, and engage deeply with the subject matter. In view of this, understanding of a concept is assessed differently from academic performance.

Researchers have developed diagnostic approaches to assess students' understanding of concepts. These include open-ended interviews, open-ended tests, multiple-choice tests and tiered instruments. Nevertheless, all these approaches have their inherent benefits and limitations (Putica, 2023). According to Gurel et al. (2015) interviews are considered a crucial instrument for assessing students' grasp of a given concept due to their comprehensive inquiry and ability to elucidate intricate details of a student's cognitive architecture. This can be done face-to-face (one-on-one) with groups. While conducting interviews offers the benefit of revealing people's thoughts, feelings, and topics of interest in depth, it requires a lengthy period of time to interview a larger sample to achieve higher generalizability. Also, sampled questions for the interview may not cover enough content areas (Putica, 2023). Furthermore, data analysis might be a bit challenging and time-consuming, coupled with bias from the interviewer which could taint the results (Gurel et al., 2015).

Open-ended tests give test takers more time and freedom to think and write about their own ideas. According to Rahayuningsih et al. (2021), open-ended assessments work well for quantifying creative thinking, which is an important skill as far as understanding is concerned (Holme et al., 2015). However, open-ended tests are challenged by both time-consuming in scoring procedure and the availability of qualified, trustworthy graders (Vasan et al., 2018). Because of this, the amount of sampled items used in open-ended tests are very limited and do not cover enough content areas like interviews (Gharehbagh et al., 2022).

Multiple-choice tests can also be used to determine students' understanding of concepts in place of interviews and open-ended tests because they can be quickly scored and utilized on a wide range of concepts within a particular subject (Gurel et al., 2015). These tests, according to Gurel et al. (2015), can also be applied as a broad assessment tool either in conjunction with or instead of in-depth interviews. Multiple-choice tests have the following benefits: they cover a wide range of topics in a relatively short amount of time; they are versatile and can be used to measure different levels of learning and cognitive skills; they are easy to score and, therefore, more reliable; and they are good for students who are proficient in their subject matter but not as good writers (Gurel et al., 2015; Vasan et al., 2018).

Despite the benefits of multiple-choice tests, Vasan et al. (2018) argue that the choices made do not offer a comprehensive evaluation of students' in-depth understanding of concepts. Additionally, examinees are unable to conceptualise, organise, and present their own responses because they are required to select each response from a very small set of alternatives (Gurel et al., 2015). For this reason, multiple-choice tests do not provide enough depth into students' conceptual understanding, and they can cause them to give accurate answers for incorrect reasons (due to guessing), which could cause results to be overestimated (Vasan et al., 2018).

To overcome the disadvantages in multiple-choice tests, while gathering enough information from students to determine their in-depth understanding about concepts, multiple-tier tests were suggested (Gurel et al., 2015). A tiered instrument is a testing tool or assessment system that is divided into different levels of difficulty (Türkoguz, 2020). These include two-tier tests, three-tier tests and four-tier tests. Two-tier test contains two levels of difficulty where the first tier consists of a multiple-choice item while the second tier consists of reason for the choice in the first tier (Gurel et al., 2015; Türkoguz, 2020). With this type of instrument, students are deemed to demonstrate full understanding when answers to each tier are both the correct choice and the correct reason (Gurel et al., 2015).

According to McClary and Bretz (2012), by including a reason tier in addition to declarative and procedural knowledge tests, teachers can ascertain whether or not students have a more thorough comprehension of the concept covered in a given item. Two-tier diagnostic tools can give teachers additional insight into how students conceptualise a particular subject, but they do not tell how such starkly different conceptions skew students' reasoning (McClary & Bretz, 2012). That is, these tests are unable to distinguish between errors resulting from a lack of knowledge and errors resulting from the existence of alternative ideas. They are also unable to distinguish between accurate answers derived from scientific knowledge and those resulting from conjecture (Gurel et al., 2015).

Following the identification of the disadvantages of the two-tier test, the third tier of the test, which asks about confidence in the answers provided in the first two tiers, was meant to make up for the shortcomings of the two-tier assessments (Gurel et al., 2015; McClary & Bretz, 2012). According to Yang and Sianturi (2019), for a student to demonstrate full understanding on a concept, the student must also exhibit full confidence in explaining the concept or anything related to the concept. By incorporating a confidence tier into the first and second tiers, educators can measure the degree to which students' conceptual understandings are supported (Gurel et al., 2015). This then produces a three-tier test. Thus, a three-tier test consists of the first tier, which is usually a multiple-choice test; the second tier, which asks for the reasoning for respondents' choices in the first tier; and the third tier which asks for the students' confidence level for the given answers for the first and second tiers. In view of this, students are considered to demonstrate full understanding when both the correct choice and reason are given with a high confidence. Similarly, students' answers are deemed as misconceptions when a wrong answer choice is selected followed by wrong reasoning and with a high confidence. Therefore, the benefit of three-tier testing is that it can distinguish between students' lack of knowledge and misconceptions.

However, because students were covertly asked about their confidence in the answers to the first two tiers of a three-tier test, this could exaggerate student scores and underestimate the percentage of students who lack knowledge (Soeharto et al., 2019). This led to the introduction of four-tier tests, where confidence ratings for the first tier and second tier can be requested independently (Gurel et al., 2015). Nevertheless, the four-tier test does have several drawbacks, such as the need for a longer testing period, and the potential for students' choices in the first tier to affect their reasoning in the second tier.

Having reviewed the various advantages and disadvantages associated with the psychometric tests, three-tier test was therefore used in this study for the purpose of determining the levels of understanding (full understanding, partial understanding, misconception, and null understanding). The choice of using three-tier test was grounded in the ability of having a confidence tier, which could help in distinguishing students' misconceptions and lack of knowledge (Gurel et al., 2015) in organic chemistry concepts investigated in this study. Also, Gurel et al. (2015) and Soeharto et al. (2019) argue that due to its nature, there may be increase in resource requirements. Also, the lengthy testing process associated with four-tier exams may cause anxiety in students.

Moreover, the three-tier test used in this study did not provide options for students to choose from in the second tier (Cetin-Dindar & Geban, 2011; Gurel et al., 2015; Kirbulut & Geban, 2014; Milenković et al., 2016; Sari et al., 2024; Soeharto et al., 2019). However, students were given the opportunities to provide their own explanations to each choice in the first-tier as adopted by Meiliyadi et al. (2023) and Japashov et al. (2024). By so doing, it was possible to gather in-depth information about students' knowledge they possess in the concept. As a result, students' reasons provided in the second tier were analysed quantitatively and supported by qualitative analysis.

2.3.4.2 Improving Students' Understanding in Organic Chemistry

The preceding section (section 2.3.4.1) brings to light that students demonstrate little understanding in organic chemistry and this has existed for several years. It is therefore important that researchers and chemistry educators develop innovative ways to enhance students' understanding in organic chemistry. According to McTighe et al. (2004), educators can do this when they actively engage learners in meaning-making. When students are given the chance to build their own understanding around important concepts and topics, meaning-making takes place (Sibomana et al., 2020). In order to learn to build meaning, McTighe et al. (2004) argue that students must first ask questions. That is, they need to engage in mental and physical activities that support their ability to form connections and create their own meaning. In this way, learning is not a direct process (from teacher to student).

Another hallmark of learning to understand, according to McTighe et al. (2004), is that students refine and revisit ideas over time, progressing from basic, occasionally incorrect constructions to more complex, accurate concepts. Thinking is the medium through which this kind of learning is mediated. That is, through asking questions, students analysing and evaluating what they observe, combining ideas, drawing conclusions, attempting to solve problems, and developing reasoning and strategic thinking skills through social and cooperative processes (Bunce, 2015). In general, learning and understanding increase the more learners engage in interactions. Adopting PBL, students' understanding of concepts is enhanced by actively engaging them in contextual, collaborative, and challenging learning experiences. It promotes critical thinking, problem-solving skills, motivation, and reflection, all of which contribute to a deeper and more meaningful grasp of the subject matter (Tan, 2003).

2.4 Empirical Review of the Study

This section presents empirical review of previous literature related to this study, through which gaps were identified which served as the rationale for this study. Thus, the empirical review of PBL on students' learning outcomes as well as empirical review of students' perceptions of teaching and learning using PBL were reviewed.

2.4.1 Empirical Review of Effectiveness of PBL on Students' Learning Outcomes in Chemistry

The implementation of PBL has been investigated by researchers in the field of chemistry. Results and findings from these researchers indicate a positive effect of PBL on students' learning outcomes in chemistry. For instance, Gurses et al. (2015) in Turkey taught 31 third-year undergraduate students the concept of enthalpy before and after using PBL. A paired sample t-test results showed that there was a statistically significant difference between the pretest (mean= 45.45) and posttest scores (mean=57.59; $t_{(30)}$=2.22, p=0.033). This indicates that the use of PBL in the teaching and learning of enthalpy was effective. In Ghana, Yaayin (2016) compared the use of PBL and the conventional teaching method in the teaching and learning of Mole concept using a quasi-experimental pretest/posttest control group design. By employing 88 first year Diploma in Basic Education students of Tamale College of Education, it was found that students exposed to PBL in the teaching and learning of mole concept performed better than those taught using the conventional teaching method.

Aidoo et al. (2016) assessed the effectiveness of PBL on chemistry students' academic achievement in KwaZulu-Natal province in South Africa. Using a quasi-experimental pretest/posttest control group design, Aidoo et al. (2016) found from the results of an independent sample t-test that there was a significant difference between students taught using PBL (mean=31.76, SD=4.394) and those taught using the conventional teaching approach (mean=19.98, SD=7.279; $t_{(100)}$=9.899, p=0.001). Per Aidoo et al.'s (2016) finding, it could be concluded that the use of PBL enhanced KwaZulu-Natal's students' performance in chemistry more than the conventional teaching approach.

Üce and Ateş (2016) investigated the effect of PBL on 10th grade chemistry students' achievement in mixtures in Istanbul, Turkey. A quasi-experimental pretest/posttest design was used with 48 students as the sample. The experimental group received PBL, while the control group was taught using a traditional, teacher-centered method. Üce and Ateş (2016) found that there was a significant difference in performance between the experimental group (M=22.04, SD=4.64) and the control group (M=17.92, SD=3.39; t= -3.897, p=0.001). This indicates that PBL was effective in improving students' achievement in mixtures in Istanbul, Turkey.

After employing quasi-experimental design, Günter and Alpat (2017) also in their study found that undergraduate second year students who were taught electrochemistry using PBL demonstrated better understanding of electrochemistry than their colleagues who were not. Specifically, using open-ended questions, Günter and Alpat (2017) found that students who were exposed to PBL recorded an average participant percentage of 81.44%, 8.25%, 2.06%, 1.03%, 7.22% who demonstrated "clear understanding", "partial understanding", "partial understanding with specific misconception", "specific misconception" and "incomprehension" respectively, while students who were not exposed to PBL recorded an average participant percentage of 48.05%, 12.98%, 3.90%, 2.69%, 32.47% who demonstrated "clear understanding", "partial understanding", "partial understanding with specific misconception", "specific misconception" and "incomprehension" respectively. In Nigeria, Jimoh and Fatokun (2020) employed a quasi-experimental pretest/posttest control group design using 110 senior secondary two (SS II) chemistry students of Karshi Zone to study the effectiveness of PBL on students' performance in mole concept. A one-way Analysis of covariance results showed that there was a significant difference between students exposed to PBL and those exposed to the conventional teaching method ($F_{(1,107)} = 575.96$, $p = 0.00 < 0.05$). According to Jimoh and Fatokun (2020), students exposed to PBL in the teaching and learning of mole concept performed better (mean=32.53, SD=1.71) than those who were taught using the conventional approach (mean = 24.85, SD= 2.43), indicating that the use of PBL in the teaching and learning of mole concept was effective among secondary chemistry students of Karshi Zone.

The reviewed studies revealed that PBL in the classroom enhances learners' learning outcomes. However, it can be identified that much attention has not been turned to students' in-depth understanding of chemistry concepts. A plethora of studies in literature focus on the overall performance of students in chemistry concepts. In this way, the use of diagnostic tests (tiered instruments) in chemistry is underutilised. Moreover, though students' difficulties in organic chemistry have been reported in literature (Adu-Gyamfi et al., 2017; Anim-Eduful & Adu-Gyamfi, 2022a; Balea, 2021; Eticha & Ochonogor, 2015; Popova et al., 2020), it appears paucity of research exist on how PBL can improve students' understanding in organic chemistry.

2.4.2 Students' Perceptions of Problem-Based Learning

In the study of Kumar and Kogut (2006), students articulated that being exposed to PBL empowered them to be self-regulated and independent learners, deep thinkers who tried to make meaning of concepts during teaching and learning. Furthermore, students perceived that their learning more meaningful by situating the ill-structured problem in real-life contexts. They also gained collaborative skills which helped them through the course of study. By so doing, students remarked that they were intrinsically motivated to learn difficult concepts and solve difficult problems. In spite of these positive perceptions, in the study of Kumar and Kogut (2006), due to lack of cooperation from some group members, there were misunderstandings and lack of cohesion among some groups which stifled the learning process. Furthermore, students deemed the assessment process in PBL as possessing a high degree of subjectivity resulting in bias due to numerous peer assessment and presentations employed.

Al-Drees et al. (2015) using a questionnaire, found out from medical students in the College of Medicine, Riyadh, Saudi Arabia that the use of PBL in their lessons enhanced their understanding in basic sciences concepts, encouraged self-directed learning, collaborative learning, and improved decision-making skills. According to Günter and Alpat (2018), even though students expressed that they were not familiar with the method, they articulated that the use of PBL in teaching electrochemistry was interesting, associated with daily life, comprehensible and educational, and that they were led to make further research after classroom interactions.

In another study conducted by Kibret et al. (2021), medical and health science students were engaged for their perceptions using a structured questionnaire, after exposure to PBL. According Kibret et al. (2021), students perceived that PBL was helpful to understand basic sciences knowledge, developed their problem-solving skills and motivated them to learn. Ahdhianto et al. (2021) in Indonesia also used a questionnaire to determine elementary school teacher education students' perceptions on the use of PBL. Ahdhianto et al. (2021) found out from learners that the use of PBL increased their engagement in the teaching and learning activities.

Various studies reviewed on the perceptions of learners on the use of PBL indicate that students usually have positive perceptions when PBL in used in the teaching and learning activities across different fields (Al-Drees et al., 2015; Günter & Alpat, 2018; Kibret et al., 2021; Kumar & Kogut, 2006), even though students sometimes have negative perceptions, especially regarding the assessment strategies involved in PBL lessons (Kumar & Kogut, 2006).

