UNIVERSITY OF CAPE COAST

SENIOR HIGH SCHOOL CHEMISTRY STUDENTS' UNDERSTANDING OF IUPAC NOMENCLATURE OF ORGANIC COMPOUNDS

KENNETH ADU-GYAMFI

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BY

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Thesis submitted to the Department of Science and Mathematics Education of the Faculty of Education, University of Cape Coast, in partial fulfillment of the requirements for award of Master of Philosophy Degree in Science Education

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DECLARATION

Candidate's Declaration

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

Candidate's Signature: ………………………… Date: ………………………

Name: Kenneth Adu-Gyamfi

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 University of Cape Coast.

Principal Supervisor's Signature: …………………..... Date: ……………….

Name: Prof. Joseph Ghartey Ampiah

Co-supervisor's Signature: ………………………….. Date: ……………….

Name: Mr. Joseph Yaw Appiah

ABSTRACT

The WAEC Chief Examiners' Reports in Ghana have repeatedly lamented the weakness exhibited by most Chemistry students in IUPAC nomenclature of organic compounds in the West Africa Senior Secondary Certificate Examination. This study was a step to determine the knowledge level of some Chemistry students in IUPAC nomenclature of organic compounds. A cross-sectional survey was adopted to collect both quantitative and qualitative data. In all, 245 SHS4 Chemistry students selected from four out of 18 schools, which offer elective science for 2010/2011 academic year in the Kumasi Metropolis, were involved in the study. An achievement test and interview were the main instruments for the data collection. The results show that the students' performance on IUPAC nomenclature of organic compounds was generally low. The Chemistry students' difficulties in IUPAC naming of organic compounds included their inability to identify the correct number of carbon atoms in the parent chain, and to identify a substituent or functional group. The Chemistry students also had difficulties in writing structural formulae of organic compounds chiefly their inability to identify from the IUPAC name the correct number of carbon atoms in the parent chain, the chemical symbol or formula of any substituent or functional group, the correct position of and number of multiple bonds, functional, or substituent group. These difficulties having been recognised could help Chemistry teachers to effectively deploy their pedagogical content knowledge in teaching organic Chemistry at the SHS level.

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DEDICATION

To my wife, Evelyn Adu-Gyamfi and daughter, Yaa Aban Adu-Gyamfi.

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

This chapter looks at some areas of the study such as the background to the study, statement of the problem, purpose of the study, research questions and hypothesis. The rest are the significance of the study, delimitations, limitation, and organisation of the rest of the study.

Background to the Study

According to Solomons and Fryhle (2008), after the nineteenth century, there emerged a formal system for naming organic compounds. It must be noted that many organic compounds were discovered prior to the nineteenth century and the names of those compounds were based on the respective sources of the compounds. For example, a carbon compound from vinegar was named as acetic acid, which takes its name from the Latin word acetum for vinegar. Also, formic acid was obtained from some ants (in Latin: formicae) and thereby the name, formic acid. Ethanol (ethyl alcohol) was once referred to as grain alcohol as it was obtained from fermentation of grains. These old names (that is acetic acid, formic acid, and grain alcohol) are currently referred to as 'common' or 'trivial' names (Solomons & Fryhle, 2008). Gillette (2004) pointed out that some of the carbon compounds (organic compounds) were also given trivial names by the scientists who were the first to have discovered them. For example, acetylene

(C_2H_2), benezene (C_6H_6), and acetone (C_3H_6O). According to Gillette (2004), some organic compounds used to have more than one trivial name and at times brought confusion among chemists and biochemists during communication. Chemists and biochemists from most part of the world today still use the trivial names.

The International Union of Pure and Applied Chemistry (IUPAC) in 1892 came out with the formal system of naming organic compounds and thereby the name, IUPAC nomenclature (Fessenden & Fessenden, 1990; Gillette 2004; Heger, 2003; Solomons & Fryhle, 2008). According to Fessenden and Fessenden (1990), "the IUPAC system of nomenclature is based upon the idea that the structure of an organic compound can be used to derive its name and, in turn, that a unique structure can be drawn for each name" (p. 92). The IUPAC system, which has been in use since 1892, has been revised many times. The current IUPAC rules of nomenclature were updated in 1993. From Solomons and Fryhle (2008), "each different compound should have an unambiguous name" (p. 134). This serves as the basic principle of the IUPAC system where no organic compound will have more than one name. Any chemist or biochemist who is used to the rules of IUPAC system can write the correct name or structural formula of any organic compound that comes his or her way.

The IUPAC system of naming organic compounds is dependent on the functional groups, which is grouping compounds by shared structural features (Gillette, 2004). For instance, all alkanoic acids and alkanols contain the carboxyl (─COOH) group and hydroxyl (─OH) group respectively bonded to carbon atom.

According to Clark (2000), there are two skills a Chemistry student can develop in using the IUPAC nomenclature system to name organic compounds. These are the ability to:

1. draw or write the structural formula of an organic compound from its IUPAC name, and
2. write the IUPAC name of an organic compound from its structural formula (p. 1).

Hines (1990) conducted a study with secondary school students in Botswana and found out that when it comes to writing of chemical formulae from IUPAC names, science students have a great challenge in doing so. Bello (1988) has revealed that the difficulties of students in solving stoichiometric problems are responsible for their inability to write chemical formulae as required by the IUPAC system.

The findings of Baah (2009) from a study conducted in the New Juaben Municipality of the Eastern Region of Ghana revealed that Senior High School (SHS) Chemistry students have difficulty in writing chemical formulae of inorganic compounds from the IUPAC names. He attributed this challenge to the lack of the students' understanding of Roman numerals that are put in the brackets within the IUPAC names. For example, 'I', 'II', and 'IV' respectively in Copper (I) oxide, Iron (II) sulphide, and Calcium trioxocarbonate (IV).

In Ghana, one of the general aims of Chemistry teaching syllabus is to help Chemistry students from SHS2-4 to appreciate and use the IUPAC system to name chemical compounds (Ministry of Education, Science, and Sports [MOESS], 2008). According to MOESS (2008), the IUPAC nomenclature of carbon compounds are introduced at the SHS3 level under section 6 of the Chemistry teaching syllabus. The IUPAC nomenclature is studied under areas such as Alkanes, Alkenes, Alkanols, Alkanoic Acids, and Alkanoic Acids derivatives (for example, Amides and Esters) (MOESS, 2008). The specific objectives outlined in the SHS Chemistry teaching syllabus are:

a. describe the nomenclature and isomerism of alkanes, alkenes, and alkynes.
b. write the names and structures of given alkanols, alkanoic acids, amides, and alkyl alkanoates (MOESS, 2008, pp. 51-56).

The WAEC Chief Examiner's Reports (WAEC 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010) on Chemistry have revealed that Chemistry students had difficulty in answering examination's questions on IUPAC nomenclature of organic compounds. Since IUPAC nomenclature of organic compounds is one of the important areas under organic Chemistry, it was not out of place to find out how SHS Chemistry students understand and use it in various situations.

Statement of the Problem

Gillette (2004) has pointed out that the study of IUPAC nomenclature of hydrocarbons, which are organic compounds containing only carbon and hydrogen atoms, must come first to that of organic compounds containing functional groups. According to Gillette (2004), "once you have mastered the IUPAC nomenclature for the different types of hydrocarbons, you will be able to apply the same basic naming principles to organic compounds containing other functional groups" (p. 1). A look at the 2008 Teaching Syllabus for Chemistry at the SHS level showed that the study of Alkanes, Alkenes, and Alkynes, which are hydrocarbons come before the study of organic compounds with functional groups such as Alkanols, Alkanoic Acids, Amides, and Alkyl Alkanoates (Esters) (MOESS, 2008). This shows that the 2008 Teaching Syllabus for Chemistry agrees to the fact that a good understanding of IUPAC nomenclature of hydrocarbons enhances a good understanding of IUPAC nomenclature of organic compounds containing other functional groups.

Clark (2000) has pointed out that the ability of Chemistry students to translate the IUPAC name of an organic compound into its structural formula is the most important and most flexible as compared to the ability of Chemistry students to give the IUPAC name of any given structural formula. In any Chemistry examination, if a student finds it difficult to write a structural formula of any named compound, he or she will find it difficult to understand what the examiner is looking for. Hence, the performance of such a student is affected on such questions (Clark, 2000).

Baah's (2009) study conducted in Ghana has revealed that Chemistry students from well-endowed SHSs performed significantly better than Chemistry students from less-endowed SHSs on naming of formulae of chemical compounds by the IUPAC nomenclature. Also, on writing of formulae of chemical compounds from IUPAC names, Baah (2009) pointed out that there is a significant difference in achievements between Chemistry students from well-endowed and less-endowed schools, which is in favour of the students from the well-endowed schools. This shows that some students have problems with the IUPAC nomenclature.

The WAEC Chemistry Chief Examiner's report in Ghana has repeatedly lamented on the weakness of most students in IUPAC nomenclature of organic compounds (WAEC, 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010). In 2001, the Chief Examiner's report showed that many candidates attempted a question on naming of organic compounds but some candidates could not give the IUPAC names of the compounds. In 2002 and 2006, the report revealed that candidates showed weakness in IUPAC naming of simple organic compounds. For example, candidates could not name C_6H_5Cl as chlorobenzene. In 2004, the report indicated that candidates referred to $CH_3{-}CH(NH_2){-}COOH$ as 2-amidepropanoic acid instead of 2-aminopropanoic acid. In 2005 and 2010, the report pointed out that candidates could not write correctly the IUPAC names of the structural formulae of some organic compounds they themselves have given from certain molecular formulae. For example, in 2005, candidates could not write the correct IUPAC names of $HCOOCH_3$, $CH_3CHOHCH_2OH$ and C_6H_5COOH as methyl methanoate, propan-1,2-diol and phenylmethanoic acid respectively.

These reports suggest that Ghanaian SHS Chemistry students have challenges with the IUPAC naming of organic compounds. It is important therefore to investigate why SHS Chemistry students are unable to use IUPAC nomenclature to name and write structural formulae of organic compounds.

Purpose of the Study

The purpose of this study therefore was to determine the knowledge level of Chemistry students in IUPAC nomenclature of organic compounds. This assisted in diagnosing the difficulties they have with naming and writing structural formulae of organic compounds. The nature of the difficulties and why students have those difficulties was then investigated.

Research Questions

The following research questions were used to guide the study:

1. What is the performance of SHS Chemistry students on test items involving naming and writing structural formulae of organic compounds by IUPAC nomenclature?
2. What difficulties do SHS Chemistry students have in using the IUPAC nomenclature system to name and write structural formulae of organic compounds?
3. What accounts for SHS Chemistry students' difficulty in naming and writing structural formulae of organic compounds by IUPAC nomenclature?

Hypothesis

The following null hypothesis was formulated for testing during the study:

There is no significant difference between the performance of SHS Chemistry students from well-endowed and less-endowed schools on naming and writing structural formulae of organic compounds by IUPAC nomenclature.

Significance of the Study

The findings from this study such as the difficulties Chemistry students have with the use of the IUPAC system in naming organic compounds at the SHS level could help Heads of SHSs, Heads of Science Departments and Chemistry teachers to create the conditions necessary for Chemistry students to overcome such difficulties with IUPAC naming of organic compounds.

The study could further provide Chemistry teachers with rich quantitative and qualitative information about the understanding of Chemistry students in IUPAC nomenclature of organic compounds. This could help Chemistry teachers to adopt some effective ways of helping SHS Chemistry students to improve their understanding in this all important area of organic Chemistry.

Delimitations of the Study

There were 18 SHSs offering elective science in Kumasi Metropolis for the 2010/2011 academic year. The population of interest was limited to Chemistry students from four schools. The SHS4 Chemistry students were used for the study. This was because they would have studied the IUPAC nomenclature at SHS3, where according to MOESS (2008) the IUPAC nomenclature of organic compounds is studied. The study also confined itself to the use of achievement test and interview to collect quantitative and qualitative data.

There were a number of topics under organic Chemistry from which the IUPAC nomenclature could be studied at the SHS level but the study was limited to alkanes, alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates.

Limitation of the Study

The study also encountered sample mortality at the time of its conduct as all the schools involved in the study were run on boarding and day status. The reduction in the sample size affected the original plan for the study and therefore decreased the generalisation of the findings.

Organisation of the Rest of the Study

There are four other additional chapters aside Chapter One which are organised logically to further give insights into the issues raised in this chapter, which helped to answer the research questions and test the hypothesis. Chapter Two of this thesis was devoted to general review of literature related to the study. The areas looked at under this chapter included theories of knowledge construction, introduction to IUPAC nomenclature of organic compounds, Chemistry students' performance on IUPAC nomenclature of chemical compounds, Chemistry students' difficulties in chemical concepts, WAEC Chief Examiners' Reports on IUPAC nomenclature of organic compounds, and conceptual framework of the study.

Chapter Three described the research methodology for the study. It described the type of study and the research design used for the study. The strengths and weaknesses of the research design were also discussed. Chapter Three further described issues relating to population, sample and sampling technique, research instruments, data collection procedure, and data analysis plan.

Under Chapter Four, the findings from the study were presented and discussed. The presentation and discussion of the research findings from the study were done with respect to the research questions and the hypothesis.

Chapter Five, which is the final chapter of this study, described the summary of the research findings and their interpretations with respect to the literature. There was also an indication to the fact that the findings confirm the research questions and null hypothesis. Chapter Five further described the implications and conclusions relating to the findings from the study. Finally, recommendations and suggestion based on the key findings from the study were described in Chapter Five.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

The study was aimed at determining the knowledge level of SHS Chemistry students in IUPAC nomenclature of organic compounds. Base on this aim, in this chapter some research works relating to knowledge and performance of Chemistry students in IUPAC nomenclature of organic compounds have been reviewed. The following review and discussion of related literature are organised in areas such as:

1. Theories of knowledge construction,
2. Introduction to IUPAC nomenclature of organic compounds,
3. Chemistry students' performance on IUPAC nomenclature of chemical compounds,
4. Chemistry students' difficulties in chemical concepts,
5. WAEC Chief Examiners' Reports on IUPAC nomenclature of organic compounds, and
6. Conceptual framework of the study.

Theories of Knowledge Construction

For the purpose of this study, theories of students' knowledge construction such as pedagogical content knowledge, generative learning, and constructivism have been reviewed. This help to give an insight as to how students learn and the difficulties they encounter in the learning processes.

Pedagogical Content Knowledge

Lee S. Shulman is said to be the first person to have introduced the concept of pedagogical content knowledge (PCK) in his paper; “those who understand: knowledge growth in teaching” presented at American Educational Researchers Association, Chicago (Shulman, 1986). From Bucat (2005), “PCK refers to knowledge about the teaching and learning of particular subject matter, taking into account the particular learning demands inherent in the subject matter” (p. 1). There is a difference between a teacher knowing his or her subject matter and knowing about teaching and learning of that subject matter. Some knowledge about teaching and learning Chemistry is specific to the particular subject matter. According to van Driel, Verloop, and de Vos (1998, p. 673), “the concept of PCK refers to teacher’s interpretations and transformations of subject-matter knowledge in the context of facilitating student learning”. PCK considers students’ learning difficulties and preconceptions.

PCK is about transformation of content knowledge so that it can be used effectively and flexibly between teachers and students during the teaching and learning process. Teachers could deduce PCK from their respective teaching experiences and schooling activities (van Driel et al., 1998). Shulman (1987) revealed that PCK extends its boundary beyond the content knowledge of a subject to areas of content knowledge of teaching.

Specific subject matter and teaching strategies are said to interact in the minds of teachers (Shulman, 1987). Teaching demands some basic skills, subject matter, and general pedagogical skills. Teacher's understanding of his or her subject matter is more critical for an inquiry oriented classroom.

Godino, Batanero, Roa, and Wilhelmi (2008) identified five components of PCK as:

> Epistemology: epistemological reflection on the meaning of concepts to be thought; Cognition: prediction of students' learning difficulties, errors, obstacles, and strategies; Teaching resources and techniques: experience with good examples of teaching situations, didactic tools, critical capacity to analyse textbooks, curricular documents, and to statistics knowledge to different teaching levels; Affect: ability to engage students' interest and take into account the students' attitudes and beliefs; Interaction: ability to create good communication in the classroom and use assessment as a way to guide instruction (p. 1).

According to Shulman (1987), PCK is an interesting area to watch as it defines the distinctive bodies of knowledge for teaching and comprises the attributes a teacher possesses that enable him or her guides students to comprehend specific content such as Chemistry. Also, PCK helps in comprehension of how particular topics or problems are organised, represented, and adapted to the different interest and abilities of students. This is because PCK combines content and knowledge of teaching. Hence, PCK differentiates the understanding of content specialist from that of pedagogue.

According to van Driel et al. (1998), the knowledge of representations of subject matter, and comprehension of specific learning difficulties and student conceptions were the two main components of Shulman's conception of PCK. These components are closely related to each other and could be used in a more relax manner by any teacher. "The more representations teachers have at their disposal and the better they recognise learning difficulties, the more effectively they can deploy their PCK" (p. 675).

From van Driel et al. (1998), there is no one accepted conceptualisation of PCK, and that different components are integrated in PCK among scholars. To them, all scholars however, agree on knowledge of representations of the subject matter, and understanding of specific learning difficulties and student conception, which were the two main components of Shulman's PCK. "All scholars suggest that PCK is developed through an integrative process rooted in classroom practice, implying that prospective or beginning teachers usually have little or no PCK at their disposal" (p. 677). The main distinctive feature of a teacher's knowledge base lies at intersection of his or her content and pedagogy, the ability to transform his or her content knowledge into forms that are pedagogically powerful and yet could be used to benefit all students notwithstanding differences in their abilities and background (Shulman, 1987).

With respect to science teachers' PCK, van Driel et al. (1998) reported that the combination of specific topic familiarity and teaching experience positively influence PCK. PCK of experienced science teachers may vary considerably notwithstanding them having similar curriculum and content knowledge. These differences occur as a result of the teachers' respective use of representations and teaching strategies during classroom interactions.

Generative Learning

Students learn with understanding whenever they themselves actively construct (or generate) meaning from sensory input (Wittrock, 1974a; 1974b). This means that a student needs to construct his or her own knowledge and no other person can do it for him or her. Shulman (1987) said that learning is the ultimate responsibility of students. According to Lee, Lim, and Grabowski (n.d.), "Wittrock emphasized one very significant and basic assumption: the learner is not a passive recipient of information; rather, he or she is an active participant in the learning process, working to construct meaningful understanding of information found in the environment" (p. 112).

Grabowski (2001) pointed out that Wittrock's generative learning model integrates various areas of cognitive psychology such as cognitive development, human abilities, information processing, and aptitude treatment interactions. To him, Wittrock's model for generative learning was introduced as a prescribed teaching strategy to reduce reading comprehension strategies. According to Grabowski (2001, p. 897),

> The importance of asking the learner to generate his or her own meaning is clearly summarised by Wittrock's statement that 'although a student may not understand sentences spoken to him by his teacher, it is highly likely that a student understands sentences that he generates himself'.

The importance of generative learning is the knowledge generation. A meaningful knowledge is generated only when the student self generated the relationships and the understanding (Lee et al., n.d.).

Wittrock's model of generative learning in which the brain is a model builder consists of attention, motivation, knowledge and preconceptions, and generation. The study on generative learning model was carried out in neural research and generative cognitive function studied in knowledge-acquisition research (Wittrock, 1992). From Grabowski (2001), there are two important aspects of Wittrock's motivational processes. These are interest and attribution. Attribution, which is the process of giving credit for success or failure to a student's effort, could cause him or her to actively learn or not. If a student appreciates that his or her success in a subject or course is as a result of his or her own effort, then he or she will be motivated to exert greater effort next time. Hence, the use of rewards and praise should be done in such a way that students can directly attribute the success to their own effort.

Arousal and intention in the brain have direct effects on students learning processes. Within the external environment of students comes arousal and attention that stimulate them internally. The key to Wittrock's learning process is attention. "Without attention, learning cannot occur" (Grabowski, 2001, p. 913). Teachers who provide behavioural objectives with questions as well as interpretations of the relevance of the chosen topic gain the attention of students during the teaching and learning process.

The components of memory are the knowledge creation processes such as beliefs, concepts, preconceptions, and experiences. Students' comprehension is generated when relationships or linkages are established between environmental stimuli and existing mental structures. According to Grabowski (2001), Wittrock revealed that scientific concepts (for example, IUPAC nomenclature of organic compounds) should be thought early before preconceptions are formed. Also, teachers should as much as possible link instruction to students' background knowledge and interest.

Wittrock (as cited in Grabowski, 2001, p. 914) said "the act of generative teaching is knowing how and when to facilitate the learner's construction of relations among the parts of the text and their knowledge". An activity is labeled generative when it creates organisational linkages among the various components of the environment, for instance, headings, questions, and graphs. Another generative activity is the one that establishes linkages between the external stimuli and memory components such as demonstrations, pictures, and applications. Grabowski (2001) explained that teachers can formulate titles and headings as organizers or ask students to formulate a title or heading. If a teacher intends to provide his or her students with a title or heading, then it should be done in such a way that it would direct students' attention.

Lee et al. (n.d.) established interrelationship among the components of Wittrock's generative learning mode. According to them, only those activities that involve actual creation of relationships and understanding could be grouped as examples of generative learning strategies. The student has to construct his or her understanding by restructuring the environmental information. If a student can generate linkages between memory such as preconceptions, abstract knowledge, experience, and new information, then understanding of a concept can be generated. In the model, students are encouraged to be mentally actively construct relationships between schema and new knowledge (Lee et al., n.d.).

Motivation given to students promotes the impulse and intention to learn. Students' interest in knowledge generation could only be sustained if the students attribute successful understanding to their own effort, students use various learning strategies from simple coding to integration strategies to construct relationship between their memory and the new knowledge whenever they are motivated (Lee et al., n.d.). Generation of knowledge should be under the control of students. This is based on the fact that when students are allowed to self monitor their efforts, they manage their efforts and resources, and alter their learning strategies to generate meaning. Grabowski (2001) said that understanding occurs when students are able to link existing mental structures and the new information and not by 'placing' information or 'transforming' information in memory.

Constructivism

Theories of learning which are based on foundations, scope, and validity alternative to objectivist theories of knowledge are termed as constructivists (Swan, 2005). Thus both constructivists and objectivists asserted that there is a real world, which we can experience. In this real world, constructivists believed that students construct meaning as they interact with the physical, social, and mental worlds. Gallagher (2000) said that students should realise that they have to construct their own knowledge whenever they are thought any scientific concept.

According to Swan (2005), constructivists are divided in the areas of focus though they all share common assumptions about the nature of learning and construction of knowledge. Some constructivists focus the student's knowledge construction on the social environment, physical, and mental world.

Social constructivism: Social constructivists agree that students construct knowledge through social interactions. Thus, psychologists of today recognise that culture shapes cognitive development by determining what and how the students will learn about the world (Crowl, Kaminsky, & Podell, 1997; Swan, 2005; Woolfolk, 2007). Lev Vygotsky, a Russian psychologist, attributed a special role in cognitive development to the social environment of the student. That meaning is constructed by a student socially as he or she indulges in activities, communicates, and interacts with others (Swan, 2005; Woolfolk, 2007). The student's culture (that is the social world) determines which stimuli occur and are attended to and that knowledge constructed is not predetermined by innate factors.

Vygotsky, being a major spokesperson of sociohistoric theory, asserted that human activities are placed in a cultural setting and cannot be understood apart from these settings. Therefore knowledge construction is the transformation of socially shared activities into internalised processes (Woolfolk, 2007). According to Swan (2005), Vygotsky considered construction of knowledge by a student as in two sections. First, students construct the knowledge socially and internalise it individually.

Vygotsky, a social constructivist, used three themes: social sources of individual thinking; the role of cultural tools in learning and development; and the zone of proximal development. The social sources of individual thinking are based on that fact that student's higher mental processes are first co-constructed during shared activities between the student and another person. Then the processes are internalised by the student and form part of his or her cognitive development (Woolfolk, 2007).

According to Vygotsky (as cited in Woolfolk, 2007), cultural tools (such as rulers, pipette, and computers) and psychological tools (such as works of art, signs, symbols, codes, and language) play vital roles in knowledge construction. Vygotsky was particularly concerned with the role of language in thinking and learning. He pointed out that language and thought were closely related (Swan, 2005). All higher order mental processes such as reasoning and problem solving are achieved by psychological tools. Language is crucial to knowledge construction as it provides a way to express ideas and ask questions, and the links between the past and the future. The student's ability to plan a solution to an identified problem depends on the language capacity of the student. According to Swan (2005), Vygotsky asserted that there is a fundamental correspondence between thought and speech in terms of one providing resource to the other; language becoming essential in forming thought.

From Swan (2005), the zone of proximal development is the distance between the actual development level as determined by the independent problem solving and the level of potential development as determined through solving under adult guidance or in collaboration with more capable peers. Knowledge construction actually occurs in this zone. The zone of proximal development varies from student to student, and from situation to situation (Crowl, Kaminsky, & Podell, 1997).

According to Woolfolk (2007), Vygotsky believed that the role of private speech in cognitive development fit with the notion of the zone of proximal development. Often, an adult uses verbal prompts and structuring to help (or support) a child to solve a problem or accomplish a task. In education psychology this support and guidance adults give as child attempts to solve problems beyond his or her current knowledge is referred to as scaffolding (Crowl, Kaminsky & Podell, 1997). This scaffolding can be gradually reduced as the child takes over the guidance, perhaps first by giving the prompts as private speech and finally as inner speech.

Dirks (1998) explained that many schools have now realised that knowledge is not objective but constructed socially and that the knowledge constructed depends greatly on experience and interactions of the students with others who know it. He emphasized that a student goes about the process of knowledge constructions through a mixture of experiences, perspectives, and interactions.

Constructivism is opposed to passive learning approach where students normally take away content, and that knowledge construction should be an active engagement of the students (Dirks, 1998). One advantage of Vygotsky's social constructivism is that it helps us to consider both the psychological and social aspects of knowledge construction.

Cognitive constructivism: Cognitive constructivism is accredited to psychologists such as Jean Piaget. Cognitive constructivists revealed that knowledge construction should be based upon the internal development of mental structures. Cognitive constructivists stressed on the students' knowledge, beliefs, and self concept, and on the inner being of the student. From Swan (2005), Piaget referred to the mental structures as schema. The two kinds of cognitive processing involving schema construction are assimilation and accommodation. For a student to assimilate means to incorporate new knowledge into his or her existing mental structures whereas to accommodate means to change his or her existing schema in order to incorporate a new knowledge that conflicts with it.

Piaget pointed out that knowledge construction is influenced by students' genetic make-up and this change as the students mature. From this, Piaget (as cited in Swan, 2005) came out his Stage Theory:

> The sensory-motor stage, which is pre-linguistic, is characterised by kinesthetic understanding and organisation of experience, while the pre-operational stage is characterized by egocentrism, the organisation of knowledge relative to oneself. In the concrete operational stage, knowledge is organised in logical categories but still linked to the concrete experience. It is only in the formal operational stage, according to Piaget, that knowledge is abstracted from experience and formal reasoning can occur (p. 2-3).

The stage theory explained that knowledge construction through these stages is affected by maturation. According to Swan (2005), cognitive constructivism is essential to us because it locates knowledge construction in the minds of students, and that students should interact with the environment in order to learn. Stage theory also shows that different students construct knowledge differently at different stages of development.

Constructionism: Constructionism is focused on how public knowledge in disciplines such as Chemistry is constructed. Hence, social constructionists do not emphasize the individual student knowledge construction as in the case of social and cognitive constructivists. From Swan (2005), Seymour Papert recognised the important roles of constructions in the world to knowledge construction. To constructionists, computers have the capacity to assist students to concretise abstract ideas. Computer-based constructions can help students to assimilate and accommodate new knowledge where necessary (Swan, 2005).