2.5 Summary of Literature Review

The literature review showed that PBL is traced to the constructivism theory. Teachers who adopt this teaching approach adhere to the philosophy that students learn best when they are given opportunities to engage in the teaching and learning activities through collaboration and discovery learning activities. PBL is therefore one of the instructional approaches which allow for students to take active part during classroom lessons.

Also, the literature review revealed that chemistry students in Ghana and outside Ghana exhibit conceptual difficulties in organic chemistry. But research has shown that PBL, which is a student-centered instructional method, can improve students' learning outcomes in chemistry. This is because students desist from rote memorisation of concepts, and learn to apply the principles involved in the material. It was also identified in literature that students' understanding of concepts, though very crucial in students' academic performance, is measured using diagnostic tests. This is because understanding of concepts, unlike students' academic performance, measures the in-depth knowledge of students which is characterised by how students can explain concepts in their own words and apply those concepts to other learning contexts. Thus, using overall performance to assess students' understanding would hinder the teachers' knowledge of the students' grasp of the subject matter.

However, the literature presents a gap which served as the basis for this study. Specifically, the literature revealed that students' difficulties in organic chemistry is well documented. Nevertheless, students' understanding in organic chemistry has not been given much attention, since most studies focus on students' academic performance. Also, the use of PBL has been documented in literature to enhance students' learning outcomes, but there is apparently a dearth of studies which have focused on assessing the effectiveness of PBL on students' understanding of organic chemistry, especially in the Ghanaian senior high school teaching context. Motivated by this gap in literature, this study therefore sought to enhance students' understanding in organic chemistry using PBL.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter presents in details the methodology of the research work. It highlights the research area, research paradigm and research design used in the study. It also outlines the population, sample and sampling techniques, instrumentation as well as validity and reliability of the test instruments. The chapter further expounds on data collection procedure and ends with data analysis procedure.

3.1 Study Site

The research took place in the Kwabre East Municipality, located in the Ashanti Region of Ghana. This municipality is one of thirty administrative districts in the Ashanti Region. Historically, it was part of the Kwabre Sekyere District until its separation in 1988. It was renamed Kwabre East District after the Afigya Kwabre District was split from Kwabre District in 2007, established under Legislative Instrument (L.I) 1894. Mamponteng, the district's capital, is about 14.5 kilometers from Kumasi. The district is renowned for its cultural heritage, unique crafts, and natural resources. It is situated between latitudes 6°45' and 6°50' North and longitudes 1°30' and 1°35' West. The district is bordered by Sekyere South District to the north, Kumasi Metropolis to the south, Ejisu Juaben District to the east, and Afigya Kwabre District to the west. At the time of the research, the municipality had three senior high schools (Ghana Statistical Service, 2021).

3.2 Research Paradigm

According to Creswell (2014), a paradigm is a term used in social science to describe a worldview that is based on philosophical presuppositions about the nature of social truth and reality. This worldview informs the interpretation or meaning of study data (Kivunja & Kuyini, 2017). There are a variety of paradigmatic viewpoints that can be chosen in social science, including positivism, post-positivism, interpretivism, constructivism, and pragmatism (Ebohon et al., 2021). For the purpose of this study, the pragmatism paradigm was adopted.

Pragmatism is an approach that contends that there are numerous techniques to comprehending reality and to interpreting the universe (Ugwu et al., 2021). Kivunja and Kuyini (2017) explain that combining these approaches can lead to a more comprehensive understanding of the phenomenon under study. According to Brierley (2017), a pragmatic study does not hold that there is a single, ultimate truth and steers clear of abstract, unchanging rules. Therefore, pragmatism acknowledges the similarities between human inquiry and scientific and experimental inquiry. In view of this, to fully understand a phenomenon, pragmatism allows for the use of both quantitative and qualitative approaches. Therefore, aligning with the principles of pragmatism, research questions were developed and answered by integrating the results of quantitative and qualitative data. Thus, research questions 1 and 2 were approached and analysed quantitatively, while research question 3 was analysed qualitatively.

3.3 Research Design

Pandey and Pandey (2015) define research design as a master plan that outlines the techniques and steps to be taken in order to gather and analyse the necessary data. According to Jilcha (2019), the research design is utilised to create an acceptable framework for a study as well as ensuring that the objectives and research questions outlined are attained. This means that research design therefore helps researchers in gathering the pertinent data and the methodologies to be applied for their analysis, while keeping in mind the goal of the research and the amount of staff time and funding that are available (Creswell, 2014).

There are different research designs which include quantitative (comprising experimental, correlational, and survey designs), qualitative (comprising grounded theory, ethnographic, and narrative research designs), and mixed method research designs (comprising a mixture of quantitative and qualitative designs, and actions research design) (Creswell, 2014). However, since the choice of a particular design depends on the objectives and research questions of the problem under study (Jilcha, 2019; Kivunja & Kuyini, 2017; Kothari, 2004), this study adopted the sequential explanatory variant of the mixed method research design. In mixed method research, collection and analysis of both quantitative and qualitative data are collected and analysed. The two sets of results are integrated at some point in the research to make generalisations from the quantitative and qualitative results (Leavy, 2017). However, adopting the sequential explanatory variant of the mixed-method research design means that quantitative data was collected and analysed in the initial phase of the study. Following the analysis of the quantitative results, qualitative data collection technique was employed to give the results more depth or context (Creswell, 2014). In this regard, quantitative data in the form of scores from a diagnostic test were collected and analysed to answer research questions 1 and 2, after which qualitative data in the form of interview responses were collected and analysed to answer research question 3. However, in this study the quantitative aspect of the study was given more weight than the qualitative aspect. The implication is that the qualitative results were used to explain the quantitative results. Therefore, few participants were selected from the total sample to be interviewed for their perceptions. This provided a comprehensive understanding on the use of PBL in enhancing SHS chemistry students' understanding in organic chemistry.

3.3.1 Overall Study Design

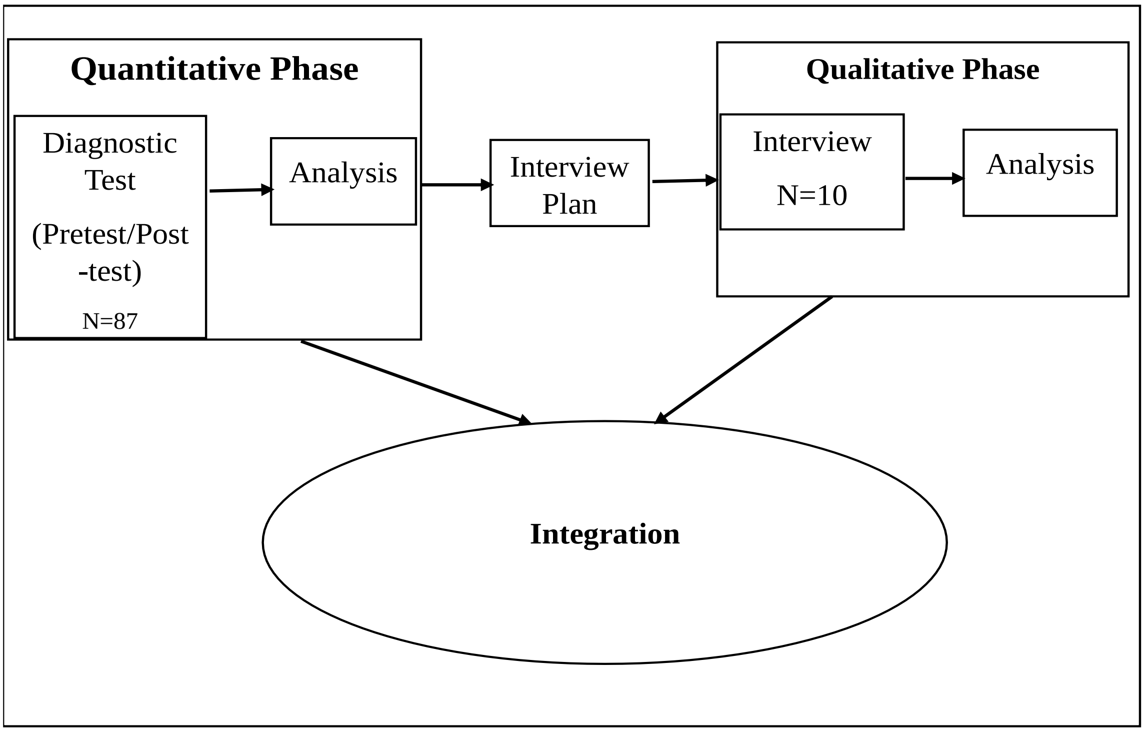

Figure 3.1: Framework of Overall Study Design

As seen from Figure 3.1, the quantitative phase of the study was characterised by the collection of numerical data using a diagnostic test with a larger sample (N=87). The diagnostic test was conducted pre- and post-intervention, after which the data were analysed quantitatively. The pre-intervention test helped to determine students' level of understanding in organic chemistry before the intervention, thereby answering research question 1. Following the pre-intervention test, an intervention was designed where students were exposed to PBL. Post-intervention test was thus conducted using the diagnostic test to determine students' level of understanding in organic chemistry after the intervention. This helped to ascertain the extent to which PBL enhances students' level of understanding in organic chemistry, ultimately answering research question 2. It must be noted however that in collection of quantitative data, intact classes were used. This was due to the fact that students were already assigned to their respective classes based on their programmes of study and therefore was not practically possible to randomly select participants.

In a bid to obtain a comprehensive understanding of the effectiveness of PBL in enhancing students' understanding of organic chemistry, a semi-structured interview was conducted where 10 participants were randomly selected to solicit their perceptions on the use of PBL in the teaching and learning of organic chemistry. This helped in answering research question 3, leading to the integration of both the quantitative and qualitative data, where the qualitative results explained the quantitative results.

3.4 Population

A research population generally refers to a large group of individuals or objects that are the primary focus of a particular scientific study (Casteel & Bridier, 2021). Accordingly, Pandey and Pandey (2015) view research population as all the units, with similar characteristics to which study findings can be applied. Populations can be small or large. In essence, the bigger group is the target population and the smaller group is the accessible population (Appiah-Twumasi et al., 2020). According to Pandey and Pandey (2015), the term "target population" refers to the total set of people or things that researchers are interested in generalising the findings to. The accessible population on the other hand is the total number of instances or components that meet the predetermined criteria and are available to the researcher as a pool of study subjects or participants (Appiah-Twumasi, 2016). In this study, the target population included all SHS chemistry students in the Kwabre East Municipality in the Ashanti Region, Ghana, while the accessible population were all SHS 3 chemistry students within the sampled schools.

3.5 Sampling and Sampling Technique

To ensure that the data collected is typical of the entire population under study, a sample of the population is chosen and examined to learn more about the overall population from which they were chosen (Shukla, 2020). The process of selecting a sample from population is called sampling, and this process uses specific methods or techniques known as sampling technique. There are two major types of sampling, namely; Probability and non- probability sampling (Kivunja & Kuyini, 2017). Probability sampling is a method where subjects are selected impartially, ensuring that every unit in the population has an equal and definite chance of being included in the sample (Casteel & Bridier, 2021). This includes; simple random sampling, multi-stage sampling, stratified random sampling, and cluster sampling. In non-probability sampling, none of the population's units has a fixed or guaranteed chance of being chosen for the sample (Marczyk et al., 2005). The choice of subjects for using non-probability is influenced by the researcher's personal preferences or willingness. This includes; snowball sampling, purposive sampling, quota sampling, and convenience sampling. However, the kind of sampling method which a researcher chooses in a study depends on a number of variables, including the sample size, population diversity, and research design.

In this study, a multi-stage sampling technique was employed since different techniques were used to select participants at different phases in the design. Table 3.1 presents the multi-stage sampling procedure employed in this study.

Table 3.1: Multi-stage Sampling Procedure Employed in this Study

Stage	Sampling Technique	Activity	Sample Size (N)
Quantitative Phase	Purposive Sampling	Selection of SHS 3 chemistry students	
	Purposive Sampling	Selection of public SHSs from the Kwabre East Municipality	2 SHSs
	Simple Random Sampling	Selection of one intact SHS 3 chemistry class from each selected school	100 SHS chemistry students
Qualitative Phase	Simple random sampling	Selection ten participants for semi-structured interview	10 SHS chemistry students

From Table 3.1, the quantitative component of this study began with purposively selecting SHS 3 chemistry students on the basis that organic chemistry was studied in SHS 3 according to Ministry of Education (2010).

This was followed by the selection of public SHSs from the Kwabre East district. There were two public SHSs and one private SHS in the district, but the permission was not granted by the private SHS to use their students for the study. Therefore, purposive sampling was used to select two SHSs to participate in the study. Again, since there were more than one intact SHS 3 chemistry class in each selected school, simple random sampling was employed to select one intact class from each school, where each selected class was exposed to the intervention. This therefore, resulted in a sample size of 100 SHS 3 chemistry students. Also, in the qualitative phase simple random sampling was used to select 10 SHS 3 chemistry students to solicit their perceptions towards the teaching and learning of organic chemistry after exposure to PBL.

3.6 Research Instruments

This study employed two main research instruments, namely; Three-Tier Organic Chemistry Concepts Test (TTOCCT) and a semi-structured interview guide. The descriptions of each instrument are explained in sections 3.6.1 and 3.6.2

3.6.1 Three-Tier Organic Chemistry Concept Test (TTOCCT)

The TTOCCT (see Appendix A) was a self-designed research instrument which covered the contents of nomenclature of organic compounds, structure of organic compounds, properties of organic compounds and reactions of organic compounds, all of which are sub-topics of organic chemistry in the Ghanaian SHS Chemistry syllabus. These concepts were selected on the basis of the evidence provided in literature (Adu-Gyamfi et al., 2017; Anim-Eduful & Adu-Gyamfi, 2022a; Davis, 2016; Donkoh, 2017; O'Dwyer & Childs, 2017) as well as chief examiners' reports (WAEC, 2017, 2018, 2020, 2021) regarding areas in organic chemistry where students have difficulties in understanding.

The TTOCCT is a 16-item three-tier diagnostic test consisting of three-tier items for assessing students' understanding of organic chemistry concepts. Each organic chemistry concept contained four items on the TTOCCT. Table 3.2 presents item distribution for each of the four organic chemistry concepts.

Table 3.2: Item Distribution of TTOCCT

Organic Chemistry Concept	Item
Nomenclature of organic compounds	1, 2, 3, 4
Structure of organic compounds	5, 6,7,8
Reactions of organic compounds	9,10,11,12
Properties of organic compounds	13,14,15,16

As shown in Table 3.2, items 1 to 4 covered the content of "nomenclature of organic compounds", items 5 to 8 covered the content of "structure of organic compounds", items 9 to 12 covered the content of "reactions of organic compounds" and items 13 to 16 covered the content of "properties of organic compounds". Sample of items for each of the four organic chemistry concepts considered in this study are presented in Table 3.3.

Table 3.3: Sample Items from TTOCCT

Organic Chemistry Concept	Sample of Items
Nomenclature of organic compounds	The correct name for cis-2,3-dimethyl-2-pentene is… a. 2,3-dimethylpent-2-ene b. 3,2-dimethylpent-2-ene c. 2,3-dimethyltpent-3-ene d. 3,2-dimethylpent-3-ene Give reason for your choice. How confident are you with your answers? a. Very confident b. Not confident
Structure of organic compounds	Which one of the following compounds exhibits geometric isomerism? a. CH_3CCH b. CH_3CHCH_2 c. $CH_3CHCHCH_3$ d. $CH_3CH_2CH_2CH_3$ What reason will you give for your answer? How confident are you with your choice? a. Very confident b. Not confident
Reactions of organic compounds	Which one of the following compounds exhibits geometric isomerism? a. CH_3CCH b. CH_3CHCH_2 c. $CH_3CHCHCH_3$ d. $CH_3CH_2CH_2CH_3$ What reason will you give for your answer? How confident are you with your choice? a. Very confident b. Not confident
Properties of organic compounds	Which of the following gives the correct trend in boiling point? a. $CH_4 > CH_3CH_3 > CH_3CH_2CH_3$ b. $CH_2CH_2 > CH_3CH_2CH_2 > CH_2CH_2CH_2CH_3$ c. $CH_3CH_3 > CH_2CH_2 > CHCH$ d. $CH_3CH_2CH_3 < CH2CH2 > CHCH$ Give reason for your answer chosen. How confident are you with your choice? a. Very confident b. Not confident

On the TTOCCT, the first tier consists of a conventional multiple-choice question with four options from which students were asked to select the correct answers to the question. The second tier asked students to provide a reason for their choice in the first tier, and the third tier asked for students' confidence about their choices and reasons in the first two-tiers. By adding the confidence tier, it was possible to differentiate between students who fully understand, partially understand, harbour misconception or had no understanding of organic chemistry.

Therefore, students' answers to the three-tier test were classified as full understanding, partial understanding, misconception and no understanding as proposed in literature (Gurel et al., 2015; Meiliyadi et al., 2023; Milenković et al., 2016). By grouping students' responses into the aforementioned categories, it was possible to gain insight into how students' conceptual understanding of organic chemistry was structured. Table 3.4 summarises how students' responses to the TTOCCT were categorised into the various levels of understanding.

Table 3.4: Categorisation of Students' Responses into Levels of Understanding

Level of Understanding	Students' Response
Full Understanding (FU)	Correct answer + Correct Reason + very confident
Partial Understanding (PU)	Correct answer + Correct Reason + not confident
	Incorrect answer + Correct Reason + not confident
	Correct Answer + Incorrect Reason + not confident
	Incorrect answer + Correct Reason + confident
	Correct Answer + Incorrect Reason + very confident
Misconception (M)	Incorrect answer + Incorrect reason + very confident
No Understanding (NU)	Incorrect answer + incorrect reason + not confident

In the classification of students' answers as shown in Table 3.4, students' answers to each item were considered "full understanding (FU)" if a student answers both the first and the second tiers correctly, and is very confident in the third tier. If a students' first and second tiers are answered wrongly and is very confident in the third tier, then the student was deemed to possess "misconception (M)". Also, a student was deemed to exhibit "no understanding (NU)" if their first and second tiers answers were wrong and was not confident in the third tier. Apart from these, any other combination, which are; correct answer + correct reason + not confident; incorrect answer + correct Reason + not confident; correct answer + incorrect reason + not confident; incorrect answer + correct reason + confident; correct answer + incorrect reason + very confident, were considered "partial understanding" (Gurel et al., 2015; Meiliyadi et al., 2023; Milenković et al., 2016).

3.6.2 Semi-Structured Interview Guide

To determine SHS chemistry students' perceptions towards the use PBL in the teaching and learning of chemistry after the intervention, a semi-structured interview guide (see Appendix B) was designed by the researcher. The interview guide contained five (5) open-ended questions, where students were given the freedom to express their opinions, however under the direction of the researcher, regarding their exposure to PBL. This therefore rendered the interview a semi-structured interview (Cohen et al., 2018).

3.7 Validity

According to Taherdoost (2021), validity is a measurement of the accuracy or falsity of the data obtained, when employing an instrument for a study. This study employed content validity to determine the content appropriateness of the items on the instruments. The determination of the content validity involves using a panel of experts to evaluate the items on the instrument and rate them based on their relevance and representativeness to the content domain (Almanasreh et al., 2018). Therefore, in this study, the TTOCCT and the semi-structured interview guide were given to three chemistry teachers at the SHS level and three chemistry education lecturers from the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) for their evaluation of the items on the instruments to determine the relevance in measuring what they intended to measure. Lawshe's (1975) criterium was used to determine the content validity of the instruments, using Lawshe’s Content Validity Ratio (CVR). The panel of experts in the CVR approach were invited to rate each item on the instruments as “essential” and “not essential”. After items had been recognised for inclusion in the final instrument, the Content Validity Index (CVI) was calculated for each item on the instrument. The CVI is determined by dividing the total number of experts who evaluated the items by the number of experts who rated the items as essential (Almanasreh et al., 2018). After determining the CVI for each item, the CVI was calculated for the entire instrument. This is the mean of all individual CVIs (Almanasreh et al., 2018). The CVRs of the instruments were then determined by dividing the overall CVI by the total number of items. Table 3.5 represents the Content Validity Ratio and Content Indices for TTOCCT.

Table 3.5: Content Validity Indices and Content Validity Ratio for Items on TTOCCT

Item	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6	Agreement	CVI
1	1	1	1	1	1	1	6	1.000
2	1	1	0	1	1	1	5	0.833
3	1	1	1	1	1	1	6	1.000
4	1	1	1	1	1	1	6	1.000
5	1	1	1	1	1	1	6	1.000
6	1	1	1	1	1	1	6	1.000
7	1	1	1	1	1	1	6	1.000
8	1	1	1	1	0	1	5	0.833
9	1	1	1	1	1	1	6	1.000
10	1	1	1	1	1	1	6	1.000
11	1	1	1	1	1	1	6	1.000
12	0	1	1	1	1	1	5	0.833
13	1	1	1	1	1	1	6	1.000
14	1	1	1	1	1	1	6	1.000
15	1	1	1	1	1	1	6	1.000
16	1	1	1	1	1	1	6	1.000
CVR								**0.968**

CVI = Content Validity Index = $\frac{N_E}{N}$

CVR = Content Validity Ratio = $\frac{CVI}{total\ number\ of\ items}$

N = total number of experts

N_E = Number of experts indicating items as essential.

According to Almanasreh et al. (2018), CVR varies between 1 and −1, where high values of CVR indicate the agreement of experts on the relevance of an item in the instrument. Therefore, as seen from Table 3.5, the CVR value for OCCT was 0.968, which indicates a valid instrument, according to Almanasreh et al. (2018). Table 3.6 also presents the Content Validity Ratio and Content Validity Indices for the semi-structured interview guide.

Table 3.6: Content Validity Indices and Content Validity Ratio for Interview Guide

Item	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6	Agreement	CVI
1	1	1	0	1	1	1	4	0.833
2	1	1	1	1	1	1	5	1.000
3	1	1	1	1	1	1	5	1.000
4	1	1	1	1	1	1	5	1.000
5	1	1	1	1	1	1	5	1.000
CVR								**0.966**

From Table 3.6, the CVR value for the interview guide was 0.966, which indicates a valid instrument, according to Almanasreh et al. (2018).

3.8 Pilot Study of the Instruments

After determining the validity of the instruments, a pilot test was conducted, with students in the Kwabre East District, who shared similar characteristics with the research participants, but did not take part in the main study. The pilot test helped to identify potential flaws in the instruments (Zailinawati et al., 2006). For a pilot study with the aim of conducting a preliminary survey or developing a scale, Johanson and Brooks (2010) recommend at least thirty (30) representative individuals from the population of interest. Accordingly, 50 third year SHS chemistry students were used for piloting the research instruments. The results from the pilot study were used to determine the reliability of the scores of the instruments.

3.9 Reliability

According to Heale and Twycross (2015), reliability is the consistency or dependability of a measurement approach. That is, A scale or test is considered reliable if it consistently produces the same results when used repeatedly under the same conditions

(Taherdoost, 2021). To determine the reliability of the scores from the pilot study of TTOCCT, the internal consistency reliability method was used. By employing the internal consistency reliability method, the Cronbach alpha was used. To determine the reliability for the TTOCCT, the scores from the pilot study of the TTOCCT was computed and the reliability, thus internal consistency of the scores (Cronbach alpha) was determined. The results are presented in Table 3.7.

Table 3.7: Internal Consistency of TTOCCT

Cronbach's Alpha	N of Items
0.802	16

According to Heale and Twycross (2015), the Cronbach's alpha statistic is a number between 0 and 1, and an acceptable reliability score is one that is 0.7 and higher. Therefore, as presented in Table 3.7, the Cronbach alpha value for the scores of TTOCCT in from the pilot study was 0.802, which indicates that the TTOCCT was reliable for use in the main study.

3.10 Data Collection Procedure

The data collection procedure involved three main stages, namely; pre-intervention stage, intervention stage, and post-intervention stage.

3.10.1 Pre-Intervention Stage

At the pre-intervention stage of the research, permission was sought from the headmasters of the participating schools. The heads of science department, as well as chemistry teachers in the sampled schools were also informed to seek their permission.

The benefits and uses of the results of this study were explained to the authorities and the students from participating schools, while assuring them of confidentiality of the results and information provided by students. The study was carried out when there were no significant activities taking place in the schools. This helped to control for "history" which would affect the validity of the results of the study (Cohen et al., 2018).

The next phase of the pre-intervention phase involved the conduction of the pre-intervention test (pretest). Participants were given one-week prior notice to prepare themselves for the pretest. The pretest was used to determine students' understanding in organic chemistry before the intervention.

3.10.2 The Intervention Stage

At this stage, the teaching method (PBL) was implemented in eight weeks after thorough preparation and mobilisation of resources. In each week there were four lessons scheduled with each lesson lasting for two hours. Students were instructed in four organic chemistry concepts which they reportedly demonstrated difficulty in understanding. In Table 3.8 is listed the various contents that were covered in every week during the research.

Table 3.8: Schedule of Content of Organic Chemistry Taught

Period	Content Taught
Week 1 and 2	Nomenclature of organic compounds
Week 3 and 4	Structure of organic compounds
Week 5 and 6	Properties of organic compounds
Week 7 and 8	Reactions of organic compounds

The intervention process is discussed in the next sub-section (section 3.10.2.1).

3.10.2.1 Intervention Process

All participants in this study were exposed to PBL. The following highlights how the PBL was used in this study.

Table 3.9: Intervention Activities

Problem-Solving Stage	Activity
Identification of problem	Teacher and students identified a real-world ill-structured problem related to organic chemistry.
Introducing the problem	Teacher presented the problem to the students, providing sufficient background information, and emphasised the relevance of the problem to capture students' interest and curiosity.
Analysing the Problem	Students formed groups and discussed the problem, analysed the information provided, and identified the key concepts and challenges involved. The teacher served as a facilitator, guiding discussions and clarifying misconceptions.
Research and Inquiry	Students carried out investigations and research to obtain the knowledge, facts, or materials required to address the problem.
Application of organic chemistry concepts	Students solved the problem by using their understanding of organic chemistry.
Peer teaching and collaboration	Groups shared their findings with the class through brief presentations
Reflection	Groups reflected on the feedback received and the challenges faced during the process of finding solution to the problem
Assessment	Using formative and summative assessment techniques to assess learning objectives attained by students

Identifying a problem

This stage involved identification of a complex, real-world problem or scenario, that required critical thinking, and related to organic chemistry that students can investigate by the application of organic chemistry concepts. Using nomenclature of organic compounds for example; one problem as follows "*Suppose you are organizing a cooking competition where contestants have to create dishes inspired by organic chemistry concepts. One challenge involves using ingredients that contain alkane molecules, and contestants must correctly identify the IUPAC names of these molecules. How would you select ingredients with alkane molecules, and how would you verify the accuracy of the contestants' naming*?"

Defining and introducing the problem

This stage was characterised by the presentation of the problem to the students, providing sufficient background information. For instance, teacher discussed with students the concept of alkanes, explaining their molecular structure, bonding, and properties, using models and diagrams to illustrate the structure of various alkanes, highlighting differences in chain length and branching. The rules for naming alkanes were also highlighted.

Analysing the problem

Students were divided into groups and each group was provided with a list of common organic ingredients found in cooking (e.g., olive oil, butter, coconut oil, etc.). They were asked to identify which ingredients contain alkane molecules and justify their selections based on the chemical composition of the molecules present. Each group collaborated to name and categorise the provided alkanes.

Students in their groups discussed the problem, analysed the information provided, and identified the key concepts and challenges involved. The teacher served as a facilitator, guiding discussions and clarifying misconceptions. For instance, reviewing of basic rules for organic compounds nomenclature, including the IUPAC rules for naming straight-chain and branched alkanes. Also included in this stage was the discussion of the significance of systematic naming in chemistry and its importance in the development of eco-friendly fuels.

Research and Inquiry

At this stage students conducted research and inquiry to gather information, data, or resources necessary to solve the problem. This involved the use of textbooks, laboratory experiments, or other materials. For instance, guiding students to investigate IUPAC rules for naming alkanes and the application of these rules to various structures, and explore the impact of alkane structure on fuel properties, such as volatility and combustion efficiency.

Apply organic chemistry concepts

During this stage students applied their knowledge of organic chemistry to address the problem. This involved the identification of relevant organic compounds, understanding reaction mechanisms, or proposing solutions based on chemical principles. For instance, naming the provided alkane structures using IUPAC nomenclature rules, and categorizing the alkanes based on their systematic names, identifying straight-chain and branched structures.

Peer teaching and collaboration

At this stage, the teacher introduced peer teaching where groups shared their findings with the class. This aimed at enhancing communication skills and allowed students to learn from their peers. For instance, in teaching nomenclature of alkanes, each group presented their named alkane structures, explaining the application of IUPAC rules.

Reflection

After presentations, there was facilitation and a reflection session where students discussed what they learned and any challenges they faced. Groups were also encouraged to revise their solutions or approaches based on feedback.

Assessment

This stage was characterised by assessment of students' understanding through various means, such as presentations, written reports, or quizzes.

3.10.3 Post Intervention Stage

After the eight weeks of intervention, students were given a prior notice to get prepared for post-intervention test (posttest). The researcher with the help of the chemistry teachers in the participating schools administered the post-intervention test (TTOCCT). The completed tests were collected and scored after which the results were analysed. Following the collection of the quantitative data, the qualitative aspect of this study, which was characterised by the conduction of semi-structured interview to solicit students' perception on the use of PBL in the teaching and learning of organic chemistry, was done. Students' voices were recorded with their consent and later transcribed for analysis.