To sum up, there is no one constructivist theory of knowledge construction and that students can construct their own knowledge through their active involvement in the processes of knowledge construction and social interactions.

Introduction to IUPAC Nomenclature of Organic Compounds

The concept IUPAC nomenclature, which is a formal system of naming organic compounds, was introduced in 1892 by the International Union of Pure and Applied Chemistry (IUPAC) (Fessenden & Fessenden, 1990; Gillette 2004; Heger, 2003; Solomons & Fryhle, 2008). From Woodcock (1996), there are other systematic nomenclature systems that came prior to the IUPAC system and that IUPAC names may not be the most commonly used one. Klinger, Kolarik, Fluck, Hofmann-Apitus, and Friedrich, (2008) noted: “trivial names can be searched for with a dictionary-based approach and directly mapped to the corresponding structure at the same time” (p. i268). But IUPAC and IUPAC-like names are identified with respect to the structure of the organic compound (Kolarik et al. as cited in Klinger et al., 2008).

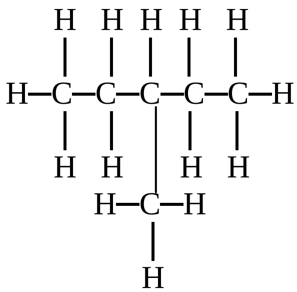
In using the IUPAC nomenclature system to name and write structural formulae of organic compounds, the functional group (which is an atom or group of atoms largely responsible for the chemical behaviour of organic compounds) of a compound is taking into consideration (Gillette, 2004; Woodcock, 1996). For instance, all alkanoic acids and alkanols contain the carboxyl (─COOH) group and hydroxyl (─OH) group respectively bonded to carbon atom. From Skonieczy (2006), preference should always be given to a functional group that has the highest precedence when the organic molecule in question contains more than one functional group. The principal functional group is usually named as the suffix and the others as the prefixes (Appendix A).

Students' ability to translate the IUPAC name of an organic compound into its structural formula is the most important and most flexible as compared to the ability of Chemistry students to give the IUPAC name of any given structural formula. In any Chemistry examination, if students find it difficult to write a structural formula of any named compound, then they will as well find it difficult to understand what the examiner is looking for. Hence, the performance of such students is affected on such questions (Clark, 2000).

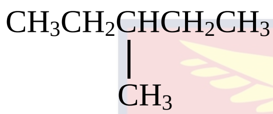
Woodcock (1996) explained that though almost every organic compound contains carbon and hydrogen atoms, the names of these two elements do not appear directly in the names of the respective compounds (Appendix A). The IUPAC names of organic compounds are influenced partly by the number of carbon atoms in the longest continuous carbon chain (Woodcock, 1996).

In simplest form, there are three parts to each organic molecule. These are a root (parent); which shows the number of carbon atoms in the longest continuous carbon chain, and suffix (ending); which shows the family to which the organic compound belongs. The third part is prefix; which is dependent upon the number, position, and identity of any atoms or groups of atoms that have replaced any hydrogen atom or atoms in the parent compound (Gillette, 2004; Woodcock, 1996). Gillette (2004) stressed that if any Chemistry student is able to learn to apply and interpret these three parts of organic compound names, then he or she will be able to "write the chemical names of organic compounds base on their Lewis structures; and draw the Lewis structures for organic compounds based on their IUPAC names. The same will be true for condensed structural formulae and line-angle drawings" (p. 2).

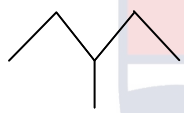
Gillette (2004) revealed that there are three ways of representing the IUPAC names of organic compounds with structural formulae. The first is the Lewis structure (referred to as expanded structural formula). The Lewis structure shows all the carbon and hydrogen atoms together with any other atom or group of atoms and the covalent bonds connecting them. The second structure is the condensed structural formula, which shows any carbon atoms in the straight chain together with any other atoms or group of atoms connecting to the chain without the covalent bonds or any unshared electron pairs. In the condensed structural formula, the covalent bond is shown only and only if there is the need to clarify a specific portion of the structure (Gillette, 2004). The line-angle drawing, which uses lines to show chemical bonds without the carbon and hydrogen atoms, is the third structural formula (Gillette, 2004). For example,



Lewis structure



Condensed structure



Line-angle structure

Gillette (2004) stressed that notwithstanding the method of structural formula used for any particular compound, the presence of any other atom or group of atoms and multiple bonds in any particular molecule must be showed. For example,

$CH_3CH{=}CHCH_3$

From Gillette (2004), "sometimes, for clarity, we use a combination of a line-angle drawing and a condensed structural formula to depict a cyclic hydrocarbon" (p. 7).

Gillette (2004) said "to draw the structure of an IUPAC-named compound, we work backwards through the compound name, from the ending to the parent name to the prefix" (p. 7). Clark (2000) explained that an IUPAC name of an organic compound is simply a code and that each part of the IUPAC name reveals some useful information about the compound. For example, 2-methylpropan-1-ol could be understood in the following ways:

1. The prop**-** shows the number of carbon atoms in the longest continuous carbon chain (and in this instance, there are three atoms of carbon) (Clark, 2000).
2. The –an that comes immediately after the 'prop' shows there is no carbon to carbon multiple bond (Clark, 2000).
3. The 2-methyl and -1-ol show what is or are happening on the first and second carbon atoms in the longest continuous carbon chain (Clark, 2000).

Clark (2000) was of the view that one has to learn the codes for number of carbon atoms in a continuous carbon chain in order to name organic compounds. Table 1 shows the codes for each group of number of carbon atoms in a continuous carbon chain.

Table 1: Codes of the First Six Groups of Carbon Atoms

Code	Number of Carbons
Meth	1
Eth	2
Prop	3
But	4
Pent	5
Hex	6

Clark (2000) pointed out that if an organic compound contains a carbon-carbon multiple bond, the two letters that come immediately after the code for the chain length will give an indication. Table 2 shows the codes for carbon-carbon single and multiple bonds.

Table 2: The Codes of Carbon-Carbon Bonds

Code	Interpretation
an	the molecule contains only carbon-carbon single bond
en	the molecule contains a carbon-carbon double bond
yn	the molecule contains a carbon-carbon triple bond

Alkanes with more than two carbon atoms can provide more than one derived group. For example, two groups can be derived from propane; namely the propyl group is derived by removal of a terminal hydrogen, and 1-methylethyl or isopropyl group is derived by removal of hydrogen from the central atom. Alkyl groups such as methyl (CH_3─), ethyl (CH_3CH_2─), and propyl ($CH_3CH_2CH_2$─) are usually attached to the longest continuous carbon chain (Clark, 2000).

Chemistry Students' Performance on IUPAC Nomenclature of Chemical Compounds

A careful look at Hofstein, Bybee, and Legro (1992) research work has revealed that the performance of science students depends on several factors of which the school environment and teaching and learning materials and equipment are among. This gives an indication that the type of school attended by a student has as influence on his or her performance on IUPAC nomenclature of chemical compounds. Baah's (2009) study conducted in Ghana found the following:

> The performance of students from well-endowed schools and less-endowed schools on naming of compounds by IUPAC nomenclature differed significantly with students from well-endowed schools doing better. This is because the mean score for students from well-endowed schools (M = 3.80, SD = 1.76) was significantly higher than the mean score of students from less-endowed schools (M = 2.085, SD = 1.710, t(332) = 8.734, p = 0.001) with an effect size of 1.0 (p. 122).

Baah (2009) further found that Chemistry students from less-endowed schools performed significantly less on writing chemical formulae of compounds and on writing chemical equations as compared to their colleagues from well-endowed schools. Under the writing of chemical formulae of compounds, he reported that the Chemistry students from the well-endowed schools recorded significantly higher mean score (M = 2.200, SD = 1.669) as compared to the mean score of Chemistry students from less-endowed schools (M = 0.940, SD = 1.184, t(332) = 1.454, p = 0.001) with 0.8 as the effect size. Under the writing of the chemical equations there was a significant difference between Chemistry students from less-endowed schools and well-endowed schools because the mean score (M = 8.493, SD = 3.357) of Chemistry students from the well-endowed schools was significantly higher to the mean score (M = 6.364, SD = 3.002, t(332) = 5.872, p = 0.001) with effect size of 0.7 of Chemistry students from less-endowed schools (Baah, 2009).

According to Wu, Krajcik, and Soloway (2001), many students studying Chemistry have difficulty learning symbolic and molecular representations. They therefore conducted a study with 71 eleventh grade students of small public high school in a midsize university town in the Midwest to investigate how Chemistry students develop and understand chemical representations using a computer-based visualising tool for 6 weeks. To them the computer-based visualizing tool was referred to as eChem. One of the chemical concepts studied within the 6 weeks period by Wu et al. (2001) was IUPAC nomenclature of organic compounds such as hydrocarbons.

Wu et al. (2001) pointed out that with the help of eChem; the Chemistry students were able to apply modern rules of IUPAC nomenclature to draw structures of some given organic compounds. For instance, the students were made to name and draw the structure of a six-carbon atom compound with a side group. The understanding of the high school Chemistry students used in the study was said to have improved reasonably resulting in high performance on IUPAC nomenclature of organic compounds. This is based on the fact that there was statistical significant difference between the means of pre-test (N = 71, M = 31.1) and post-test (N = 71, M = 59.5) results after they had been subjected to a paired two-sample t-test analysis (SD 2.5, t(70) = 13.9 p 0.001) with an effect size of 2.68 (Wu et al., 2001).

Chemistry Students' Difficulties in Chemical Concepts

Learning Chemistry at the microscopic level (that is, nature and arrangement, and motion of molecules used to explain the properties of compounds or natural phenomena) and symbolic level (that is, representations of atoms, molecules, and compounds, such as chemical symbols, formulae, and structures) is extremely difficult for science students (Ben-Zvi, Eylon, & Silberstein, 1986). This is because the microscopic and the symbolic levels of Chemistry are invisible and abstract in nature, and hence learning of Chemistry for understanding depends much more on the use of the senses. It is no wonder that Chemistry students find it difficult in comprehending chemical equations, formulae, and symbols. The concept of IUPAC nomenclature of compounds is at the symbolic level and could be said to be difficulty to most students.

Chemistry students' understanding is hindered by the surface features of representations (Kozma & Russell, 1997). Thus, most Chemistry students see equations or formulae of chemical substances (for example, CH_3CH_2OH or C_2H_6O) as a combination of letters and numbers rather than chemical formula (Wu et al., 2001). The difficulty of some students in understanding chemical representations is also seen as an area where a large number of them are unable to make translations among formulae (Keig & Rubba, 1993).

According to Keig and Rubba (1993), for learning to be meaningful to a student, it has to be built on an important set of concepts that him or her is used to. This means that an attempt must be made to link chemical phenomena which are abstract to their representations in order to make them understandable.

Kavanaugh and Moomaw (1981) asserted that science students perceived Chemistry to be a difficult subject. This in effect has resulted in many science students having difficulties in understanding scientific concepts in Chemistry. Kelly (as cited in Jones, 1991) revealed that most science students drop out of the physical sciences of which Chemistry is included to the biological sciences and other fields of academics as such students perceive them to be difficult.

The findings of Baah (2009) revealed that students have difficulty in writing chemical formulae of inorganic compounds from the IUPAC names. He attributed this challenge of Chemistry students in writing chemical formulae from IUPAC names of inorganic compounds partly to the lack of understanding of the students in the Roman numerals that are put in the brackets of the IUPAC names such as ‘II’ and ‘V’ in Copper (II) tetraoxosulphate (V). Also, the challenge of the students was attributed to their inability to determine the number of atoms of each element in a compound and to write the correct formulae of radicals. For example, PO_4^{3-} for tetraoxophosphate (V) ion and CO_3^{2-} for trioxocarboate (IV) ion. Hines (1990), who conducted a study with secondary school students in Botswana, has pointed out that when it comes to writing chemical formulae from IUPAC names, science students have a greater challenge in doing so. Bello (1988) has revealed that the difficulties of students in solving stoichiometric problems are responsible for their inability to write chemical formulae as required by the IUPAC system.

In naming some inorganic compounds (chemical formulae) using the IUPAC system, Baah (2009) found out that Chemistry students are faced with some difficulties due to their inability to correctly write the names of some elements and some radicals. These difficulties, according to Baah (2009), are as a result of the Chemistry students’ inability to locate the central atoms of some given chemical formulae. Also, these difficulties are as a result of the Chemistry students’ inability to write the correct names of some radicals and to deduce the oxidation numbers of the central atoms of some chemical formulae as a result of their lack of knowledge about the concept of valency (Baah, 2009).

WAEC Chief Examiners' Reports on IUPAC Nomenclature of Organic Compounds

The WAEC Chief Examiner of Chemistry at the SHS level in Ghana has repeatedly lamented on the weakness of most students in IUPAC nomenclature of organic compounds (WAEC, 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010). In 2001, the Chief Examiner's Report showed that many candidates attempted Question 2 but some candidates could not give the IUPAC names of the compounds. In 2002, according to the Chief Examiner's Report, candidates showed weakness in IUPAC naming of simple organic compounds. For example, candidates could not name C_6H_5Cl as chlorobenzene. In 2004, the Chief Examiner's Report indicated that candidates referred to $CH_3{-}CH(NH_2){-}COOH$ as 2-amidepropanoic acid instead of 2-aminopropanoic acid.

In 2005 and 2010, according to the Chief Examiner's Reports, candidates could not correctly write the IUPAC names of the structural formulae of some given organic compounds. For example, in 2005, candidates could not write the correct IUPAC names of $HCOOCH_3$, $CH_3CHOHCH_2OH$ and C_6H_5COOH as methyl methanoate, propane-1,2-diol and phenylmethanoic acid respectively. In 2006, the Chief Examiner's Report pointed out that candidates could not give the correct IUPAC names and structure of some organic compounds.

From the above revelations of the Chief Examiner's Reports, it is clear that Ghanaian students have been facing a challenge with the IUPAC naming of organic compounds in their Chemistry final examinations conducted by WAEC.