3.11 Data Analysis Procedure

This study involved a collection of both quantitative and qualitative data. As a result, data were analysed quantitatively and qualitatively based on the research questions. The quantitative data employed in this study was students' responses to items in the TTOCCT, while the qualitative data employed students' articulations from the semi-structured interview. In view of this, descriptive statistics and thematic analysis were used to analyse the data.

3.11.1 Quantitative Data Analysis

Descriptive statistics, specifically percentages, was employed on the data obtained from the TTOCCT. This helped to determine the levels of understanding of SHS chemistry students in organic chemistry, and in doing so, research question 1 was partly answered. To provide the intricacies of students' understanding in organic chemistry, representative statements of students' explanations provided in the second tier of the TTOCCT were presented and analysed. Research question 2 was also answered using percentages on students' responses from the TTOCCT before and after the intervention. Specifically, the results obtained before and after the intervention were compared to determine the difference in percentage of students in the various levels of understanding. This helped to ascertain the extent to which PBL enhanced students' understanding in organic chemistry.

3.11.2 Qualitative Data Analysis

Qualitatively, thematic analysis was employed to answer research question 3. This helped to explain the finding in research question 2 by soliciting the perceptions of students regarding the use of PBL in the teaching and learning of organic chemistry.

3.12 Ethical Consideration

The following ethical guidelines and standards were crucial for carrying out this investigation. Introductory letter from the Department of Integrated Science of AAMUSTED was used to seek permission from the Kwabre East Municipal Education Directorate and from the heads of participating schools. Strict adherence was upheld throughout the research procedure to safeguard the participants' rights, welfare, and privacy. Every participant gave their informed consent, with a focus on their voluntary involvement. There were precautions taken to minimise any possible discomfort or harm, and participants were guaranteed the freedom to leave the study at any moment without facing repercussions. Protocols were followed during data management and storage to protect participants' privacy and confidentiality. As a result, the identity of the schools and participants and any private information were made anonymous.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

In this chapter, the qualitative and quantitative results or findings are presented, which aims to address the research questions. The presentation of the results and findings is followed by their discussions, which was also done according to the research questions.

4.1 Results of the Study

4.1.1 Results for Research Question 1

Research question 1 sought to determine SHS chemistry students' level of understanding in selected organic chemistry concepts. In view of this, this research question was answered using students' answers from the TTOCCT. Students' answers from the TTOCCT were analysed quantitively. In the quantitative analysis, students' answers to the three-tier test were classified as full understanding, partial understanding, misconception and no understanding as proposed in literature (Gurel et al., 2015; Meiliyadi et al., 2023; Milenković et al., 2016). Students' responses to the TTOCCT were categorised into the "full understanding", "partial understanding", "misconception" and "no understanding" as already explained in Table 3.5. Table 4.1 therefore presents the results of students' correct choices and responses in the TTOCCT.

Table 4.1: Percentage of Students' Correct Responses Across the Three Tiers

Organic Chemistry Concept	Item	TIER 1	TIER 1+2	TIER 1+2+3
Nomenclature of organic compounds	1	32	10	4
	2	34	8	6
	3	34	9	8
	4	24	5	5
	Average %	**31.00**	**8.00**	**5.75**
Structure of organic compounds	5	19	5	4
	6	13	3	3
	7	10	2	2
	8	12	3	3
	Average %	**13.5**	**3.25**	**3.00**
Reactions of organic compounds	9	21	9	8
	10	24	20	18
	11	15	2	2
	12	20	10	7
	Average %	**20.00**	**10.25**	**8.75**
Properties of organic compounds	13	11	5	5
	14	41	33	32
	15	26	3	3
	16	45	20	19
	Average %	**30.75**	**15.25**	**14.75**
	Average % of all items	**23.81**	**9.19**	**8.06**

Source: (field data)

The results as presented in Table 4.1 reveal that in all the items, low percentages of participants were able to score correctly across the first two tiers with full confidence (TIER 1+2+3). In the first tier (TIER 1) of all the items, an average percentage of 23.81% of the participants provided correct choices, while an average percentage of 9.19% of the participants provided correct choices in the first tier followed by correct explanations in the second tier (TIER 1+2). Additionally, a relatively lowest average percentage of 8.06% participants were able to demonstrate full confidence on their choices and explanations in the first and second tiers (TIER 1+2+3). Also, moving across the three tiers on all the items, there were apparently very large differences between the first tier, second tier, and third tier. Overall, not more than half of the participants were able to correctly provide the correct answers on all the items. That is, low percentages of students were able to give the correct answers to both first and second tiers with full confidence.

For instance, from Table 4.1, item 16 which had the highest percentage of students who provided correct answers in first tier, only 45% of the total participants (N=100) were able to give the correct answers in the first tier with corresponding 20% of the students, who provided correct reason for their chosen answers in the first tier. On the same item 16, 19% of the students demonstrated full confidence on their chosen answers and associated reasons. However, item 7 had the least percentage of the students (10%) who chose correct options in the first tier while corresponding 2% of students provided the appropriate explanation for their chosen answers in first tier, with equally 2% also demonstrating full confidence on their chosen answers and associated explanations or reasons.

When the results in Table 4.1 was further analysed according to each sub-topic, even though low percentages were recorded, it was found that the highest percentage of students, who provided correct choices in the first tier was found in 'nomenclature of organic compounds', with an average participant percentage of 31.00%, while the least percentage of participants who provided correct choices in the first tier was found in 'structure of organic compounds' with an average participant percentage of 13.5%. Also, the highest percentage of the participants who successfully provided the correct explanations in the second tier to their correct choices in the first tier was found in 'properties of organic compounds' with an average participant percentage of 15.25%

while the least percentage of participants who correctly provided the correct explanations to their choices in the first tier was found in ‘structure of organic compounds’.

Moreover, to demonstrate full confidence in the third tier on the correct choices in the first tier and correct explanations in the second tier, Table 4.1 reveals that the highest percentage of students was recorded in ‘Properties of organic compounds’ with an average percentage of 14.75% of the participants, while the least percentage of students was recorded in ‘structure of organic compounds’ with an average percentage of 3.00% of the participants. In general, there were decrease in percentage of students as one moves from the first tier to third tier. This can graphically be inspected in Figure 4.1.

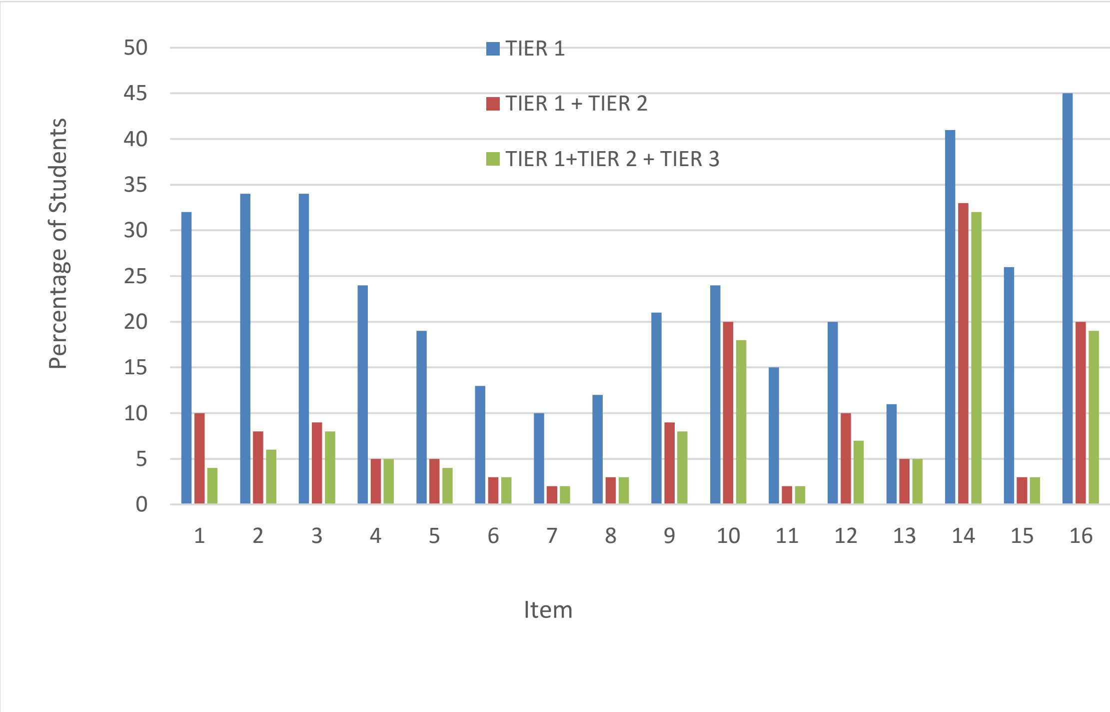

Figure 4.1: A graphical view of correct responses of items in three tier OCCT before intervention

From Figure 4.1, it can be seen that percentage of students across all the three tiers are apparently reduced on all items, as previously explained from the results in Table 4.1. This indicates that participants demonstrated low levels of understanding in organic chemistry concepts. The levels of understanding obtained from the responses of the participants are presented in Table 4.2.

Table 4.2: Levels of SHS Chemistry Students' Understanding in Organic Chemistry

Organic Chemistry Concept	Item	FU	PU	M	NU	χ^2	df	p
Nomenclature of organic compounds	1	4	44	20	32	35.04	3	0.00
	2	6	40	23	31	25.04	3	0.00
	3	8	38	21	33	21.52	3	0.00
	4	5	37	19	39	31.04	3	0.00
	Average %	**5.75**	**39.75**	**20.75**	**33.75**	**27.31**	**3**	**0.00**
Structure of organic compounds	5	4	22	49	25	41.04	3	0.00
	6	3	18	56	23	59.92	3	0.00
	7	2	35	53	10	65.52	3	0.00
	8	3	41	35	21	34.24	3	0.00
	Average %	**3.00**	**29.00**	**48.25**	**19.75**	**42.725**	**3**	**0.00**
Reactions of organic compounds	9	8	52	20	20	42.72	3	0.00
	10	18	49	14	19	31.28	3	0.00
	11	2	12	19	67		3	0.00
	12	7	14	22	57	59.12	3	0.00
	Average %	**8.75**	**31.75**	**18.75**	**40.75**	**23.87**	3	0.00
Properties of organic compounds	13	11	16	65	8	86.64	3	0.00
	14	45	9	14	32	33.04	3	0.00
	15	13	17	67	3	98.24	3	0.00
	16	26	27	33	14	27.6	3	0.00
	Average %	**23.75**	**17.25**	**44.75**	**14.25**	**22.69**	**3**	**0.00**
	Average % of all items	**7.94**	**31.06**	**26.25**	**34.75**	**16.976**	**3**	**0.00**

Source: (field data)

It can be seen from Table 4.2 that there was a significant association between the various levels of understanding and all the items. Specifically, least percentages of the participants demonstrated 'full understanding' in organic chemistry with an average percentage of 7.94% of the participants. Also, among the levels of understanding, the highest percentage of students was recorded in the 'no understanding' category with an average participant percentage of 31.06%. This can be graphically observed in Figure 4.2.

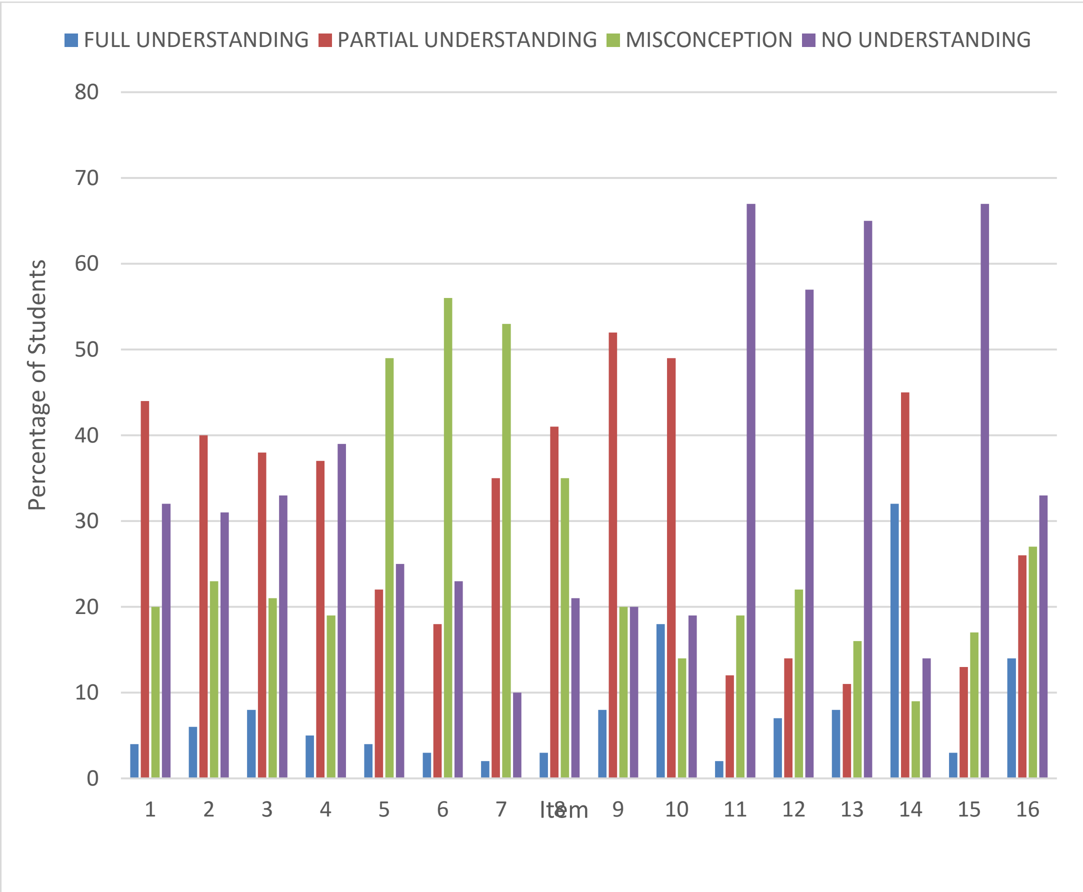

Figure 4. 2: A graphical representation of students' level of understanding on all items Before Intervention

Figure 4.2 shows that high percentages of participants demonstrated 'no understanding' on all the items as revealed in Table 4.2. Students' levels of understanding were further analysed according to the various sub-topics in organic chemistry considered in this study as depicted in Figure 4.3.

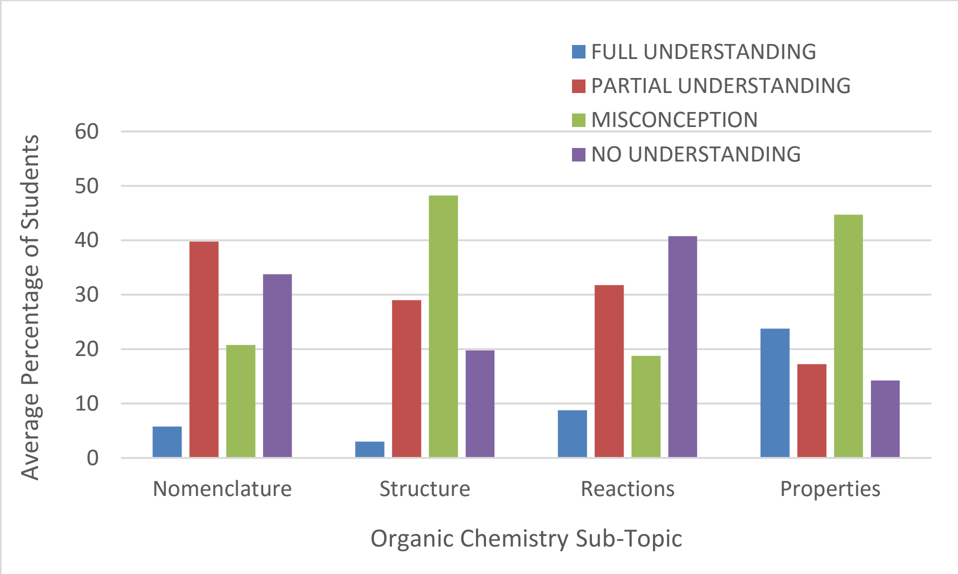

Figure 4.3: Participants' levels of understanding in each organic chemistry sub-topic Before Intervention

From Figure 4.3, it can be seen that the average percentage of the participants in each level of understanding under each sub-topic was below 50%. Specifically, in the 'full understanding' category, highest percentage of participants was recorded in 'properties of organic compounds', while least percentage of participants was recorded in "nomenclature of organic compounds". Also, in the 'partial understanding category', highest percentage of participants was recorded in "nomenclature of organic compounds" while least percentage of participants was recorded in "properties of organic compounds". Furthermore, in the 'misconception' category, highest percentage of participants was recorded in "structure of organic compounds" while least percentage of participants was recorded in "properties of organic compounds". In the 'no understanding category', highest percentage of participants was recorded in "properties of organic compounds" while least percentage of participants was recorded in "structure of organic compounds".

To fully understand SHS chemistry students' levels of understanding in organic chemistry, participants' explanations to their choices were analysed qualitatively using content analysis. Not all 16 items on the three tier OCCT were used for the qualitative analysis. The items selected for the qualitative analysis were items where higher percentages of students demonstrated misconceptions. These are items 2, 6, 12 and 16. The qualitative analysis was however done to reflect various levels of understanding of participants, with the correct option to each item highlighted green. The qualitative analysis are as follows with participants explanations italicised in quotations.

Item 2

What is the correct IUPAC name for the compound: CH3-CH(CH3)-CH2-C≡C-CH3?

a. 2-Methyl-hex-2-yne

b. 5-Methyl-hex-2-yne

c. 2-Methyl-4-hexyne

d. 5-Ethyl-2-methylhex-3-yne

What reason will you give for your choice?

One participant who selected option '**b**', however, was **not confident** in their choice explained that:

> "*The reason why I chose option b is because, the longest carbon chain was 7. And the substituent was on the second carbon in the parent chain*."

An analysis of the participant's explanation revealed that the participant, even though chose the correct option, they misapplied the rules for naming organic compounds. Instead of considering the parent chain as 6, the participant considered it as 7, which means the participant counted the branched substituent (methyl – CH_3) as part of the parent chain. This makes the participant's understanding a 'partial understanding'. However, failing to provide the appropriate explanation to their choice means that the participant likely guessed.

Also, another participant who chose option '**a**' and was **very confident** with regards to the explanation of their choice in answering item 2 stated that:

> "*The answer is 'A' because the substituent is on the second carbon when you count from the left. Also, the triple bond is on the second carbon when you count from the right. Therefore, the name is 2-methyl-hex-2-yne*".

The explanation from this participant in answering item 2 indicates that the participant had a misconception. The misconception lies in the fact that the participant's explanation did not follow the IUPAC rule that the triple bond (C≡C) should have the lowest number in the compound's name, regardless of the position of the substituents. Since the participant was very confident in their incorrect choice and explanation, the participant's understanding on this item was deemed a misconception.

Another response from a participant who chose option '**c**' and was **very confident** was that:

> "*The ethyl group was on the second carbon and the triple bond was on the fourth carbon so the name becomes 2-Methyl-4-hexyne*".

"This participant also incorrectly gave priority to only the substituent instead of the triple bond in naming alkynes. The student thought that numbering the carbon atoms should start from the position closer to the substituent. Being very confident in their choice and explanation means that the student demonstrated misconception."

Item 6

Determine which of the following compounds does not show cis-trans isomerism.

a. but-2-ene

b. buta-1,3-diene

c. 1-bromo-2-chloroethene

d. pent-2-ene

i. Give reason for your choice.

In providing an explanation to item 6, one participant who chose option '**a**' and was **very confident** explained that:

> "*Hex-3-ene does not show a cis-trans isomerism because there are more carbon atoms that will make sure that the compound shows a cis-trans isomer*".

In analysing the participant's explanation, one can decipher that the participant considered the number of carbon atoms as a factor in cis-trans isomerism. However, for cis-trans isomerism to occur, there must be two different groups attached to each of the carbon atoms of the double bond. The participant's response could have been considered as having no understanding but being confident in his choice and explanation means that the participant demonstrated misconception.

Another participant who chose option '**b**' and was **not confident** in their explanation also stated that:

> "*All the compounds contain only one double bond. It is only buta-1,3-diene that contains two double bonds*".

From the participant's explanation, instead of acknowledging the fact that buta-1,3-diene does not show cis-trans isomerism due to the absence of distinct substituent groups around its double bond, the participant focused on the number of double bonds for a compound to show a cis-trans isomerism. Therefore, providing an incorrect explanation and not being confident in their choice and explanation means that the participant demonstrated partial knowledge.

In explaining their choice in item 6, a participant who chose option '**d**' and was **very confident** in their choice and explanation stated that:

> "*Since 1-bromo-2-chloroethene contains a bromine atom, it cannot show a cis-trans isomerism*".

The participant's explanation to their choice revealed that the participant thought cis-trans isomerism only occurs in hydrocarbons instead of pointing to the fact that for cis-trans isomerism to occur, there must be two different groups attached to each of the carbon atoms of the double bond. By providing the wrong choice, incorrect explanation and being very confident means that the participant demonstrated misconception.

Item 12

1,3-Butadiene reacts with HBr at low temperature to give …

a. 3-bromo 1-butene
b. 1-bromo 4-butene
c. 1-bromo 2-butene
d. 3-bromo-1-propene

What reason will you give for your choice?

For this item, one participant who chose option '**a**' and was **very confident** in his choice provided an explanation which stated that:

> "*In the reaction, one of the double bonds will break and the HBr will divide and each one will attach itself to the carbon where the double bond was broken. This will now produce 3-bromo 1-butene*".

Though the participant made the correct choice, the participant failed to acknowledge that the reaction was an addition reaction, where the hydrogen bromide adds across the double bond of the butadiene, and that by applying Markovnikov's rule, the electrophile (H^+) in the HBr will attack the carbon with more hydrogen atoms and the nucleophile (Br^-) will attack the carbon with less hydrogen atom. Therefore, by providing the incorrect explanation and being very confident, however, choosing the correct option means that the student demonstrated partial understanding.

Another participant who chose option '**c**' and was **very confident** in their choice and explanation also explained that:

> "*When the reaction takes place, the hydrogen bromide will break and attach to the carbon atoms without the double bond. The final product will then be 1-bromo 2-butene*".

This participant also demonstrated misconception in their explanation. Specifically, the participant in one way or the other acknowledged that the reaction is an addition reaction. However, the participant had an incorrect application of the Markovnikov's rule and also demonstrated no understanding in naming the final product. But the participant's demonstration of strong confidence means that the participant exhibited misconception.

Additionally, one participant who selected option '**c**' and was **very confident** in their explanation also stated that:

> "*In this reaction, the HBr will break and will add to each of the carbon atoms with the double bonds. The two double bonds will break and either the H or Br*

will add to each of the carbon atoms with the double bonds. This will make the name of the new compound formed be 1-bromo 4-butene".

In this participant's explanation, it can be noticed that the participant acknowledged the reaction being an addition reaction. Nevertheless, the participant failed to apply the Markovnikov's rule correctly. The participant's principle of addition though unscientific, produced a compound with a name which was wrongly chosen by the participant from among the options provided. As a result, the participant being very confident with their incorrect choice and explanation classifies them as demonstrating misconception.

Item 16

Which of the following sets of molecules form a homologous series?

I. C_3H_6, C_3H_8, C_4H_8

II. C_3H_7OH, C_2H_5OH, CH_3OH

III. C_4H_{10}, C_3H_8, C_2H_6

IV. C_6H_5COOH, CH_3COOH, $HCOOH$

a. II and III

b. II, III and IV

c. I and III

d. II and IV

What reason will you give for your choice?

A participating student in providing an answer to item 16 chose option '**c**' and was **very confident** in their choice. However, in explaining their choice, the participant stated that:

"*Among all the options, I and II have only carbon and hydrogen atoms but the rest have oxygen included so they cannot form a homologous series*".

Analysing the participant's response, it can be seen that the participant's concept of a homologous series is limited to only hydrocarbons, instead of acknowledging a homologous series as a series of compounds in which each member differs from the next by a specific number and kind of atoms. The participant's choice, in addition to their unscientific explanation as well as being very confident with their answers means that the participant demonstrated misconception on this item.

A participant who also chose option '**c**' and was **very confident** in their choice explained that:

"*I and III are compound from alkanes and alkenes while II and IV are compounds from alcohols and alkanoic acids and they cannot form a homologous series, so the answer is I and III*".

A careful analysis of the participant's explanation reveals that the participant considered homologous series to be functional group specific. That is, according to the participant, some functional group can form a homologous series while others cannot. However, the participant failed to understand that, a homologous series are only a series of compounds in which each member differs from the next by a specific number and kind of atoms, irrespective of the functional group. This understanding coupled with the demonstration of a high confidence renders the participant's answer as misconception.

4.1.2 Results for Research Question 2

Research question 2 also aimed to determine the extent to which the use of PBL enhanced SHS Chemistry students' understanding in organic chemistry. In view of this, this research question was quantitatively answered using participants' answers and explanations from the TTOCCT after the intervention. Participants' answers to the three-tier test after the intervention were classified as full understanding, partial understanding, misconception and no understanding as proposed in literature (Gurel et al., 2015; Meiliyadi et al., 2023; Milenković et al., 2016). Participants' responses were categorised into the various levels of understanding according to the criteria as already shown in Table 3.5. Participants' correct responses after the intervention to all 16 three tiered items were analysed and the results are presented in Table 4.3.

Table 4.3: Percentage of Students' Correct Responses Across the Three Tiers After Intervention

Organic Chemistry Concept	Item	TIER 1	TIER 1+2	TIER 1+2+3
Nomenclature of organic compounds	1	81	73	70
	2	85	66	61
	3	79	68	66
	4	79	69	59
	Average %	**81.00**	**69.00**	**64.00**
Structure of organic compounds	5	72	63	57
	6	80	71	68
	7	80	74	69
	8	77	68	62
	Average %	**77.25**	**69.00**	**64.00**
Reactions of organic compounds	9	68	56	56
	10	84	80	80
	11	73	58	51
	12	79	61	59
	Average %	**76.00**	**63.75**	**61.50**
Properties of organic compounds	13	76	64	60
	14	86	80	85
	15	85	79	76
	16	88	80	80
	Average %	**83.75**	**75.75**	**75.25**
	Average % of all items	**79.50**	**69.38**	**66.19**

Source (field data)

As presented in Table 4.3, in all the items high percentages of students were able to score correctly across the three tiers. The first tier of all items saw an average percentage of 79.50% of students who provided correct choices, while an average of 69.38% of students provided correct reasons in the second tier to their choices in the first tier. Additionally, an average percentage of 66.19% were able to demonstrate full confidence in their choices and explanations in the first and second tiers. Overall, more than half of the participants were able to correctly provide the correct answers on all the items. That is, high percentages of students were able to give the correct answers to both first and second tiers with full confidence.

Comparatively, before the intervention, an average percentage of 23.81% of the participants provided correct choices in the first tier, while an average percentage of 9.19% of the participants followed their correct choices with correct explanations in the second tier. Also, a relatively lowest average percentage of 8.06% of the participants were able to demonstrate full confidence in their choices and explanations in the first and second tiers. Moreover, moving across the three tiers on all the items, there were apparently differences in the average percentage of the participants in all the items between the tier 1, tier 1+tier 2, and tier 1+tier 2+tier 3 (79.50%, 69.38%, 66.19% respectively). However, compared to that of before the intervention (see Table 4.1), there were increase in average percentages of the participants between the tier 1, tier 1+tier 2 and tier 1+tier 2+tier 3 (23.81%, 9.19%, 8.06% respectively).

Also, when the results in Table 4.3 were further analysed according to each sub-topic, even though high percentages of the participants were recorded on all 16 items, it was found that the highest percentage of participants who provided correct choices in the first tier (tier 1) was found in ‘properties of organic compounds’, with an average percentage of 83.75% of the participants, while the least percentage of participants who provided correct choices in the first tier was found in 'reactions of organic compounds' with an average percentage of 76.00% of the participants. Compared to before the intervention, these sub-topics recorded an average percentage of 30.75% and 20.00% of the participants respectively.

Moreover, the results presented in Table 4.3 reveal that the highest percentage (75.75%) of the participants who followed up with correct explanations in the second tier to their correct choices in the first tier (tier 1 + tier 2) was found in 'properties of organic compounds' while the least percentage (63.75%) of the participants in tier 1 + tier 2 was found in 'reactions of organic compounds'. However, these sub-topics recorded average percentage of 15.25% of the participants, and 10.25% in tier 1 + tier 2 before the intervention.

Furthermore, from Table 4.3, it can be seen that the highest average percentage of the participants in tier 1 + tier 2 + tier 3 (participants who were very confident in their correct choices and correct explanation in first and second tiers) was recorded in 'properties of organic compounds' (75.25%) while the least average percentage (61.50%) of the participants was recorded in 'reactions of organic compounds'. Nevertheless, prior to the intervention, average percentage of the participants in tier 1 + tier 2 + tier 3 of these sub-topics was 14.75% and 8.75 respectively.