Conceptual Framework of the Study

The concept map in Figure 1 was formulated as a guide to the study. It was used to show the important stages through which the knowledge level of the SHS Chemistry students involved in the study was examined.

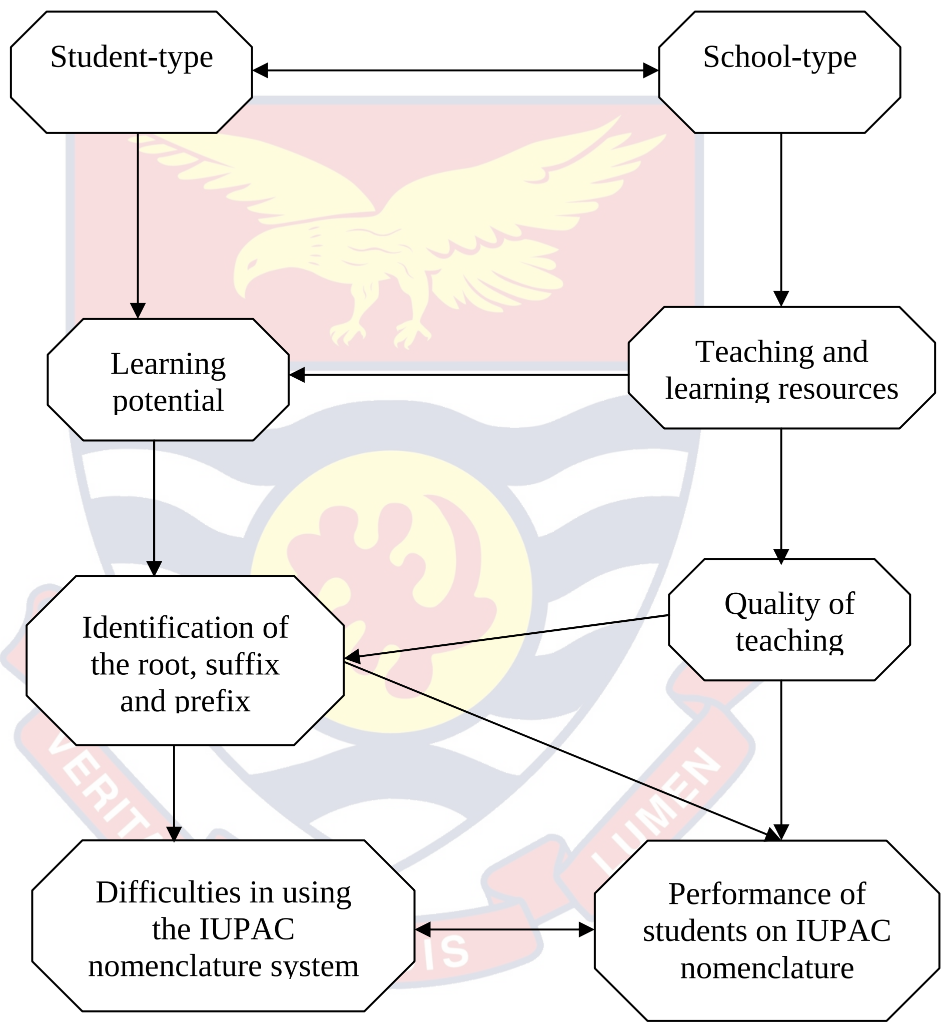


Figure 1. **Conceptual understanding of the stages involved in the study**.

The concept map in Figure 1 illustrates the theories and the vital stages of the study through which it was conducted. There were two school-types seen from the literature reviewed. These were well-endowed and less-endowed schools. The quality of students, in terms of grade in Science and overall aggregate obtained by students at the junior high school level, and available school facilities such as single sex, boarding, day, and science facilities underpinned the school-type classification. The well-endowed schools have a better share of these characteristics. Quality teaching and learning could be said to occur in the well-endowed schools as teachers with qualified academic and professional certificates and teaching experience are employed to teach in these schools as compared to the less-endowed schools. From the literature, it was observed that the experienced science teachers combine both familiarity and teaching experiences to positively influence their PCK.

The learning potentials of the students are enhanced when an enabling environment is created. People across the country prefer to have their education in the well-endowed schools because they are competitive and produce students with academic excellence. The theoretical literature has shown that the social world of the student influences his or her knowledge construction. Hence, the literature shown that students from the well-endowed schools performed better on chemical concepts such as naming and writing formulae of inorganic compounds using the IUPAC nomenclature and writing chemical equations.

As a result of quality teaching and good learning potentials, Chemistry students at the SHS level could be thought effectively to identify the three components of an organic molecule. These are the root, suffix, and prefix. The root shows the number of carbon atoms in the continuous carbon chain, which forms the parent chain. The suffix gives an indication of the family of the organic compound. This helps students to identify the chemical formulae or symbols as well as the names used in IUPAC nomenclature for such identified family.

Finally, the prefix describes the number and position of substituent groups. When students understand these three components of organic molecule, they could use the IUPAC nomenclature system to name and write structural formulae of organic compounds. Hence, enhanced performance and less difficulty levels will be shown by students in IUPAC nomenclature of organic compounds.

Summary of Major Findings of the Literature Review

1. The more representations teachers have at their disposal and the better they recognise learning difficulties, the more effectively they can deploy their PCK (van Driel et al., 1998).
2. PCK helps in comprehension of how particular topics or problems are organised, represented, and adapted to the different interest and abilities of students (Shulman, 1987).
3. Experienced science teachers combine both familiarity and teaching experiences to positively influence their PCK (van Driel et al., 1998).
4. Generative learning model consists of attention, motivation, knowledge and preconceptions, and generation (Wittrock, 1992).
5. Generative learning model was introduced as a prescribed strategy to reduce reading comprehension strategies (Grabowski, 2001).
6. The use of rewards and praise should be done in such a way that students can directly attribute the success to their own effort (Grabowski, 2001).
7. Teachers should as much as possible link instruction to students' background knowledge and interest (Grabowski, 2001).
8. The generative learning model encourages students to actively construct relationships between existing mental structures and new information and

not by ‘placing’ information or ‘transforming’ information in memory (Grabowski, 2001; Lee et al, n.d.).

9. Students construct meanings as they interact with the physical, social, and mental worlds (Swan, 2005).
10. Psychologists of today recognise that culture shapes cognitive development by determining what and how the students will learn about the world (Crowl, Kaminsky, & Podell, 1997; Swan, 2005; Woolfolk, 2007)
11. Vygotsky considered construction of knowledge by a student as in two sections. First, students construct the knowledge socially and internalise it individually (Swan, 2005).
12. Language is crucial to knowledge construction as it provides a way to express ideas and ask questions, and the links between the past and the future (Woolfolk, 2007).
13. The zone of proximal development varies from student to student, and from situation to situation (Crowl, Kaminsky, & Podell, 1997).
14. Many schools have now realised that knowledge is not objective but constructed socially and that the knowledge constructed depends greatly on experience and interactions of the students with others who know it (Dirks, 1998).
15. The two kinds of cognitive processing involving schema construction are assimilation and accommodation (Swan, 2005).
16. Piaget pointed out that knowledge construction is influenced by students’ genetic make-up and this change as the students mature (Swan, 2005).

17. Cognitive constructivism is essential to us because it locates knowledge construction in the minds of students, and that students should interact with the environment in order to learn (Swan, 2005).
18. Computer-based constructions can help students to assimilate and accommodate new knowledge where necessary (Swan, 2005).
19. The IUPAC nomenclature system of organic compounds is dependent on the functional group (Gillette, 2004; Skonieczy, 2006; Woodcock, 1996).
20. The names of carbon and hydrogen, which are atoms found in every organic compound do not appear in the names of the respective compounds (Woodcock, 1996).
21. There are three parts to each organic molecule that appear in the IUPAC names. These are the root (parent); which shows the number of carbon atoms in the longest continuous carbon chain, suffix (ending); which shows the family of the organic compound, and prefix; which is based on the number, position, and identity of any atom or groups of atoms that have replaced any hydrogen atom or atoms in the parent compound (Gillette, 2004; Woodcock, 1996).
22. The IUPAC nomenclature of carbon compounds is introduced and completed at the SHS3 level under section 6 of the Ghanaian Chemistry teaching syllabus (MOESS, 2008).
23. The mastery of the IUPAC nomenclature of hydrocarbons is said to enhance the performance of Chemistry students on the IUPAC nomenclature of organic compounds with other functional group (Gillette, 2004).

24. The Ghanaian SHS Chemistry students have been facing a challenge with the IUPAC naming of organic compounds in their Chemistry final examination conducted by WAEC (WAEC, 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010).
25. The difficulty of science students in using the IUPAC system in writing chemical formulae of inorganic compounds depended on the science students' lack of understanding of the Roman numerals that are put in the brackets of the IUPAC names and on that of the stoichiometry (Baah, 2009; Bello, 1988; Hines, 1990).
26. The difficulty of the science students in using the IUPAC system in naming chemical formulae of inorganic compounds was attributed to their inability to name correctly some elements and radicals, their inability to identify the central atom in a given chemical formula, and their inability to deduce the correct oxidation numbers of the central atoms (Baah, 2009).
27. The performance of science students from well-endowed schools was significantly better than that of science students from less-endowed schools on naming of chemical formulae of inorganic compounds (Baah, 2009).
28. The performance of the science students from well-endowed schools was also significantly better than that of the science students from less-endowed schools on writing of the chemical formulae of inorganic compounds (Baah, 2009).
29. The performance of science students on the use of the IUPAC nomenclature system to name and write structural formulae of organic

compounds was high after the students have been introduced to the eChem model (Wu et al., 2001).

CHAPTER THREE

METHODOLOGY

The research methodology talks about all the important details about the research design, the population, the sample and sampling procedure, the instruments together with information on how the data collected were analysed. The details therein are given to demonstrate the appropriate technical principles that serve as the backbone of the study. These technical principles were strictly used during the study. The facts that are given here under the research methodology further give the assurance that the basis for the conclusions reached could be seen as valid and reliable, and could be used as a body of new knowledge. The research work described here was undertaken to survey the knowledge of the SHS Chemistry students in IUPAC nomenclature of organic compounds. The sample for the study was stratified based on well-endowed and less-endowed schools.

Research Design

The study used the mixed method design employing both qualitative and quantitative methods (Cohen, Manion, & Morrison, 2005; Creswell, 1994) to determine the knowledge level of students in IUPAC nomenclature of organic compounds. With the help of cross-sectional survey, this mixed method design provided the study with both qualitative and quantitative data on the knowledge level of Chemistry students in naming and writing structural formulae of organic compounds by IUPAC nomenclature. A descriptive quantitative design was used to answer the research question on the general performance of students on test items involving naming and writing structural formulae of organic compounds by IUPAC nomenclature. It was also used to answer another research question on students' difficulty in using the IUPAC nomenclature system to name and write structural formulae of organic compounds. The qualitative design was used to answer the research question on the reason behind students' difficulty in using the IUPAC nomenclature system to name and write structural formulae of organic compounds.

The survey design used for the study involves three stages. An achievement test of two sections was constructed by me at the first stage of the survey. The section 1 of the achievement test was on naming organic compounds by IUPAC nomenclature whereas the section 2 was on writing structural formulae of organic compounds by IUPAC nomenclature. After the construction of the instrument, it was pilot-tested with SHS4 Chemistry students from Obuasi Senior High School. The purpose was to help determine the level of difficulty of test items and to establish the reliability of the instrument. At the second stage of the survey, the achievement test was administered to SHS4 Chemistry selected from four schools in Kumasi Metropolis of the Ashanti Region. At this stage, the achievement test helped to ascertain the difficulties and the performance of students on naming and writing structural formulae of organic compounds using the IUPAC system. The third stage was an interview with some selected Chemistry students based on their performance in the achievement test. The interview was conducted to find out the reasons behind students' difficulty in using IUPAC nomenclature system to name and write structural formulae of organic compounds.

Population

There were 39 SHSs in Kumasi Metropolis consisting of 18 public schools and 21 private schools for the 2009/2010 academic year. Out of the 39 schools in Kumasi Metropolis, Chemistry students from 18 schools that offer elective science were used for the study. The target population for the study was all SHS4 Chemistry students offering elective science for the 2010/2011 academic year. This was because the SHS4 Chemistry students have studied Chemistry for two years and they were in the better position to contribute to the study.

Sample and Sampling Procedure

The Chemistry students were selected from four schools. The four schools were classified as well-endowed and less-endowed with two schools in each group. The classification was based on the fact that the Ghana Education Service (GES) considers some SHSs as most prestigious and academically competitive, attracting students from all parts of the country whereas others are not (Ampiah, 2007). The availability of single sex, boarding, day, and science facilities also inform the grouping of schools by the GES. The classification of the four schools was also based on the grade in science with which the students were admitted into the general science programme at the SHS level. The well-endowed schools selected only students with grade one in science into the General Science programme whereas students with grade two or better in science were selected into the General Science programme for the less-endowed schools. Table 3 shows the number of Chemistry students who were present in their respective schools at the time of the study and took part in it.

Table 3: Number of Students from the Two School Types who took Part in the Study

School	Type of school	Number of students	Percent
A	well-endowed	56	63.6
B	well-endowed	92	46.0
C	less-endowed	45	78.9
D	less-endowed	52	72.2

The percentages in Table 3 were calculated by comparing the number of students who took part in the study to the maximum number of students in each SHS4 class of the four schools.

In all, the sample consisted of 245 SHS4 Chemistry students. In each school, six students who took part in the study were further selected for interview based on their respective difficulties in answering the achievement test correctly. The selection of the 24 students for interview was achieved by stratifying the achievements of the Chemistry students in each school into three groups as: below the score of 10 marks, between the scores of 10-20 marks, and above the score of 20 marks out of a maximum of 35 marks.

Instruments

An achievement test and interview were used as the main instruments for collection of data.

Achievement Test

The achievement test was in two sections consisting of 30 test items (Appendix B). In section 1, the 20 test items required the students to correctly name some given structural formulae of organic compounds by IUPAC nomenclature. The test items covered alkane, alkene, alkyne, alkanol, alkanoic acid, and alkyl alkanoate areas of organic compounds. Any correctly named structure attracted one mark. The purpose was to find out the performance of Chemistry students on naming structural formulae of organic compounds by IUPAC nomenclature. Here, Chemistry students' difficulties in the following areas were tested. The ability to:

1. identify the longest continuous carbon chain;
2. number the atoms in the continuous carbon chain to assign the lowest position or positions possible to any substituent group or groups present;
3. identify any substituent or functional group present; and
4. give the correct IUPAC name of any graphical or condensed structural formula.

In the first part of section 2, the test items required the students to provide condensed and graphical formulae of the five given IUPAC names of organic compounds. These compounds consisted of unbranched and unsubstituted chains of hydrocarbons together with an alkanol, alkanoic acid, and alkyl alkanoates.

Any correct condensed or graphical formula provided to each test item carried one mark. The purpose was to find out the performance of Chemistry students on supplying condensed and graphical formulae to a named organic compound by IUPAC nomenclature. In the second part of section 2, the test items required the students to provide the structural formulae of the five given IUPAC names of organic compounds. These compounds consisted of branched- and substituted-chains of hydrocarbons together with an alkanol, alkanoic acid, and alkyl alkanoate areas of organic compounds (Appendix B). The correct structural formula provided to each test item carried one mark. The purpose was to find out the performance of Chemistry students on supplying a structural formula to a named organic compound by IUPAC nomenclature. Here, Chemistry students' difficulties in the following areas were tested. The ability to:

1. identify the number of carbon atoms in the longest continuous chain;
2. identify whether there is the presence of carbon-carbon single, double, or triple bond;
3. identify the presence of any functional group;
4. identify the presence of any substituent group; and
5. write the graphical or condensed structural formula of an organic compound.

The achievement test items were constructed by the researcher. In the process of designing the instrument, the test items were compared to standardised questions on IUPAC nomenclature of organic compounds set by the WAEC for the West African Secondary School Certificate Examinations. The purpose of this was to ensure that the instrument was valid. To further ensure the face and content validity, the instrument was showed to two Chemistry teachers from Obuasi Senior High School where it was pilot-tested and a science education lecturer from the Department of Science and Mathematics Education, University of Cape Coast for an expert judgment on the content. The purpose was for them to determine the construct validity of the achievement test and offer suggestions.

The instrument was pilot-tested with 10 SHS4 Chemistry students from Obuasi Senior High School in Obuasi Municipality of Ashanti Region. After the pilot test, the test items were subjected to item analysis. This was to facilitate the determination of the difficulty and discrimination indices of the test items, which helped to improve on the internal consistency of the instrument. Hence, test items that were found to be too difficulty or too easy were deleted. After the test items that were too difficult or too easy have been deleted, the KR 21 coefficient of reliability was calculated out as 0.8 (Appendix D).

Interview

An interview with one student at a time was used (Appendix C). A week after the scripts have been scored, the researcher returned to each school and interviewed six of the Chemistry students involved in the study based on their respective scores in the achievement test. The purpose was to find out the students' reasons for supplying such answers to the test items using the IUPAC nomenclature.

Data Collection Procedure

A letter of introduction was obtained from the Department of Science and Mathematics Education, University of Cape Coast. With the letter of introduction, I visited the selected schools and sought permission from the Heads of the schools, Heads of Science Departments as well as the class teachers for the administration of the research instruments. A briefing section was organised with the Chemistry teachers in the selected schools on the purpose of the study and how it was going to be carried out. This was done to ensure that the study does not encounter any interruptions with school activities during the period of the administration of the instruments. Thereafter, a meeting was organised with the Chemistry students and they were briefed on the purpose of the study and the number of days involved in the study. This helped to prepare the students psychologically towards the study.

The administration of the research instruments was done by me in order to ensure that all rules were adhered to properly and in particular during the administration of the achievement test. This was done to prevent biasness or preferential treatment to any school. The achievement test was immediately scored to facilitate the interview with some of the Chemistry students from each school. In all it took almost 21 school working days for the data collection.

Data Analysis

Percentages, means, and standard deviations were used to answer the research questions on the general performance and difficulties of Chemistry students in naming and writing structural formulae of organic compounds by IUPAC nomenclature. The independent-samples t-test was used to test for the difference in general performance of Chemistry students from well-endowed and less-endowed schools on naming and writing structural formulae of organic compounds using the IUPAC system.

The qualitative data gathered from the interview was transcribed by reducing them to patterns and themes. They were then coded and analysed to serve as an explanation to Chemistry students' answers given in the achievement test.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussion from the study of senior high school form 4 (SHS4) Chemistry students' understanding of IUPAC nomenclature of organic compounds. The chapter presents answers to the research questions on performance, difficulties and what accounts for the SHS Chemistry students' difficulty in naming and writing structural formulae of organic compounds using the IUPAC nomenclature system. Also, the results of the independent-samples t-test on naming and writing structural formulae of organic compounds by IUPAC nomenclature are presented in this chapter.

Research Question One: What is the performance of SHS Chemistry students on test items involving naming and writing structural formulae of organic compounds by IUPAC nomenclature?

General Performance of Students on Naming Organic Compounds

Research question 1 sought to find out SHS Chemistry students' performance on naming organic compounds using IUPAC nomenclature. To be able to do this, 245 SHS4 Chemistry students were given the structural formulae of 20 organic compounds consisting of alkanes, alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates and asked to name them using the IUPAC nomenclature (Appendix B). The correct naming of each organic compound carried one mark and the maximum score on the 20 test items was 20 marks.

The mean of the distribution of the scores on naming organic compounds was 7.3 (SD = 4.2) out of a maximum score of 18. The scores of almost two-thirds of students on naming organic compounds were in the range of 3.1 to 11.5. The large standard deviation of 4.2, which was the measure of the extent of error in the distribution of the scores on naming organic compounds using the IUPAC nomenclature system, could be due to the relatively small total marks for the tests. The general performance of students on naming structural formulae of organic compounds was low as only 25.7% of the students scored more than half of the total marks.

The low performance of students reflects the revelation in the WAEC Chief Examiner's Reports (WAEC, 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010) on the weakness of most SHS Chemistry students on IUPAC nomenclature of organic compounds. For instance, the Chief Examiner's Report pointed out that candidates fail to provide the correct IUPAC names of the structural formulae of some organic compounds provided from certain given molecular formulae (WAEC, 2005).

Chemistry students from two school types were involved in the study. The two school types were well-endowed and less-endowed schools. The classification of the schools was based partly on the grade in science with which students were selected into the General Science programme in the two school types. The well-endowed schools selected only students with grade one in science into the General Science programme whereas students with either grade one or two in science were selected into the General Science programme for the less-endowed schools. The percentages of students from each school type who scored more than half the total marks on IUPAC naming of organic compounds are presented in Table 4.

Table 4: Scores of Students scoring more than 50% of the Marks on Naming Organic Compounds

School	Type	Total	N	%	M	SD	Max score
A	Well-endowed	56	9	16.1	6.7	3.5	16
B	Well-endowed	92	22	23.9	7.2	4.1	17
C	Less-endowed	45	15	33.3	8.2	4.6	18
D	Less-endowed	52	17	32.7	7.3	4.6	17

N is the number of students who scored more than half of the total marks from each school.

From Table 4, for school A, out of 56 students with low mean (M = 6.7, SD = 3.5, Max score = 16), only 16.1% of them scored more than half of the marks and for school B, out of 92 students with low mean (M = 7.2, SD = 4.1, Max score = 17), only 23.9% obtained scores which were more than half of the total marks. For the less-endowed schools, out of 45 students who took part in the study from school C with a low mean (M = 8.2, SD = 4.6, Max score = 18), 33.3% of them scored more than half the total marks and for school D, out of 52 students with low mean (M = 7.3, SD = 4.6, Max score = 17), 32.7% students scored more than half of the total marks on naming organic compounds using the

IUPAC nomenclature system. The findings show that more students from the less-endowed schools C and D attained high scores on IUPAC naming of organic compounds than their counterparts from the well-endowed schools A and B. This could be attributed to the presence of some exceptional students who were found in the less-endowed schools.

The general scores obtained by Chemistry students from well-endowed and less-endowed schools on naming organic compounds are presented in Figure 2.

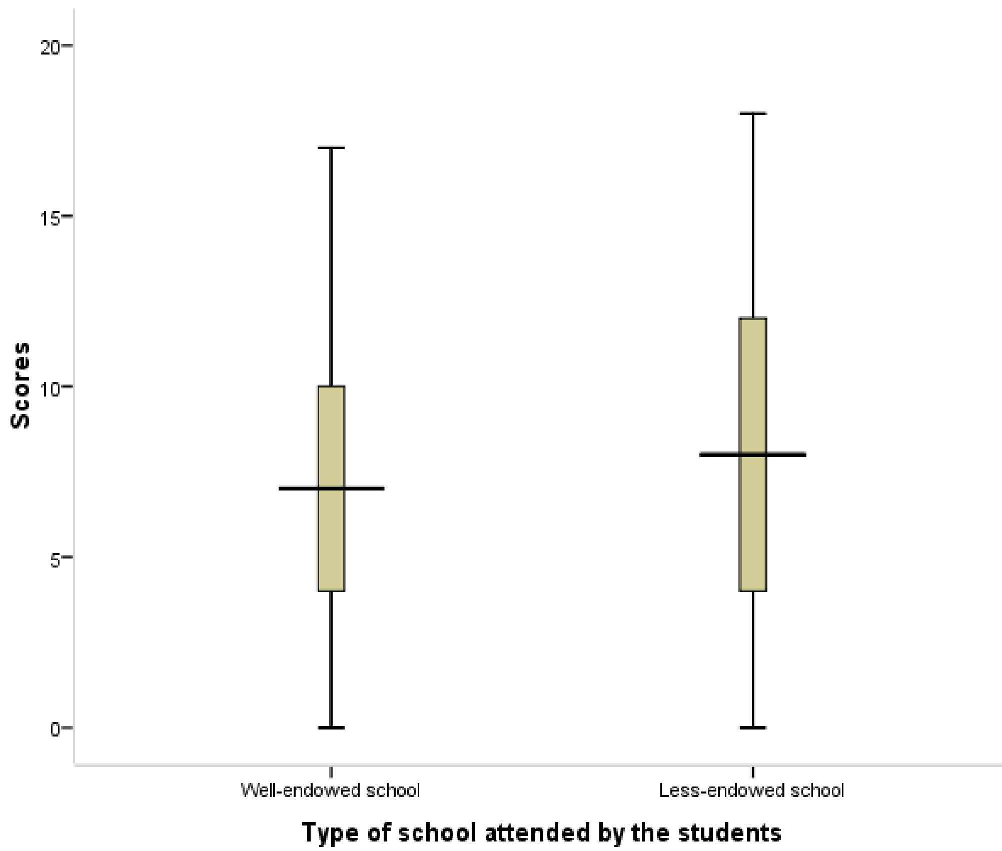


Figure 2. Boxplots of school-type differences in students' scores on IUPAC naming of organic compounds.

The boxplot in Figure 2 shows there were differences in the average performance between students from well-endowed schools and less-endowed schools on naming organic compounds. The median scores for the two boxplots for well-endowed and less-endowed schools were seven and eight respectively. As shown in Figure 2, there was considerable overlap in the distributions of scores between well-endowed and less-endowed schools. The interquartile range was higher for less-endowed schools (8) than well-endowed schools (6). This means that the middle 50.0% of the distribution of scores was higher for less-endowed schools. This could be attributed to the presence of some exceptional students who were found in the less-endowed schools.

The independent-samples t-test analysis was used to find out whether there was any statistical significant difference between the mean scores of the two school types. The results are presented in Table 5.

Table 5: Independent-Samples t-test Results of Scores for Well- and Less-Endowed Schools on Naming Organic Compounds

School	N	M	SD	t	df	p
Well-endowed	148	7.0	3.9	1.3	243	0.211*
Less-endowed	97	7.7	4.6			

* Not significant, $p > 0.05$

The results in Table 5 show that there was no statistical significant difference between the scores of students from well-endowed and less-endowed schools on the naming of organic compounds using the IUPAC nomenclature system. The mean score for the students from well-endowed schools (M = 7.0, SD = 3.9) on naming organic compounds using the IUPAC nomenclature system was not statistically significantly different from the mean score for students from less-endowed schools (M = 7.7, SD = 4.6, $t(243) = 1.3$, $p = 0.211$) with relatively small effect size ($d = 0.006$).

The test items on the IUPAC naming covered six areas of organic compounds. These were alkanes, alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates (Appendix B). The results of the performance of students who scored more than half of the marks on the six areas are presented in Figure 3.