The graphical representation of average participant percentage in tier 1, tier 1+tier 2 as well as tier 1 + tier 2 + tier 3 is shown in Figure 4.4.

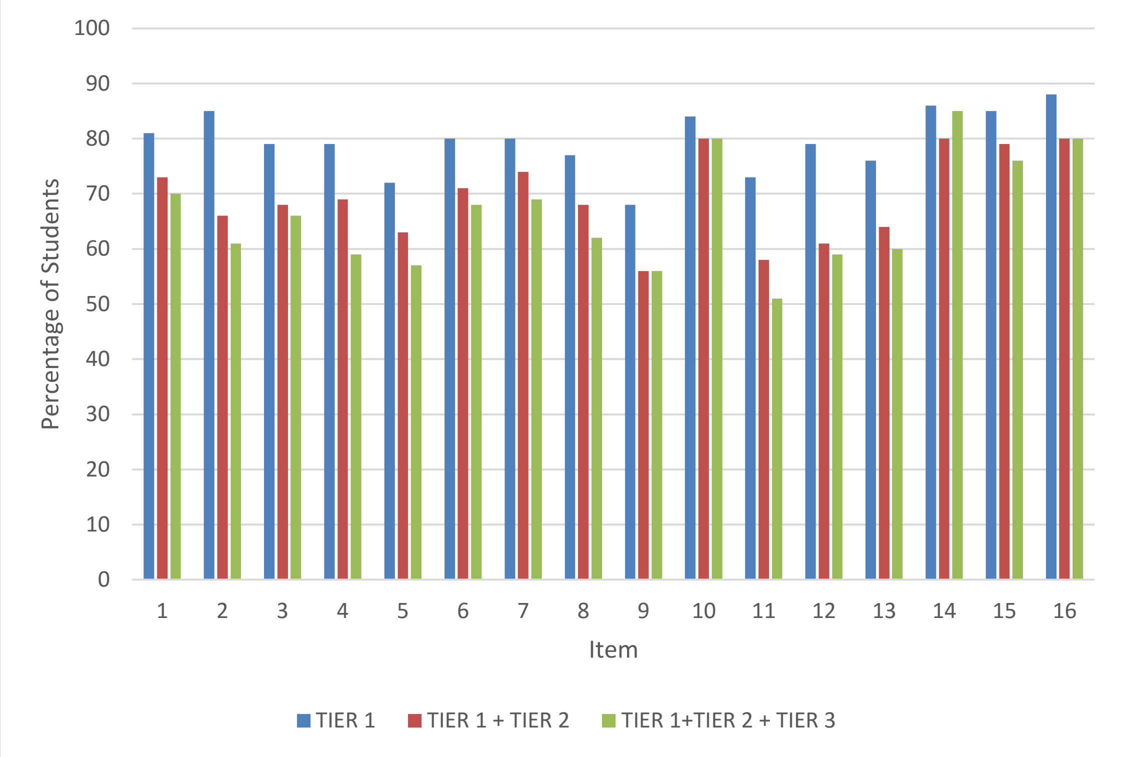

Figure 4.4: A graphical view of correct responses of all items in three tier OCCT after intervention

Figure 4.4 depicts that in all the items, very high percentages of the participants made the correct choice in tier 1, followed up with the appropriate explanation in tier 2, and demonstrated full confidence in tier 3. The results presented in Table 4.3 and Figure 4.4 indicate that high percentages of participants demonstrated 'full understanding' in organic chemistry concepts. To confirm this, students' levels of understanding on all items after the intervention were analysed and the results are presented in Table 4.4.

Table 4.4: Levels of SHS Chemistry Students' Understanding in Organic Chemistry After Intervention

Organic Chemistry Concept	Item	FU	PU	M	NU	χ^2	df	p
Nomenclature of organic compounds	1	70	15	9	6	109.68	3	0.00
	2	61	29	6	4	84.56	3	0.00
	3	66	29	5	0	108.88	3	0.00
	4	59	33	7	1	84.8	3	0.00
	Average %	**64.00**	**26.50**	**6.75**	**2.75**	**94.055**	3	0.00
Structure of organic compounds	5	57	37	3	3	85.44	3	0.00
	6	68	27	3	2	114.64	3	0.00
	7	69	26	5	0	118.48	3	0.00
	8	62	29	6	3	89.2	3	0.00
	Average %	**64.00**	**29.75**	**4.25**	**2.00**	**100.12**	3	0.00
Reactions of organic compounds	9	56	35	7	2	76.56	3	0.00
	10	80	20	0	0	172	3	0.00
	11	51	34	5	10	55.28	3	0.00
	12	59	30	7	4	77.84	3	0.00
	Average %	**61.50**	**29.75**	**4.75**	**4.00**	**88.235**	3	0.00
Properties of organic compounds	13	60	30	6	4	82.08	3	0.00
	14	85	9	6	0	193.68	3	0.00
	15	76	19	4	1	146.16	3	0.00
	16	80	17	2	1	167.76	3	0.00
	Average %	**75.25**	**18.75**	**4.50**	**1.50**	**141.47**	**3**	**0.00**
	Average % of all items	**66.19**	**26.19**	**5.06**	**2.56**	**104.13**	**3**	**0.00**

Source (field data)

Table 4.4 reveals that after the intervention, high percentage of participants generally demonstrated 'full understanding' in organic chemistry with an average percentage of 66.19% of the participants. Also, the least percentage of participants showed 'no understanding' in organic chemistry after the intervention with an average percentage of 2.56% of the participants. The results presented in Table 4.4 can be graphically observed in Figure 4.5.

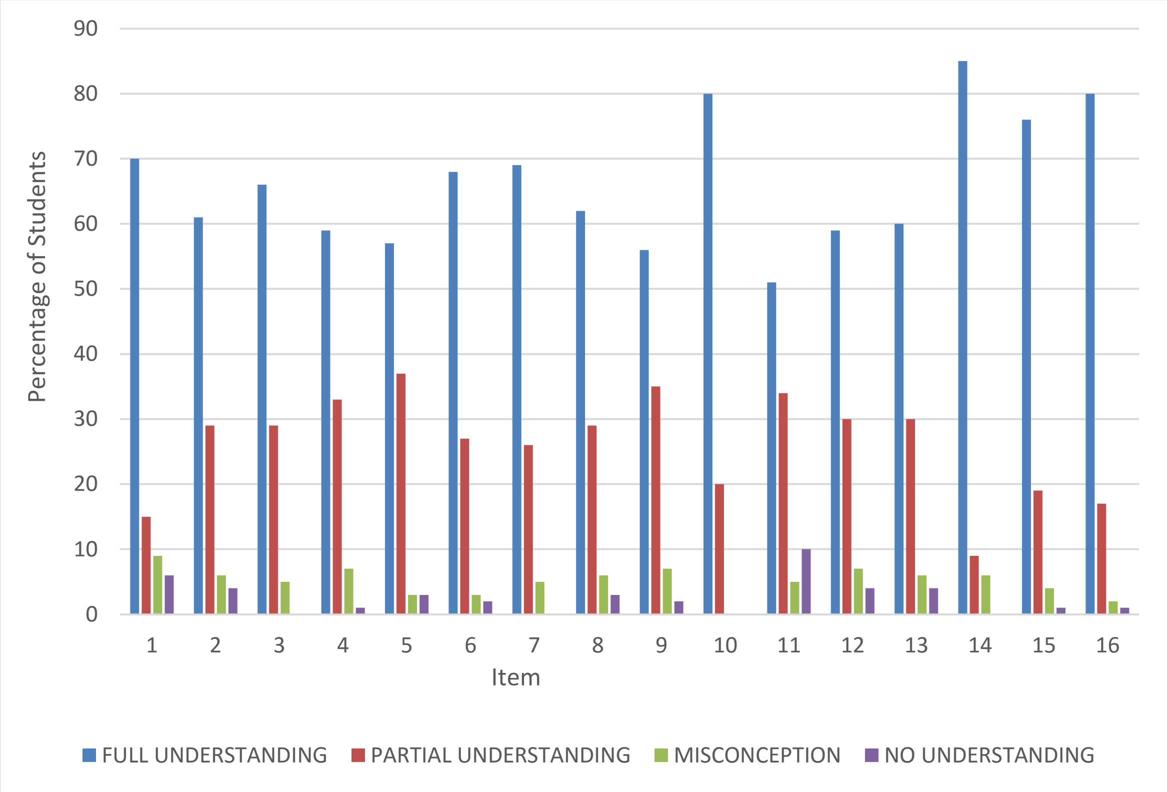

Figure 4.5: A graphical representation of students' level of understanding on all items after intervention

It can be seen from Figure 4.5 that on all the items, high percentages of participants demonstrated 'full understanding' while very low participants demonstrated 'partial understanding', 'misconception', and 'no understanding'.

Moreover, students' levels of understanding after the intervention were further analysed according to the various sub-topics in organic chemistry considered in this study as depicted in Figure 4.6.

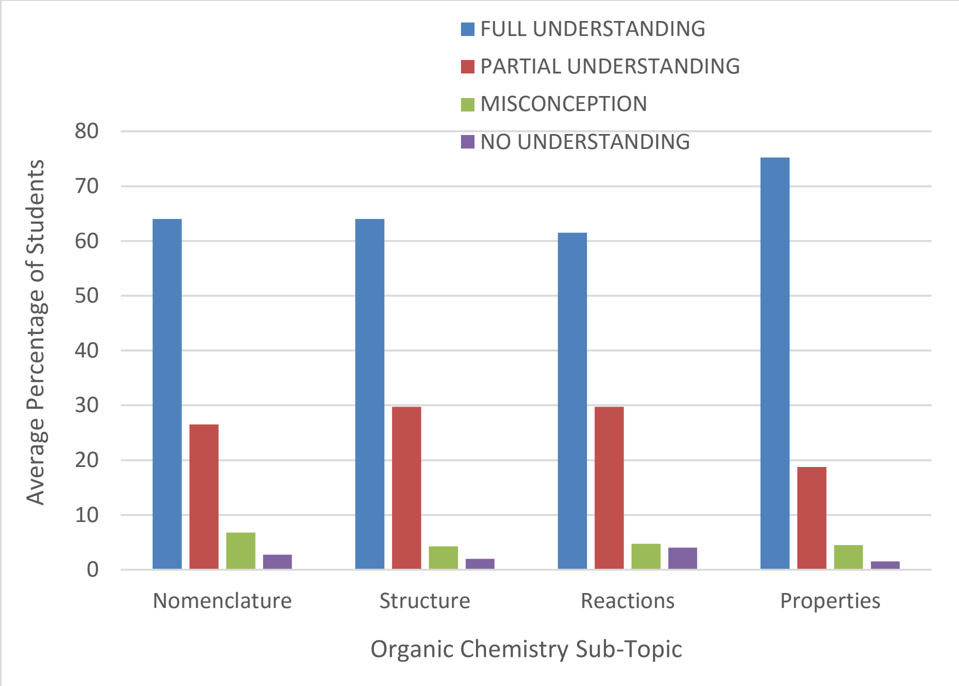

Figure 4.6: Participants' levels of understanding in each organic chemistry sub-topic after intervention

As portrayed in Figure 4.6, there were high average percentage of the participants in the 'full understanding' category compared to the other levels of understanding in each sub-topic, with the average percentage of 'full understanding' exceeding 50%. This indicates that more than half of the participants demonstrated 'full understanding' in each sub-topic. From Figure 4.6, the sub-topic which recorded the highest average participant percentage in "full understanding" was "properties of organic compounds" while the least average percentage of the participants was recorded in "reactions of organic compounds". It can further be revealed from Figure 4.6 that very low average percentage of the participants was recorded under "misconceptions" and "no understanding" in each of the sub-topic.

Furthermore, participants' overall average percentage of the various levels of understanding before and after the intervention were compared as presented in Table 4.5 and Figure 4.7.

Table 4.5: Comparison of Levels of SHS Students' Understanding Before and After Intervention

	FU	**PU**	**M**	**NU**	χ^2	df	p
Before Intervention	7.94	31.06	26.25	34.75	16.976	3	0.00
After Intervention	66.19	26.19	5.06	2.56	103.97	3	0.00

It can be observed from Table 4.5 that there were significant differences in the levels of understanding in both before (χ^2 = 16.976, p=0.00) and after (χ^2 = 103.97, p=0.00) the intervention. Specifically, the percentage of students in the "full understanding" understanding category increased by 58.25% after the intervention. However, there was a decrease in the percentage of students in the "partial understanding category by 4.87%. Similarly, the percentage of students in the misconception and null understanding categories decreased by 21.19% and 32.19% respectively. These differences can be visually observed in Figure 4.7.

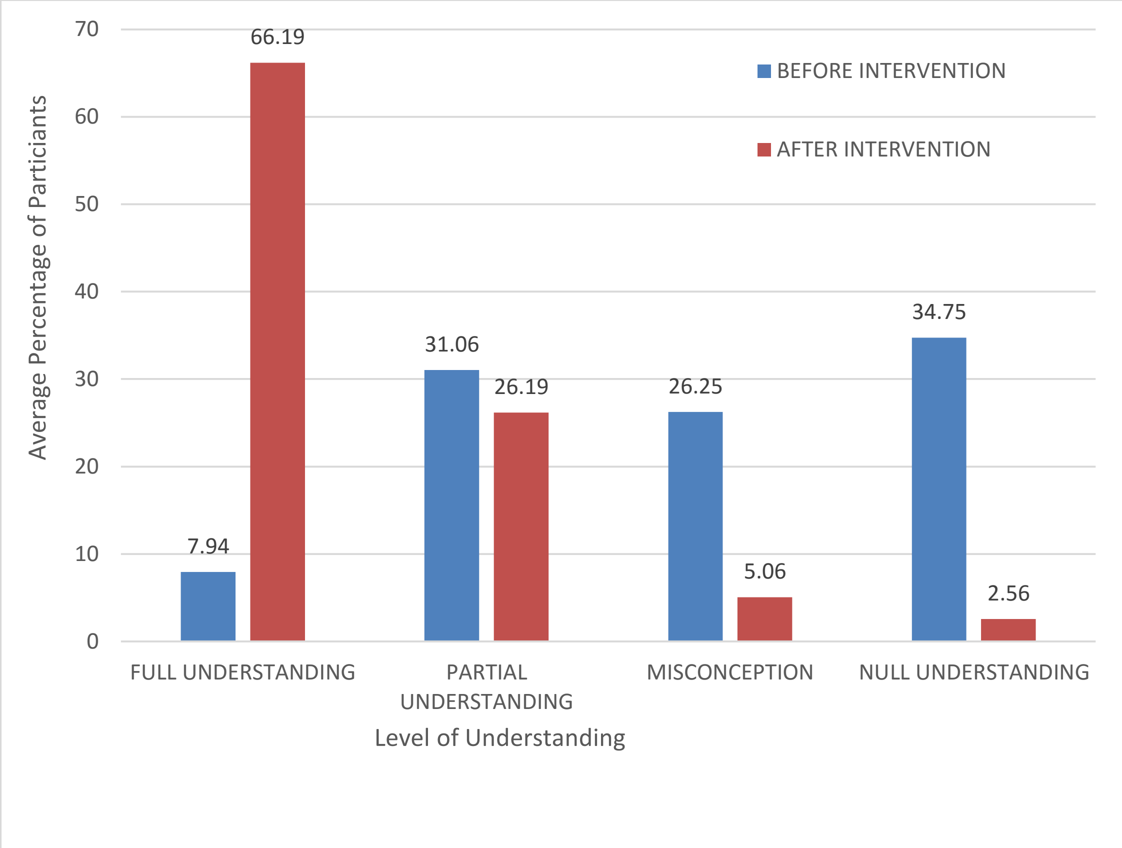

Figure 4.7: Participants' Overall levels of understanding in organic chemistry before and after intervention

It can be seen from figure 4.7 that overall, after the intervention, there was a far higher average percentage of the participants (66.19%) in the 'full understanding' category compared to that before the intervention (7.94%). However, in the 'partial understanding', 'misconception' and 'no understanding' categories, there were relatively higher average percentage of the participants before the intervention than after the intervention.