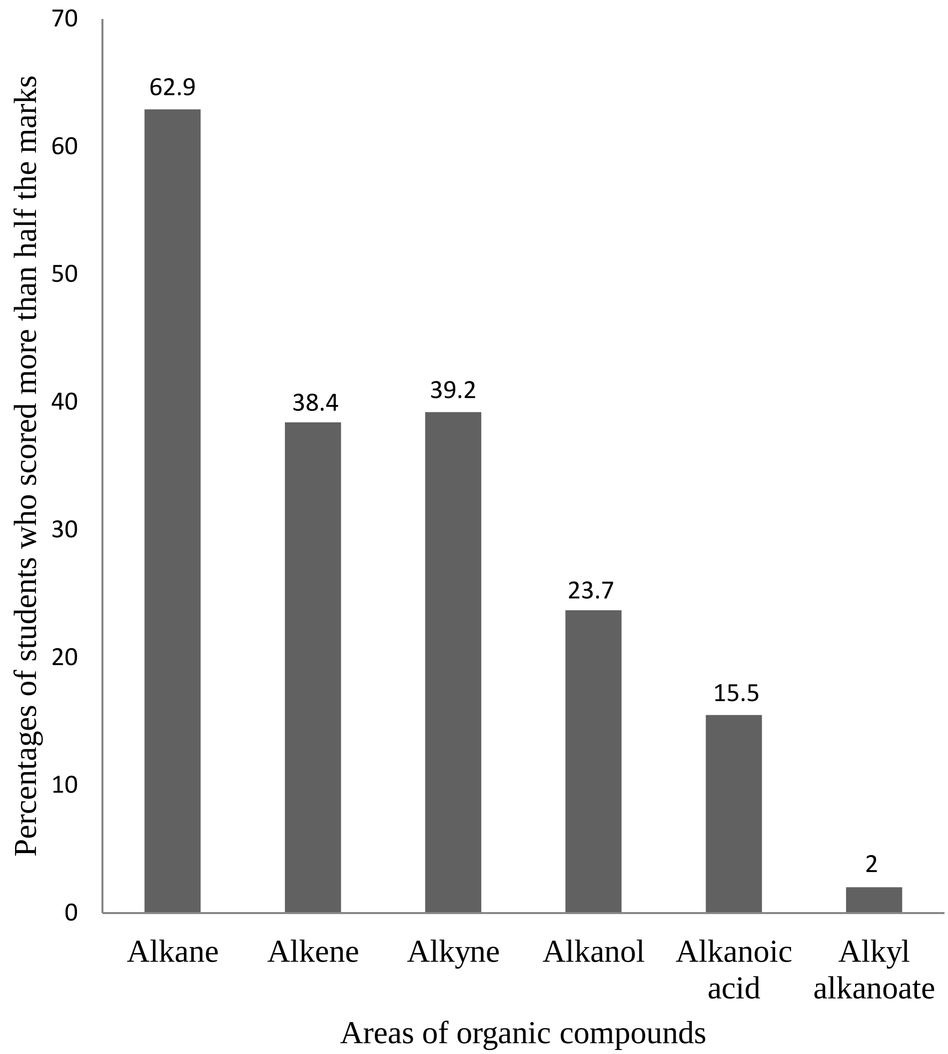


Figure 3. Bar chart of students who scored more than half of the marks on naming of some areas of organic compounds.

From Figure 3, a pattern was observed in the performance of students on IUPAC naming of the six areas of organic compounds. The bars in the bar chart show that an overall 62.9% of students scored more than half of the marks on IUPAC naming of alkanes, 38.4% students scored more than half the marks on naming of alkenes and 39.2% of students scored more than half the marks on naming of alkynes. On IUPAC naming of alkanols, alkanoic acids, and alkyl alkanoates, only 23.7%, 15.5%, and 2.0% of the students respectively scored more than half of the marks under the three areas. This means that students perform better on the IUPAC naming of alkanes and this performance decreases from alkane to alkyne, alkene, alkanol, alkanoic acid, through to alkyl alkanoate. This could be attributed to relatively short time and attention given to the teaching of IUPAC nomenclature of other areas of organic compounds after that of the alkanes.

General Performance of Students on Writing Structural Formulae of Organic Compounds

Research question 1 further sought to find out SHS Chemistry students' performance on writing structural formulae of organic compounds using IUPAC nomenclature. To accomplish this, the students were given 10 IUPAC names of compounds belonging to the families of alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoates to provide their respective structural formulae. The first five test items sought to look for both condensed and graphical formulae of the compounds from the given IUPAC names. This gave a total score of 10 marks. The next five test items sought to find out structural formula of the IUPAC names of the given compounds. These also gave a total score of five marks (Appendix

B). In all, the total score on writing structural formulae of organic compounds was 15 marks.

With the mean of 5.0 (SD = 3.2) out of a maximum score of 15 on writing structural formulae of organic compounds, the scores of almost two-thirds of the students were in the range of 1.8 to 8.2. The large standard deviation of 3.2 could be attributed to the relatively small total marks for the tests. Chemistry students' performance on writing structural formulae of organic compounds was very low as only 21.6 % of them scored more than half the total marks.

The numbers and percentages of students from the two school types who scored more than half of the total marks on writing structural formulae of organic compounds using the IUPAC nomenclature system are presented in Table 6.

Table 6: Scores of Students scoring more than 50% of the Marks on Writing Structural Formulae

School	Type	Total	N	%	M	SD	Max score
A	Well-endowed	56	10	17.9	5.5	2.0	10
B	Well-endowed	92	19	20.7	4.6	3.3	12
C	Less-endowed	45	16	35.6	6.0	3.9	15
D	Less-endowed	52	8	15.4	4.3	3.2	12

N is the number of students who scored more than half of the total marks on writing structural formulae of organic compounds from IUPAC names.

The results in Table 6 show that for school A, out of 56 students with low mean (M = 5.5, SD = 2.0, Max score = 10), only 17.9% of them scored more than half of the total marks and for school B, out of 92 students with low mean (M = 4.6, SD = 3.3, Max score = 12), only 20.7% students scored more than half of the total marks. For the less-endowed schools, out of 45 students from school C with a low mean (M = 6.0, SD = 3.9, Max score = 15), 35.6% of them scored more than half the total marks and for school D, out of 52 students with low mean (M = 4.3, SD = 3.2, Max score = 12), only 15.4% students scored more than half of the total marks on writing structural formulae of organic compounds using the IUPAC nomenclature system. The findings from Table 6 show that one-third of the students from the less-endowed school C attained high scores on writing structural formulae of organic compounds using the IUPAC nomenclature system and therefore performed better than the students from the well-endowed schools A and B as well as the less-endowed school D. This could be due to the presence of some exceptional students who were found in the less-endowed school C.

The general scores obtained by students from well-endowed and less-endowed schools on writing structural formulae of organic compounds from IUPAC names are presented in Figure 4. From Figure 4, it can be seen that there was considerable overlap in the distribution of scores between well-endowed and less-endowed schools. The interquartile range for less-endowed school was higher (6) than that of the interquartile range for well-endowed schools (4). This shows that the middle 50.0% of the distribution of scores for the less-endowed schools was higher. This could be due the exceptional student in the less-endowed schools who scored all the maximum 15 marks on writing structural formulae of organic compounds.

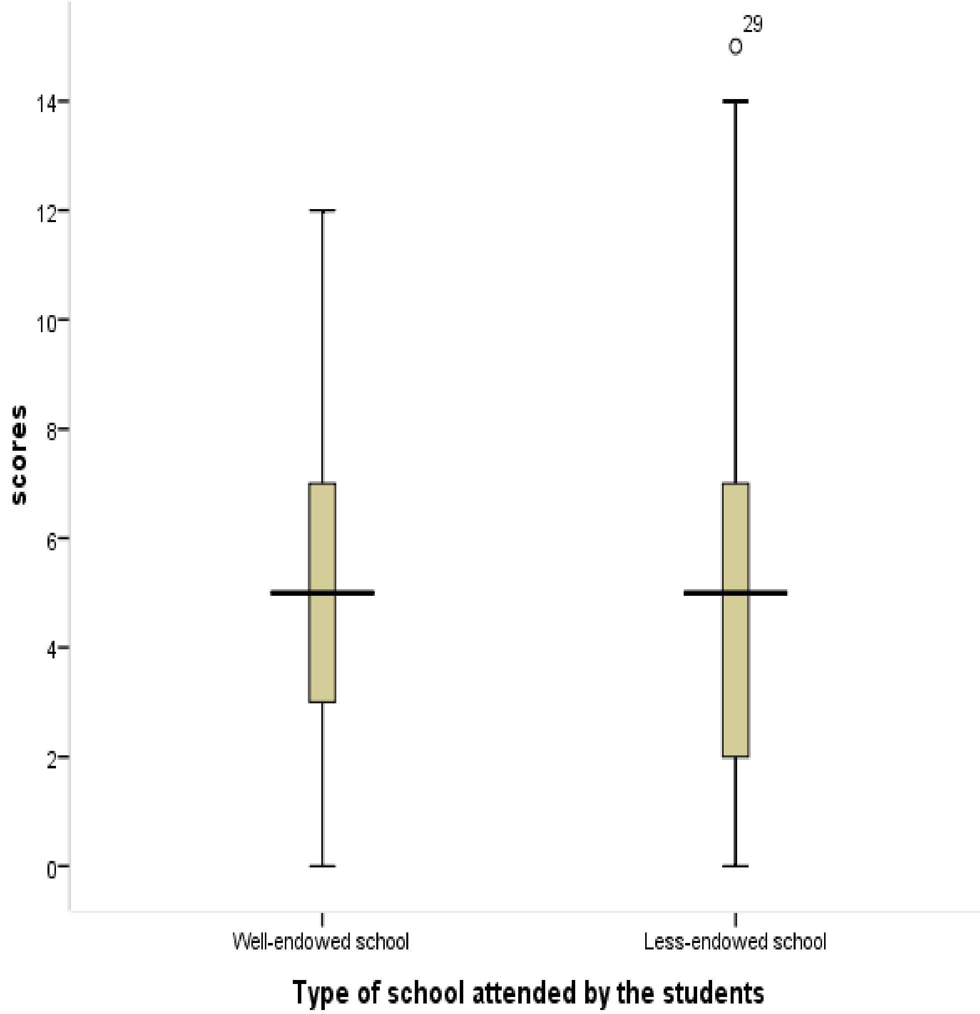


Figure 4. **Boxplots of school-type differences in students' scores on writing structural formulae of organic compounds using the IUPAC system**.

The independent-samples t-test analysis was used to ascertain whether there was any statistical significant difference between the mean scores of students from well-endowed and less-endowed schools or not on writing structural formulae of organic compounds from the IUPAC names. The results for the independent-samples t-test are presented in Table 7.

From Table 7, there was no statistical significant difference between the scores of students from well-endowed and less-endowed schools on the writing of structural formulae of organic compounds using the IUPAC nomenclature system.

Table 7: Independent-Samples t-test Results on Scores for Well- and Less-Endowed Schools on Writing Structural Formulae

School	N	M	SD	t	df	p
Well-endowed	148	4.9	2.9	0.5	243	0.649*
Less-endowed	97	5.1	3.6			

* Not significant, p > 0.05

The mean score for students from well-endowed schools (M = 4.9, SD = 2.9) on writing structural formulae of organic compounds using the IUPAC nomenclature system was not significantly different from the mean score for students from less-endowed schools (M = 5.1, SD = 3.6, t(243) = 0.5, p = 0.649) with relatively small effect size (d = 0.0009).

The IUPAC names used in the achievement test from which the students provided structural formulae were on areas such as alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoates (Appendix B). Figure 5 presents the results of percentages of students who scored more than half the marks on each area.

The distribution in Figure 5 shows a pattern in the performance of students on writing structural formulae of organic compounds from IUPAC names. The percentage for the bar of alkane was higher (74.3%) than the other areas, which were alkene (38.8%), alkanol (33.1%), alkanoic acid (18.8%), and alkyl alkanoate

(6.5%). The findings show that the students performed better on writing structural formulae of alkanes than the other areas of organic compounds.

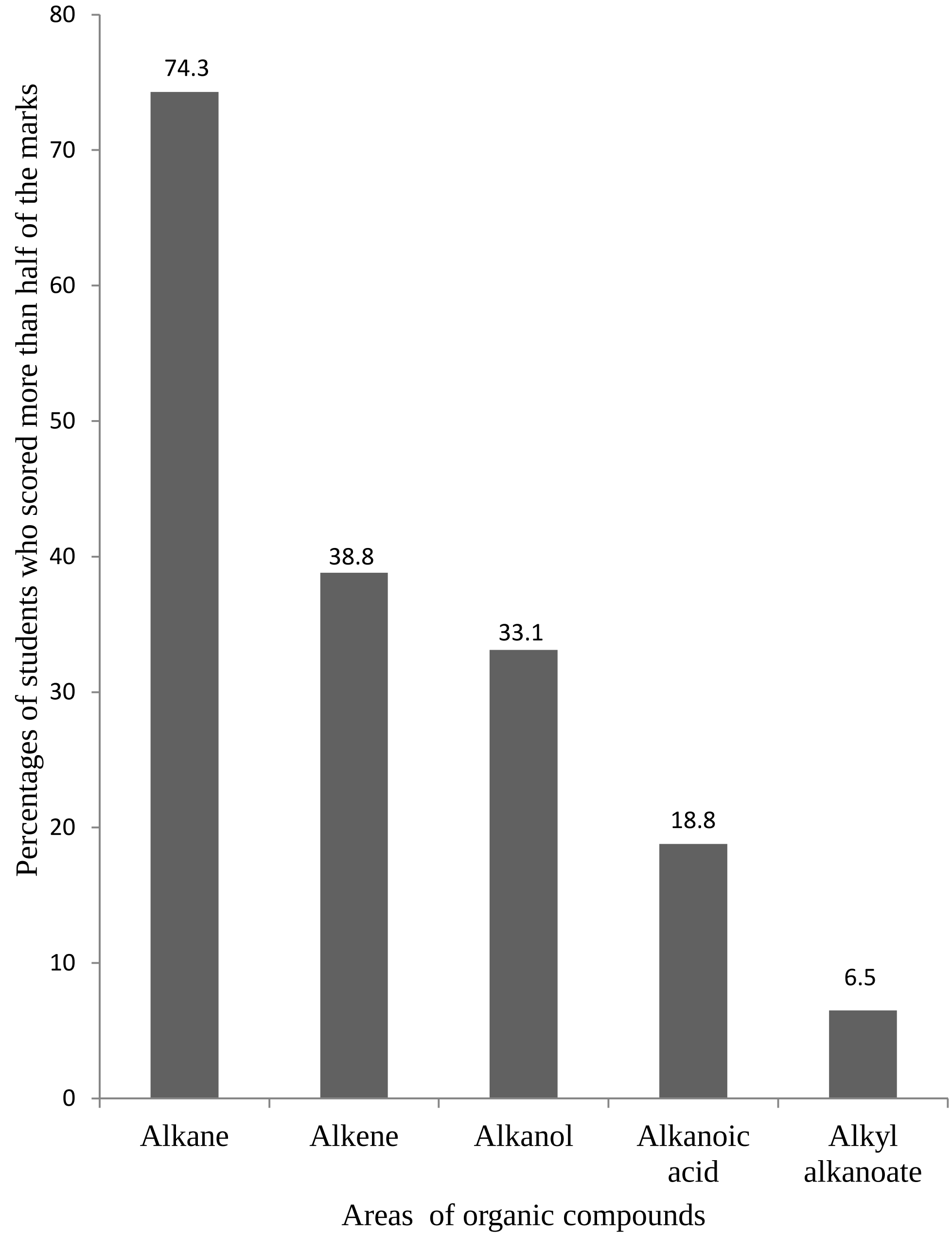


Figure 5. Bar chart of students who scored more than half of the marks on writing structural formulae of areas of organic compounds.