4.1.3 Results for Research Question 3

This research question sought to solicit SHS Chemistry students' perceptions towards the use of PBL in the teaching and learning of organic chemistry. Thus, to answer this research question, ten (10) students were randomly selected for a semi-structured interview. Students' responses were analysed in themes, which included enhanced engagement and interest, improved collaboration and communication skills, development of critical thinking skills, improvement of problem-solving confidence, and improved application of knowledge.

Theme 1: Enhanced Engagement and Interest

Students stated that their level of interest and involvement increased when they were exposed to real-life scenarios or problems during the lessons. They believed that by devising their own methods to look for viable answers to the problems and considering several theories before selecting the best one, they were empowered to actively participate in the problem-solving activities and increased their interest in learning organic chemistry. Students became more diligent in their planning and conceptualization of bridging the knowledge gap between what they previously knew and what they needed to study to reach their predefined learning goals as a result of having the liberty to direct their own learning process. For instance, student **A** expressed that:

> "*Learning about organic compounds became more engaging and applicable to everyday life because of the problem-solving component of your instruction, which I appreciate. By trying to find solutions to the problems you gave us, I felt more involved in every lesson. It was almost different from how we have been taught in the past years*".

Also, student **B** articulated that:

> "*The scenarios and cases we worked on made me more curious about organic chemistry. It felt like I was solving puzzles rather than just memorizing facts*.

Because of this, I always tried to work hard in order to learn more organic chemistry concepts I did not understand".

Theme 2: Enhanced Communication and Collaboration Skills

It makes sense that students also emphasized the benefits of Problem-Based Learning's collaborative learning elements. Through cooperative problem-solving exercises, students actively participated in class discussions, exchanged varied viewpoints, and worked together to solve challenging organic chemistry problems. In addition to promoting a deeper comprehension of the material, this cooperative method helps students build critical communication skills in a scientific setting. Students who were encouraged to present and defend their views were better able to think clearly and successfully communicate difficult chemical concepts. Furthermore, PBL's collaborative style emulated the teamwork frequently needed in scientific research and industry, helping students prepare for future pursuits in organic chemistry by developing their communication and collaboration skills, which in turn raises academic performance and subject competency. From the students' viewpoints, two students made the following articulations:

Student **C**: "*During the group learning activity, it helped me to work together with my group members to identify and analyze different organic compounds, focusing on identifying and categorizing functional groups. By discussing and comparing their findings within the group, I gained a deeper understanding of how functional groups impact the properties and reactivity of organic molecules*".

Student **D**: "*I remember the group activities we did during the exploration of reaction mechanisms, such as nucleophilic substitution or addition reactions. It helped us work together to study these mechanisms, discussing the movement of electrons, the role of specific reagents, and the transformation of reactants into products. Using this approach, I was able to fully understand reaction pathways. This helped me to clear my thoughts, explain complex concepts to my colleagues, and engage in scientific discussion*".

Theme 3: Improvement in Critical Thinking Skills

In order to foster critical thinking and intellectual discussions in the classroom, students must pose questions that elicit thoughtful answers from facilitators and colleagues. The communication of diverse perspectives within the group promoted critical thinking and allowed students to consider multiple approaches to solving problems. For instance, in the words of student **E**, it was said that:

"*I remember during the nomenclature, when you gave us complex molecule with substituents and functional groups, where we were to analyze its structure and apply nomenclature rules to name the compound in groups. In the grouping stage, we discussed the unclear nature in certain structural features, debated some naming conventions, and decided some appropriate names. This did not only make me understand the naming rules, but also helped me to think critically about the differences when I come across a real-world molecular structure*".

Student **F** also added that:

"*The discussions within the group encouraged me to ask questions concerning the reason why some members suggest certain names for some compounds, explain my choice in using some names, and think about how name choices* *affect society at large. This created in me a deeper level of critical thinking in the application of organic compound nomenclature*".

Theme 4: Improvement in Problem-Solving Confidence

Through the use of real-world scenarios, active involvement, and collaborative learning, Problem-Based Learning (PBL) was shown to increase students' confidence in their ability to solve issues in organic chemistry. Students were able to connect theoretical knowledge with real-world applications through self-directed inquiry and an ongoing feedback loop, feeling a sense of achievement and responsibility. PBL is an effective method for developing problem-solving abilities in the setting of organic chemistry because of the apparent advancement and mastery attained through cooperative problem-solving, which further bolstered students' confidence. For instance, student **G** expressed that:

> "*We got feedback and comments from you, the teacher, as well as from our classmates while we worked on the issues. This method gave me the knowledge, growth, and approval I needed to strengthen my problem-solving techniques and boost my confidence*".

To add to student G's expression, student **H** stated that:

> "*The problems you often presented to us were issues which we see and hear them happen in everyday life. I wish to become a chemist in future, so by trying to solve those problems that are similar to those found in research or industries, I was able to gain confidence in the ability to apply organic chemistry concepts to practical situations*".

Theme 5: Improved Application of Knowledge

PBL, in the opinion of students, enhances their capacity to apply their understanding of organic chemistry by putting them in situations that call for the contextual application of concepts. Students stated that they were able to integrate different organic chemistry principles to solve challenging problems through problem-solving, critical thinking, and collaborative learning. A habit of continual learning was thus fostered by PBL's emphasis on inquiry-based investigation, which encouraged active information-seeking. As a result, students highlighted that they took responsibility for their work and engaged in reflective practices that improved their comprehension and application of knowledge. For instance, student **I** stated that:

> "*The activities we used during the study of organic chemistry have made me develop abilities to apply knowledge I learnt to other organic chemistry situations in real life. For instance, in combustion of organic compounds in candles, I understand the chemical reactions involved in the burning of wax, considering factors like flame color, heat production, and the environmental impact of combustion by-products*".

Student **J** also stated that:

> "*By solving real-world problems, I did not only have better understanding of organic chemistry but also, I developed problem-solving skills relevant to various fields and industries. This made me like learning organic chemistry all the time. For example, during the study of the organic chemistry of laundry detergents, I understood the role of enzymes and other organic compounds in stain removal, fabric softening, and the general effectiveness of cleaning clothes*".

4.2 Discussion of Results

This section discusses the results of the study according to the research questions.

4.2.1 Discussion of Results for Research Question 1

Research question 1 aimed to determine SHS chemistry students' levels of understanding of organic chemistry concepts. To obtain an in-depth knowledge of students' levels of understanding, quantitative and qualitative approaches were employed using students' choices, their explanations and confidence levels from a three-tier diagnostic test. Thus, students' levels of understanding were categorised as "full understanding", "partial understanding", "misconception" and "no understanding". The quantitative results showed that least percentages of participants demonstrated "full understanding" in organic chemistry, while the highest percentage of students was recorded in the "no understanding" category. When participants' levels of understanding were analysed according to each of the four major organic chemistry concepts considered in this study (nomenclature, structure, reactions and properties) it was found that average percentage of participants in each level of understanding under each sub-topic was below 50%, with higher percentage of participants demonstrating "no understanding" and least percentage of participants demonstrating "full understanding" in each concept.

This was observed through students' explanations which were analysed qualitatively to complement the quantitative results. The high percentages of participants' demonstration of "partial understanding", "misconception" and "no understanding" were further understood in the qualitative analysis. From the qualitative analysis, majority of students had erroneous understanding in organic chemistry concepts due to wrong identification of the parent chain, incorrect identification of the position of substituents, double bonds and triple bonds, considering the number of carbon atoms as a factor in determining geometric isomerism, amongst others. This indicates that students did not understand the concepts of organic chemistry better.

According to O'Dwyer and Childs (2017), because of its abstract nature and the intricate relationships between its principles, organic chemistry frequently poses a significant barrier for students. For this reason, it might be difficult for students to close the gap that exists between theoretical ideas and real-world applications. For example, understanding the reasons behind the particular reactions of various molecules under particular conditions requires not only memorisation but also the capacity to reason from the fundamental ideas.

Moreover, understanding the vocabulary of organic chemistry itself might be challenging (O'Dwyer & Childs, 2017). Terms like functional groups, carbocations, resonance structures, electrophiles, and nucleophiles are all part of the subject's own lexicon. Understanding the relevance and meaning of these words can be similar to navigating a foreign language for students who are unfamiliar with this terminology. Therefore, it takes more than simply memorisation to become fluent in this language. The student also needs to comprehend the fundamental ideas that each term stands for.

This calls for a different way of thinking than the simpler facts that are memorised for introductory chemistry courses (Adu-Gyamfi et al., 2017), as well as the learning of a new language, the capacity to deal with uncertainties and exceptions, and the smooth integration of theoretical knowledge and real-world application (O'Dwyer & Childs, 2017). In this way, students studying organic chemistry will be able to understand and apply basic concepts like reactivity, electron mobility, and molecular structure (Bunce, 2015). However, this transition can be challenging, particularly for people who were good at memorising facts by heart but now had to comprehend the fundamental principles that underpin chemical interactions (Konicek-Moran & Keeley, 2015). Therefore, educators can resort to active learning techniques through collaborative learning, where learners can discuss difficult concepts, solve problems together, and get new views on the subject matter (Holme et al., 2015).

The finding from this research question thus corroborates with the findings of previous studies (Adu-Gyamfi et al., 2017; Anim-Eduful & Adu-Gyamfi, 2022a; Balea, 2021; Eticha & Ochonogor, 2015; Nartey & Hanson, 2021; O'Dwyer & Childs, 2017; Popova et al., 2020). Adu-Gyamfi et al. (2017) found that greater percentages of students exhibited difficulties in detection of functional groups in saturated and unsaturated carbon compounds, draw the appropriate chemical structures of organic compounds undergoing chemical reactions, demonstrated little or no knowledge on organic reagents required to test functional groups, as well as providing appropriate reactants and observations in given reactions. Eticha and Ochonogor (2015) also saw students expressing their difficulties in understanding functional groups, stereoisomerism and organic compounds reactions while O'Dwyer and Childs (2017) saw students stating that reactions of organic compounds, isomerism, mechanisms and syntheses of organic compounds were difficult to understand.

4.2.2 Discussion of Results for Research Question 2

Research question 2 sought to determine the extent to which the use of PBL enhanced SHS Chemistry students' understanding in organic chemistry. Therefore, quantitative analysis was conducted on students' answers from the three-tier OCCT after the intervention. Similar to before the intervention, students' levels of understanding were categorised as "full understanding", "partial understanding", "misconception" and "no understanding". The result revealed that high percentages of participants generally demonstrated "full understanding" in organic chemistry. Also, the least percentage of participants showed "no understanding", with very low percentage of participants demonstrating "partial understanding", "misconception" in organic chemistry after the intervention.

In terms of the various organic chemistry concepts considered in this study, there were high average participant percentage in the 'full understanding' category compared to the other levels of understanding in each sub-topic, with the average percentage of "full understanding" exceeding 50%. This indicates that more than half of the participants demonstrated "full understanding" in each sub-topic. The organic chemistry concept which recorded the highest average participant percentage in "full understanding" was "properties of organic compounds" while the least average participant percentage was recorded in "reactions of organic compounds".

To further justify the extent to which the use of PBL in this study enhanced SHS Chemistry students' understanding in organic chemistry, students' levels of understanding before and after the intervention were compared. It was found that after the intervention, there was a far higher average participant percentage (66.19%) in the “full understanding” category compared to that before the intervention (8.06%). However, in the “partial understanding”, “misconception” and “no understanding” categories, there were relatively higher average participant percentage before the intervention than after the intervention. These results provide an indication that the use of PBL might have contributed to the enhancement of students’ understanding in organic chemistry to a possibly large extent.

According to Tan (2003), by giving students real-world, challenging tasks that resemble real-world situations, students will be motivated to actively interact with the subject matter. In this study, students were therefore expected to do research, analyse it, and come up with solutions rather than just passively absorbing knowledge. This called for a deeper level of engagement with the subject matter. This active participation can aid students in developing a comprehensive understanding (Dole et al., 2016), particularly in organic chemistry where interactions between structures, reactions, and properties can be complex (Adu-Gyamfi et al., 2017). Due to the PBL scenarios’ complex and ill-structured character, students frequently experienced cognitive dissonance when they attempted to solve novel challenges. Piaget (1976) postulated that students are motivated to seek answers as a result of this cognitive dissonance, which forces them to revise their mental schemas – a crucial component of Piagetian learning and a prerequisite for conceptual comprehension.

Because organic chemistry focuses on molecular structures, reactions, and mechanisms, it can be quite abstract (Adu-Gyamfi et al., 2017; Anim-Eduful & Adu-Gyamfi, 2022a). PBL gives students the opportunity to apply their theoretical knowledge to real-world scenarios (Hmelo-Silver, 2004). Thus, in this study, by working through ill-structured problems, students had a personal understanding of how these theoretical ideas apply to actual situations, which made learning more applicable and concrete. Students could therefore assimilate new concepts in organic chemistry through PBL by using them to solve problems presented in scenarios. Accommodation, on the other hand, involves altering already existing knowledge to fit in new information. In this study, students were challenged to adapt their understanding to new situations through problem-solving scenarios, where simple application of prior knowledge might not be sufficient. This process of accommodation fostered deeper understanding as students refined their mental models to solve complex problems, supporting Piaget's (1976) theory.