Also, the performances of students on writing structural formulae of organic compounds using IUPAC nomenclature system decreased from alkane to alkene, alkanol, alkanoic acid, through to alkyl alkanoate. This could be due to relatively long time and attention given to the teaching of IUPAC nomenclature of alkanes as compared to the other areas of organic compounds.

Research Question Two: What difficulties do SHS Chemistry students have in using the IUPAC nomenclature system to name and write structural formulae of organic compounds?

Students' Difficulties in Naming Organic Compounds by IUPAC Nomenclature and Reasons for the Difficulties

Research question 2 sought to find out SHS Chemistry students' difficulties in naming organic compounds using IUPAC nomenclature. To show the difficult areas, students' performance is presented for each of the 20 test items. The distributions of the scores on the 20 test items in Figure 6 show that some items were not difficult whereas others were difficult.

The difficult items were those where less than 50.0% of the students provided the correct IUPAC names. As seen in Figure 6, items q5, $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$; q10, $BrCH{=}CHBr$; q11, $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$; q12, $CH_2{=}CH\text{-}CH{=}CHCH_3$; q14, $CH_3CH_2CH_2OH$; q16, $HOCH_2CH_2CH_2CH_2OH$; q18, $(CH_3)_2C(Br)COOH$; and q19, CH_3COOCH_3 were very difficult to most students. This is because the items' difficulty index was less than 0.4. The most difficult item was item q20, $(CH_3)_2CHCH_2COOCH_2CH_3$ because the difficulty index of this item was less than 0.1.

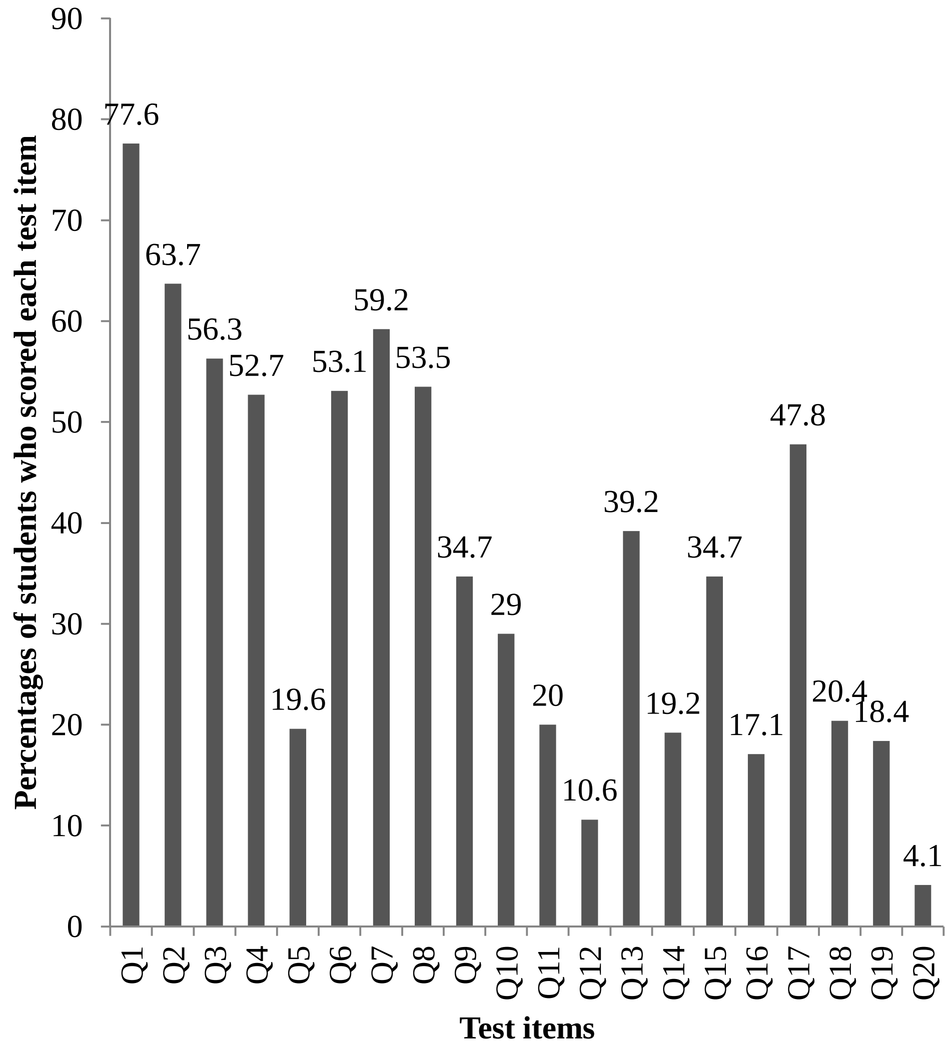


Figure 6. **Bar chart of students' performance on naming organic compounds using the IUPAC nomenclature system**.

The difficulties encountered by the Chemistry students who participated in the study were not presented in terms of well-endowed and less-endowed schools because there was no significant difference between the mean scores of the students from both school types. As the compounds used in the study belong to alkane, alkene, alkyne, alkanol, alkanoic acid, and alkyl alkanoate areas of organic compounds, students' difficulties in naming organic compounds using the IUPAC system were presented in terms of these areas.

Alkanes

The difficulty of students in naming alkane compounds was measured with items q1, $CH_3CH_2CH_2CH_3$; q2, $CH_3(CH_2)_6CH_3$; q3, $(CH_3)_2CHCH_2CH_3$; q4, $(CH_3CH_2)_3CH$; and q5, $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$ on the achievement test. From Figure 6, the findings show that it was not difficult for majority of the students to provide the correct IUPAC names of $CH_3CH_2CH_2CH_3$, $CH_3(CH_2)_6CH_3$, $(CH_3)_2CHCH_2CH_3$, and $(CH_3CH_2)_3CH$. However, majority of students (80.4%) found it difficult to name $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$ correctly as 3-chloro-2,4-dimethylhexane. The difficulty index of $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$ was 0.2, which is an indication that majority of the students provided wrong IUPAC names for this compound. Table 8 presents the wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$.

An overall 20.8% of the students did not provide any response on the IUPAC name of $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$. From Table 8, out of the 24 students interviewed, only 12.5% of the students could not identify the number of carbon atoms in the longest continuous carbon chain. This is because 8.3% of the students named it as oct- (for eight carbon atoms in the parent chain) as they counted all the carbon atoms of the groups in the brackets within the structure of the molecule as part of the parent chain. One student named it as pent- (for five carbon atoms in the parent chain) as he or she did not identify the carbon atom of one of the two methyl groups written as $(CH_3)_2$ as a member of the parent chain.

Table 8: Wrong Names of $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$ given by Some Students (N = 12)

Name given by students	N	%
2,4-dimethylhexane	3	12.5
4-chloro-1,4-dimethylhexane	2	8.3
3-chloro-1,4-dimethylhexane	1	4.2
4-chlorooctane	1	4.2
1,6-dimethyl-4-chlorooctane	1	4.2
3-chloro-2,5-dimethylhexane	1	4.2
2-chloro-2,4-dimethylhexane	1	4.2
3-chloro-4-methylhexane	1	4.2
2-chloro-1,1,3-dimethylpentane	1	4.2

N is the number of students who provided wrong IUPAC names.

With respect to the substituents on the compound $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$, only 12.5% of the students could not identified the Cl as a substituent and only 8.3% of the students could not identify one or both of the CH_3- substituents. They failed to identify them as such because they counted them among the carbon atoms in the parent chain and

others just ignored them. The rest of the students named correctly the Cl and CH_3- side groups as chloro and methyl respectively. However, 25.0% of the students could not identify the right positions of the three substituents present in $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$. Examples of such wrong positions stated for the chloro substituent were 2- and 4-, which was an indication that the Cl atom was attached to the second carbon atom and fourth carbon atom of the parent chain respectively. This shows that for the 2-chloro, the students counted the carbon atoms in the longest continuous chain from the left side of the structure excluding the carbon atom of one of the $(CH_3)_2$ group, which was part of the parent chain. In the case of the 4-chloro, the students included both carbon atoms of the $(CH_3)_2$ as part of the length of the parent chain, hence increasing the positional value of chloro substituent. Examples of wrongful positional numbers used by the students to described the points of attachment of the two methyl groups were 1,4-, 1,6-, and 1,1,3-. The reasons given by the students show that the positions of the carbon atoms in the parent chain were assigned from the left hand side of the structure of the molecule as written and included the carbon atom of one of the $(CH_3)_2$ group as part of the longest chain. The carbon atom of one of $(CH_3)_2$ group which was part of the longest chain was excluded from the chain and taken as a side group for 1,1,3-dimethyl. The reason given by one of the students was that CH_3 in a bracket is always a substituent which is not necessarily the case. For the arrangement of the names of the substituents, only one person could not arrange them in alphabetical order as required by the IUPAC nomenclature system. This was because the student thought the organic substituent must be named before the inorganic substituent.

In summary, the main difficulties of students who could not name $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. identify some of the atoms or groups in brackets as substituent groups, and

3. assign the substituents the correct positions in the structure of the molecule.

Alkenes

The difficulties of students in naming alkenes were measured with items q6, $CH_2{=}CHCH_2CH_2CH_3$; q7, $CH_3CH_2CH_2CH{=}CHCH_3$; q8, $(CH_3)_2C{=}CH_2$; q9, $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$; q10, $BrCH{=}CHBr$; q11, $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$; and q12, $CH_2{=}CH\text{-}CH{=}CHCH_3$;. The findings in Figure 6 show that majority of the students did not find it difficult to provide the correct IUPAC names of $CH_2{=}CHCH_2CH_2CH_3$, $CH_3CH_2CH_2CH{=}CHCH_3$, and $(CH_3)_2C{=}CH_2$. However, majority of students found it difficult to name the rest of the alkene compounds using the IUPAC nomenclature system.

In the case of $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$, the item's difficulty index was calculated as 0.4. This is because, from Figure 6, only 34.7% students gave the correct IUPAC name as 5-chloro-5-methyl-2-hexene (or 5-chloro-5-methylhex-2-ene). Hence, an overall 65.3% students found it difficult to provide the correct IUPAC name of $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$. The wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$ are presented in Table 9. The names in Table 9 show that out of the 24 students interviewed 12.5% could not identify the correct number of carbon atoms in the longest continuous carbon chain. This is because 8.3% of the students named it as pent- (for five carbon atoms in the parent chain) as they took the two methyl groups written as $(CH_3)_2$ as substituents.

Table 9: Wrong Names of $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$ given by Some Students (N = 11)

Name given by students	N	%
2-chloro-2-methyl-4-hexene	3	12.5
2-chloro-2-methylhexene	3	12.5
2,2-chloromethylhexene	1	4.2
2-chloromethylpentane	1	4.2
2-methyl-2-chloro-3-pentene	1	4.2
5-methyl-5-chlorohexene	1	4.2
5-chloro-5-dimethylprpo-2-ene	1	4.2

One student named the compound as prop- (for three carbon atoms in the parent chain). Almost all students used –ene to indicate the presence of a double in the molecule except one who used –ane. The reason given by the student was that he or she was used to the sound of '-ane'.

The students appreciated that the position of the double must be indicated in the name of the compound but out of the 24 students, an overall 41.7% of the students could not assign and use the correct position of the double bond in the name of the compound. This is because the students assigned the positions of the carbon atoms in the parent chain from the right hand side as written in order to assign the least positions possible to the substituents, which is not necessarily the case for multiple bond organic compounds.

Almost all students named the substituents of the compound $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$ correctly as chloro for Cl and methyl for CH_3-. However, all the students except two persons could not identify the correct positions of the substituents. The wrong positions used for the substituents were 2- for the chloro substituent and 2- and 4- for the methyl substituent. This could be attributed to the fact the counting of the carbon atoms in the parent chain as done by students was done in such a way to assign the least positions possible to the substituents but not the double bond as required by the IUPAC nomenclature system. In the case of the arrangement of names of substituent groups, only 8.3% of the students could not arrange the substituents in alphabetical order as demanded by the IUPAC nomenclature system. This was because the students thought organic substituent must be named before the inorganic substituent.

In summary, the main difficulties of students who could not name $CH_3CH{=}CHCH_2C(Cl)(CH_3)_2$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. identify and use the correct position of the double bond,
3. use '-ene' in place of '-ane' for double bond organic molecule,
4. assign correct positional numbers to the substituents, and
5. arrange the names of the substituent groups in alphabetical order.

From Figure 6, the findings show that only 29.0% of the students gave the correct IUPAC name of the cis isomer of $BrCH{=}CHBr$ as cis-1,2-dibromoethene. Hence, an overall 71.0% of the students found it difficult to provide the correct IUPAC name of the cis compound, $BrCH{=}CHBr$. This is because the difficulty index of this compound was calculated as 0.3. Table 10 presents the wrong names and percentages of the 24 students who were interviewed on the IUPAC name of cis isomer of BrCH═CHBr.