Furthermore, the collaborative nature of the PBL exercises in this study necessitated that students work in teams. This cooperative effort was analogous to the teamwork that is frequently needed in scientific research and professional settings in the area of organic chemistry. Students evaluated various viewpoints and clarified concepts to peers as they expand their comprehension through group discussions and debates. This is consistent with Vygotsky's (1978) theory that social interaction is essential to learning. Students participated in group discussions while working cooperatively to solve problems, clarifying ideas, arguing points, and expressing their logic. It is possible that this verbalization strengthened their comprehension of the ideas of organic chemistry.

In addition, Vygotsky (1978) brought to light the concept of “Zone of Proximal Development” (ZPD), which is the difference between what a learner can accomplish on their own and what they can accomplish with the direction or help of a more experienced person. In this study, PBL offered the setting for students to function inside their ZPDs. Students were required to apply their knowledge in meaningful ways during lessons, for instance, and they received support, encouragement, and advice from their peers and instructors in doing so. Additionally, the complex problems which were presented to students in class might have pushed their comprehension limits as they got assistance from peers and facilitators through active collaboration activities as Sibomana et al. (2020) argue. This scaffolding process, in which the instructor and group members offered assistance and direction, might have been essential to PBL enhancing students' understanding in organic chemistry.

This finding, in agreement with previous research, supported the findings of Günter and Alpat (2017) who found that students who were exposed to PBL in the teaching and learning of electrochemistry recorded an average participant percentage of 81.44%, 8.25%, 2.06%, 1.03%, 7.22% who demonstrated "clear understanding", "partial understanding", "partial understanding with specific misconception", "specific misconception" and "incomprehension" respectively, while students who were not exposed to PBL recorded an average participant percentage of 48.05%, 12.98%, 3.90%, 2.69%, 32.47% who demonstrated "clear understanding", "partial understanding", "partial understanding with specific misconception", "specific misconception" and "incomprehension" respectively. Moreover, other studies including Gurses et al. (2015), Aidoo et al. (2016), Yaayin (2016), as well as Jimoh and Fatokun (2020) did not focus on conceptual understanding, but found that the use of PBL enhanced students' academic performance in enthalpy and mole concepts.

4.2.3 Discussion of Results for Research Question 3

Research question 3 determined to solicit SHS chemistry students' perceptions towards the use of PBL in the teaching and learning of organic chemistry. In doing so, a semi-structured interview was conducted and the respondents' expressions were qualitatively analysed using thematic analysis. The themes which emerged from the interview were enhanced engagement and interest, improved collaboration and communication skills, development of critical thinking skills, improvement of problem-solving confidence, and improved application of knowledge. These responses indicated that students expressed positive perceptions towards the use of PBL in the teaching and learning of organic chemistry. These positive perceptions expressed by students echo the fact that PBL offers a multifaceted approach that greatly benefits students' overall learning experience (Tan, 2003). Firstly, according to Tan (2003) through PBL, students are actively engaged in the learning process, which inherently boosts their interest and motivation. By presenting real-world problems, PBL makes the subject matter relevant and applicable, sparking curiosity and a desire to delve deeper into organic chemistry concepts. This engagement, according to Caesar et al. (2016), is further enhanced by the interactive nature of PBL, where students collaborate in small groups, sharing ideas, perspectives, and solutions. This collaborative environment fosters a sense of friendship and shared learning, making the process not just educational but enjoyable and fulfilling.

Moreover, Bentil and Ababio (2020) assert that the collaborative nature of PBL cultivates essential communication and teamwork skills among students. In organic chemistry, where complex concepts often require discussion and explanation (Sibomana et al., 2020), this skill development is invaluable. Students learn to articulate their ideas, listen actively to their peers, and work together towards common goals. According to Bodagh et al. (2017), these communication and collaboration skills are not only crucial in academic settings but also highly sought-after in professional environments. Thus, students exposed to PBL in organic chemistry not only deepen their understanding of the subject but also acquire practical skills that are transferable to various aspects of their academic and future careers.

Furthermore, PBL nurtures critical thinking and problem-solving abilities, fundamental for success in organic chemistry and beyond (Tan, 2003). As students grapple with challenging problems, they learn to analyse information, evaluate different approaches, and synthesise solutions (Savery, 2006). This process of inquiry and discovery builds their confidence in tackling complex problems, a skill set, which according to Bodagh et al. (2017), are particularly relevant in scientific research and professional practice. Therefore, through repeated exposure to diverse problems in organic chemistry, students might develop a problem-solving toolkit that they can apply to new and unfamiliar situations. This improvement in problem-solving confidence, coupled with a deepened understanding of the subject, can result in a more robust application of knowledge. In this way, students not only learn the concepts but also gain the ability to apply them in practical scenarios, bridging the gap between theory and real-world applications.

Compared to previous findings, this finding agrees with the findings of Kumar and Kogut (2006), Al-Drees et al. (2015), Günter and Alpat (2018), Kibret et al. (2021) and Ahdhianto et al. (2021). These studies also reported that students expressed positive perceptions on the use of PBL in teaching and learning. The perceptions were increased collaborative skills, self-regulation, independent learning, and deep thinking skills (Al-Drees et al., 2015; Kumar & Kogut, 2006). Others include enhanced problem-solving skills, better understanding of concepts, increased motivation (Kibret et al., 2021) and increased engagement in the teaching and learning activities (Ahdhianto et al., 2021).

CHAPTER FIVE

SUMMARY, CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

5.0 Overview

In this chapter, the summaries of the findings of the study have been captured. Conclusions, recommendations and suggestions were noted based on the findings for further research work.

5.1 Summary of Findings

The aim of this study was to determine the effect of PBL on SHS chemistry students' understanding in organic chemistry in the Kwabre East Municipality in the Ashanti Region, Ghana. Mixed-method design, specifically the explanatory sequential design, was employed using 100 SHS chemistry students from two intact classes. Research questions were answered quantitatively and qualitatively.

The findings of the study indicated that SHS chemistry high percentages of students demonstrated "partial understanding", "misconception", and "no understanding" while least percentage of participants demonstrated "full understanding" in all four organic chemistry concepts (nomenclature, structure, properties and reactions) which were considered in this study. This means that students' understanding in organic chemistry was not encouraging. In view of this, an intervention was designed using PBL to ascertain the extent to which PBL can improve students' understanding in organic chemistry. After the intervention, the results indicated that the use of PBL can enhance students' understanding in organic chemistry to a possibly high extent. This is because, compared to before the intervention, very low percentages of students demonstrated "partial understanding", "misconception", and "no understanding" while high percentage of participants demonstrated "full understanding" in all four organic chemistry concepts (nomenclature, structure, properties and reactions) which were considered in this study.

To further validate the findings of this study, qualitative data were collected through semi-structured interview from sampled students to solicit how they perceived the use of PBL in the teaching and learning of organic chemistry. Respondents' perceptions from the interview were that the use of PBL enhanced their engagement and interest, improved their collaboration and communication skills, developed their critical thinking skills, improved their problem-solving confidence, and improved their application of knowledge. These qualities play major roles in the understanding of concepts. These perceptions provided an understanding of the process of the intervention where students were made to fully participate in lessons. This understanding however, would not have been possible using only quantitative data.

5.2 Conclusions

From the findings of this study, it can therefore be concluded that majority of SHS chemistry students within the Kwabre East District in the Ashanti Region, Ghana possess "partial understanding", "misconception" and "no understanding" while very few students have "full understanding" of organic chemistry concepts. Moreover, it can be concluded that the use of Problem-Based Learning can be effective in enhancing SHS chemistry students' understanding in organic chemistry within the Kwabre East

District. Also, SHS chemistry students within the Kwabre East District have positive perceptions on the use of PBL in the teaching and learning of organic chemistry.

5.3 Recommendations

The following recommendations were therefore made from the findings of this study. It is recommended that:

1. SHS chemistry teachers within the Kwabre East District should turn their attention to identifying the various levels of understanding of SHS chemistry students in the teaching and learning of organic chemistry.
2. SHS chemistry teachers within the Kwabre East District can consider the use of Problem-Based Learning in enhancing chemistry students' understanding of organic chemistry.
3. To develop positive perceptions about the teaching and learning of organic chemistry among SHS chemistry students within the Kwabre East District, teachers can consider the use of Problem-Based Learning.

5.4 Suggestions for Further Research

The following suggestions were therefore made for further research.

1. Further studies should be conducted on the effect Problem-Based Learning on students' understanding in other organic chemistry concepts.
2. The use of control group should be considered in subsequent studies in an attempt to control for other extraneous variable which might have influenced the results of the study.
3. The use of four-tier diagnostic test or more advanced diagnostic tests should also be considered in identifying students understanding in organic chemistry in

subsequent studies. This will help provide more insight of students' levels of understanding.

4. Also, the gender perspective of ascertaining SHS chemistry students' understanding and enhancing their understanding using Problem-Based Learning should also be considered.

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APPENDICES

Appendix A

Three-Tier Organic Chemistry Concept Test

This test is a 16-item three tier test consisting of a multiple-choice item with options in tier 1, a reason for your choice in tier 2, and a declaration of your level of confidence in tier 3. Answer all items in all three-tiers.

Duration: 60 minutes

1. The correct name for cis-2,3-dimethyl-2-pentene is…

a. 2,3-dimethylpent-2-ene

b. 3,2-dimethylpent-2-ene

c. 2,3-dimethyltpent-3-ene

d. 3,2-dimethylpent-3-ene

Give reason for your choice.

How confident are you with your answer?

a. Very confident

b. Not confident

2. What is the IUPAC name for the compound: CH3-CH(CH3)-CH2-C≡C-CH3?

a. 2-methyl-hex-2-yne

b. 5-methyl-hex-2-yne

c. 2-Methyl-1-ethylhexane

d. 5-Ethyl-2-methylhex-3-yne

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

3. Hydrogen is added to pent-2-yne using Ni or Pd as a catalyst in the presence of heat. What is the IUPAC name given to the product formed?

a. Pent-2-ene

b. Pent-3-yne

c. But-3-ene

d. But-3-yne

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

4. Propene completely reacts with chlorine to form an organic compound, give the IUPAC name of the compound produced?

a. 1,1-dichloropropane

b. 1,2-dichloropropane

c. 1,3-dichloropropane

d. 1,1-dichloropropene

What reason will you give for your answer?

How confident are you with your choice?

a. Very confident

b. Not confident

5. Which of the following compounds is a saturated hydrocarbon?

a. Isobutane

b. 2-Ethyl-1-pentene

c. Butyl

d. 6-Methyl-oct-3-yne

Explain the reason for your choice.

How confident are you with your choice?

a. Very confident

b. Not confident

6. Determine which of the following compounds does not show cis-trans isomerism.

a. but-2-ene

b. buta-1,3-diene

c. 1-bromo-2-chloroethene

d. pent-2-ene

Give reason for your choice.

How confident are you with your structures and naming?

a. Very confident

b. Not confident

7. Which one of the following compounds exhibits geometric isomerism?

a. CH_3CCH

b. CH_3CHCH_2

c. $CH_3CHCHCH_3$

d. $CH_3CH_2CH_2CH_3$

What reason will you give for your answer?

How confident are you with your choice?

a. Very confident

b. Not confident

8. Which of the following molecules has the highest carbon to hydrogen ratio?

a. ethane

b. ethene

c. methane

d. acetylene

Give reason for your choice.

How confident are you with your choice?

a. Very confident

b. Not confident

9. Which of the following reactions is a valid termination step in the reaction of methane with chlorine in the presence of sunlight?

a. $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$

b. $CH_4 + Cl\cdot \rightarrow CH_3Cl + H\cdot$

c. $CH_3\cdot + Cl\cdot \rightarrow CH_3Cl$

d. $CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot$

Give reason for your choice

How confident are you with your choice?

a. Very confident

b. Not confident

10. What does C_xH_y represent in the equation; $2\ C_xH_y + 7O \rightarrow 4CO_2 + 6H_2O$?

a. Butane

b. Butene

c. Ethane

d. Ethene

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

11. Dehydrohalogenation of 1,4-dibromobutane with alcoholic KOH gives 1,3-Butadiene. What role does KOH play in the reaction?

a. The KOH directly reacts with 1,4-dibromobutane to form the product.

b. The KOH provides a correct pathway for the elimination reaction to occur.

c. The KOH serves as a base, abstracting a proton during the elimination reaction.

d. The KOH serves as a catalyst in the elimination reaction.

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

12. 1,3-Butadiene reacts with HBr at low temperature to give …

a. 3-bromo 1-butene

b. 4-bromo 1-butene

c. 1-bromo 2-butene

d. 3-bromo-1-propene

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

13. Which of the following gives the correct trend in boiling point?

e. $CH_4 > CH_3CH_3 > CH_3CH_2CH_3$

f. $CH_2CH_2 > CH_3CH_2CH_2 > CH_2CH_2CH_2CH_3$

g. $CH_3CH_3 > CH_2CH_2 > CHCH$

h. $CH_3CH_2CH_3 <$ CH2CH2>CHCH

Give reason for your answer chosen.

How confident are you with your chosen answer?

a. Very confident

b. Not confident

14. Which of the following statements is true regarding the physical state of C_4H_{10} and C_4H_6 at room temperature?

a. C_4H_{10} is a gas, while C_4H_6 is a liquid at room temperature.

b. C_4H_{10} is a liquid, while C_4H_6 is a gas at room temperature.

c. Both C_4H_{10} and C_4H_6 are typically gases at room temperature.

d. Both C_4H_{10} and C_4H_6 are typically liquids at room temperature.

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

15. From the list of compounds provided in options “a” to “d”, select the one which is most acidic.

a. $CHCCH_2CH_2CH_3$

b. $CH_3CCHCH_2CH_3$

c. $CH_3CH_2CCCH_3$

d. $CH_3CH_2CCCH_2CH_3$

What reason will you give reason for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

16. Which of the following sets of molecules form a homologous series?

V. C_3H_6, C_3H_8, C_4H_8

VI. C_3H_7OH, C_2H_5OH, CH_3OH

VII. C_4H_{10}, C_3H_8, C_2H_6

VIII. C_6H_5COOH, CH_3COOH, $HCOOH$

a. II and III

b. II, III and IV

c. I and III

d. II and IV

What reason will you give for your choice?

How confident are you with your choice?

a. Very confident

b. Not confident

Appendix B

Semi-Structured Interview Guide

1. How did the learning activities influence your motivation to learn organic chemistry concepts?
2. Reflecting on your experiences with the learning activities, how did it impact your ability to work effectively in groups?
3. How do you believe instructional approach helped you develop your ability to approach complex organic chemistry problems?
4. Describe any changes you noticed in your confidence in solving organic chemistry problems after engaging in the learning activities.
5. Reflecting on your overall learning experience, how has the instructional approach contributed to your ability to apply organic chemistry knowledge beyond the classroom?