Table 10: Wrong Names of Cis Isomer of BrCH═CHBr given by Some Students (N = 10)

Name given by students	N	%
1-2-dibromoethene	2	8.3
Cis-1,2-bromoethene	2	8.3
Cis	1	4.2
Trans	1	4.2
Cis-2,2-dibromethene	1	4.2
Cis-1,2-diethene	1	4.2
Cis-1,2-dibromo-2-ethyl	1	4.2
2-bromoethanoate	1	4.2

Amongst the 24 students who were interviewed, 12.5% of the students did not provide any name for the cis isomer of BrCH═CHBr. Out of the 24 students interviewed, only 8.2% of the students named wrongly the two carbons atoms in the parent chain as ethyl and ethanoate instead of ethene. In the case of the structure of compound, from Table 10, only 12.5% of the students could not identify the structure of the compound BrCH═CHBr as a geometrical isomer. This was because the students thought the structure was a normal structure of an alkene compound. Only one person identified the compound as a trans isomer because he or she failed to see that the arrangement of substituents on the same side of the double bond gives a cis isomer.

With respect to the substituents on the compound BrCH═CHBr, only 12.5% of the students could not identify and name Br substituent as bromo because these students named the compound BrCH═CHBr as ethene or only cis or trans. There were two Br substituents, which demands the prefix di- according to the IUPAC nomenclature but 12.5% of the students could not name them as dibromo though they identified the correct positions of the substituents as 1- and 2-. Reason given by 8.3% of the students who named BrCH═CHBr as 1,2-dibromoethene instead of cis-1,2-dibromoethene was that for geometrical isomers where the prefix di- is used, the cis is omitted. However, this is not the case according the IUPAC nomenclature of organic compounds.

In summary, the main difficulties of students who could not name the cis isomer of BrCH═CHBr using the IUPAC nomenclature system were their inability to:

1. name a double bond compound as -ene,
2. assign the positions 1 and 2 to only the two carbon atoms in the chain,
3. use the prefix di- for two identical substituents,
4. give full IUPAC name for the compound instead of referring to it as a cis- or trans-, and
5. appreciate that for geometrical isomers, the prefixes di- and cis- can be used at the same time, where necessary.

In the case of the compound $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$, from Figure 6, only 20.0% students gave the correct IUPAC name of the trans isomer of the compound as trans-3,4-dichloro-3-hexene (trans-3,4-dichlorohex-3-ene). The difficulty index of this item was calculated as 0.2 and hence, an overall 80.0% of the students found it difficult to provide the correct IUPAC name of the trans isomer of $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$. Table 11 presents wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of trans isomer of $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$.

Table 11: Wrong Names of Trans Isomer of $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$ given by Some Students (N = 12)

Name given by students	N	%
Trans	3	12.5
Trans-1,2-dichlorohex-3-ene	1	4.2
2-chloroethylpentane	1	4.2
Trans-2,3-dichloro-2-hexene	1	4.2
3,4-dichloro-3-hexene	1	4.2
1,2-dichloro-2-ethylethene	1	4.2
3,3-dichloro trans hexane	1	4.2
Trans-3,4-chlorohexane	1	4.2
Trans-3,4-dichloro-4-ethyleth-1-ene	1	4.2
Trans-2-chlorohexane	1	4.2

Out of the 24 students interviewed, an overall 29.4% of the students did not provide any response on the IUPAC name of trans isomer of $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$. From Table 11, only 12.5% students could not identify the number of carbon atoms in the longest continuous carbon chain. This is because 8.3% of the students named it as eth- (for two carbon atoms in the parent chain) because they identified the two -CH_2CH_3 groups as ethyl substituents instead of as part of the parent chain. One student named the compound as pent- (for five carbon atoms in the parent chain) as he or she identified one of the two –CH_2CH_3 structures as an ethyl substituent.

With respect to the name of the double bond, 16.7% of the students named it as –ane instead of –ene as required by the IUPAC nomenclature for an organic compound with a double bond. This could be attributed to the way the parent name of a double bond organic compound is pronounced by some of the students. In the case of the positional value of the double bond, 29.2% of the students could not assign and use the right position for the double. Examples of such wrong positions used were 1- and 2-. Some students said that they only counted the two carbon atoms at the site of the double bond whereas others counted excluding the –CH_2CH_3 structures that they thought were substituent groups. All students except 12.5% identified the arrangement of the substituents about the double bond as a trans and use it in the IUPAC name of the compound.

The 24 students who were interviewed identified the substituent as chloro for Cl. Only 12.5% of the students failed to use the prefix di- to show that there were two identical substituents. One person who used the prefix di- said that where such prefix is used the name trans for geometrical isomers with substituents arranged alternatively about the double bond is omitted in the IUPAC name but this is not necessarily the case. In the case of the positions of the substituents, 25.0% of the students stated wrong positions for the two chloro substituents. Examples of such wrong positions stated were 1,2-, which was an indication that the students counted the carbon atoms in the parent chain excluding the two –

CH_2CH_3 groups and 3,3-, where the students counted the carbon atoms in the parent chain from the opposite side of the chain at the same time.

In summary, the main difficulties of Chemistry students who could not name the trans isomer of $CH_3CH_2(Cl)C{=}C(Cl)CH_2CH_3$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. name a double bond as –ene instead of –ane,
3. identify the correct position of the double bond,
4. give full name for the compound instead of just referring to it as trans,
5. identify the correct positions of the substituents,
6. use the prefix trans- in the name, and
7. use the prefixes (such as di-) for the number of identical substituents in a molecule.

The students' difficulty in naming diene class of alkene compounds was determined with item q12, $CH_2{=}CH\text{-}CH{=}CHCH_3$. The findings in Figure 6 mean that only 10.6% of the students gave the correct IUPAC name of $CH_2{=}CH\text{-}CH{=}CHCH_3$ as 1,3-pentanediene (or pentan-1,3-diene). Hence, an overall 89.4% of the students found it difficult to provide the correct IUPAC name of $CH_2{=}CH\text{-}CH{=}CHCH_3$. This is because the item's difficulty index was 0.1. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $CH_2{=}CH\text{-}CH{=}CHCH_3$ are presented in Table 12. An overall 33.3% of the students failed to provide any response on the IUPAC name of $CH_2{=}CHCH{=}CHCH_3$. The names in Table 12 show that half of the students (50.0%) interviewed identified correctly the number of carbon atoms in the longest continuous carbon chain.

Table 12: Wrong Names of CH_2=CH-CH=$CHCH_3$ given by Some Students (N = 12)

Name given by students	N	%
1,3-pentene	8	33.3
1,4-pentene	2	8.3
1,2-pentanediene	1	4.2
Pentene	1	4.2

This could be attributed to the fact the structure of the compound was written in an open chain form and was without substituents. With the exception of one student who named the double as –ane, the rest of the students name it as –ene, but could not identify the compound as a diene. This could be due that fact students were used to only one double bond in an organic compound usually referred to as -ene but not diene.

In the case of the two double bonds, 16.7% of the students could not assign the correct positions to them. This was due to how the counting was done by the students, and that the students were not used to naming dienes. The 33.3% students who had the positions of the two double bonds and the name of the number of carbon atoms in the parent chain right but could not provide the correct IUPAC name of the compound, CH_2=CH-CH=$CHCH_3$, also said they were not used to the IUPAC rules of naming dienes.

In summary, the main difficulties of students who could not provide the correct IUPAC name of CH_2=CH-CH=$CHCH_3$ were their inability to identify the

1. two double bonds in a compound as diene, and
2. correct positions of the two double bonds.

Alkynes

The only test item that was used to measure students' difficulties in IUPAC naming of alkynes was item q13, $HC{\equiv}CCH_2CH_3$. The difficulty index of this item was calculated as 0.4. The bars in Figure 6 show that only 39.2% of the students gave the correct IUPAC name of $HC{\equiv}CCH_2CH_3$ as 1-butyne (or but-1-yne). Hence, an overall 60.8% of the students found it difficult to provide the correct IUPAC name of $HC{\equiv}CCH_2CH_3$. Table 13 presents some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $HC{\equiv}CCH_2CH_3$.

Table 13: Wrong Names of $HC{\equiv}CCH_2CH_3$ given by Some Students (N = 7)

Name given by students	N	%
Butyne	5	20.8
Alkyne	1	4.2
Propyne	1	4.2

Out of the 24 students, 20.8% of them failed to provide any name for the compound. From Table 13, the names show that only 8.3% of the students could not identify the number of carbon atoms in the longest continuous carbon chain. This is because one student named the compound just as alkyne and the other named it as prop- (for three carbon atoms in the parent chain). A total of seven students (29.2%) named the triple bond as –yne. However, none of them could assign the triple its positional value in the name. The reason given by the students was that when the triple is attached to the first carbon atom of the parent chain, the positional value is not stated in the name. This is however not the case according the IUPAC rules for naming alkyne compounds except for a chain of two or three carbon atoms.

In summary, the main difficulties of students who could not provide the correct IUPAC name of $HC{\equiv}CCH_2CH_3$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain, and
2. assign the triple bond its correct position in the IUPAC name.

Alkanols

The difficulty of students in naming alkanols was determine with items q14, $CH_3CH_2CH_2OH$; q15, $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$; and q16, $HOCH_2CH_2CH_2CH_2OH$. From Figure 6, the findings show that majority of the students found it difficult to name any of the alkanol compounds.

In the case of the compound, $CH_3CH_2CH_2OH$, which was a primary alkanol, the difficulty index was calculated as 0.2. The findings in Figure 6 show that only 19.2% of the students gave the correct IUPAC name of $CH_3CH_2CH_2OH$ as propan-1-ol (or 1-propanol). Hence, an overall 80.8% of the Chemistry students found it difficult to provide the IUPAC name of $CH_3CH_2CH_2OH$. Some wrong names provided and the percentages of the 24 students who were interviewed on IUPAC name of $CH_3CH_2CH_2OH$ are presented in Table 14.

Out of the 24 students interviewed, only 16.7% of the student did not provide any name for the compound. Majority of the students interviewed

(83.3%) identified correctly the number of carbon atoms in the longest continuous carbon chain because there were no substituents attached to the parent chain of the compound. Also such a proportion of students named the compound correctly as prop**-** (for three carbon atoms in the parent chain). However, one student could not add **–**an to show that the compound is made up of only carbon-carbon single bonds. The reason given by the student who failed to add the –an to the name of the compound was that the suffix –ol indicates that the compound is alkanol whereas the –an indicates that the compound is alkane.

Table 14: Wrong Names of $CH_3CH_2CH_2OH$ given by Some Students (N = 12)

Name given by students	N	%
Propanol	11	45.8
Prop-ol	1	4.2

In the case of the –OH functional group, from Table 14, 83.3% of the students identified it correctly as hydroxyl group and therefore named it as **–**ol. However, 50.0% students could not state the positional value of the –OH functional group in the name. This is because the students thought when the –OH functional is attached to the first carbon atom of the parent then the position is not stated in the name of the compound which is not necessarily the case.

In summary, the main difficulties of Chemistry students who could not provide the correct IUPAC name of $CH_3CH_2CH_2OH$ were their inability to:

1. add –an to the name of the parent chain to indicate that there is no carbon-carbon multiple bond, and
2. state the position of the –OH functional group in the IUPAC name.

Students' difficulties in naming tertiary alkanols was measured with the compound, $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$. The difficulty index of this compound was 0.4 because from Figure 6, out of the 245 student who took part in the study, only 34.7% of the students provided the correct IUPAC name of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$ as 2-methylhexan-2-ol (or 2-methyl-2-hexanol). Hence, an overall 65.3% of the students found it difficult to provide the correct IUPAC name of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$ are presented in Table 15.

Table 15: Wrong Names of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$ given by Some Students (N = 9)

Name given by students	N	%
2-methylhexanol	4	16.7
Hexan-2-ol	1	4.2
2-methylhex-2-OH	1	4.2
2-alkanol-2-methylhexane	1	4.2
2-methylhexane	1	4.2
2-methylpropan-2-ol	1	4.2

Out of the 24 students interviewed, an overall 12.3% of the students could not provide any response on the IUPAC name of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$. From Table 15, only one person could not identify the correct number of carbon atoms in the longest continuous carbon chain. This is because the student named the compound as prop- (for three carbon atoms in the parent chain). However, this person said he or she even made a mistake for using prop- instead of hex- (for six carbon atoms in the parent chain).

In the case of the –OH functional group of the compound, $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$, only one student could not identify it because of how it was written. One student failed to name the –OH functional group with the suffix –ol as the student took it as a substituent and named it as alkanol. This is because the student thought that all groups written in brackets are substituents, which is not necessarily the case. Only one student could not state the positional value of the –OH functional group in the name of the compound because he or she did not even identify it.

With respect to the substituents on the compound, $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$, majority of the students (83.3%) interviewed except one identified one of the two $(CH_3)_2$ group as a substituent and named it as methyl. An overall 83.3% of the students except one assigned the right positional value to the methyl substituent as 2-. This could be attributed to the fact that this student never saw $(CH_3)_2$ group to be two separate methyl groups and that he or she counted the two carbon atoms as one and as part of the parent chain.

In summary the main difficulties of students who could not provide the correct IUPAC name of $(CH_3)_2C(OH)CH_2CH_2CH_2CH_3$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. name the –OH functional group as –ol instead of hydroxyl or alkanol, and
3. identify the compound as alkanol instead of an alkane.

Students' difficulties in naming diol class of alkanol compounds were determined with item q16, $HOCH_2CH_2CH_2CH_2OH$. The findings in Figure 6 show that only 17.1% of the students involved in the study gave the correct IUPAC name of $HOCH_2CH_2CH_2CH_2OH$ as 1,4-butanediol (or butan-1,4-diol). Hence, it was difficult for majority of the students (82.9%) to name the compound, $HOCH_2CH_2CH_2CH_2OH$ using the IUPAC nomenclature system. This is because the item's difficulty index was calculated as 0.2. Table 16 presents wrong names provided and the percentages of the 24 who were interviewed on the IUPAC name of $HOCH_2CH_2CH_2CH_2OH$.

Table 16: Wrong Names of $HOCH_2CH_2CH_2CH_2OH$ given by Some Students (N = 8)

Name given by students	N	%
butan-1,4-ol	4	16.7
Butan-2-ol	2	8.3
Butanoic acid	2	8.3

Out of the 24 students interviewed, an overall 45.8% of the students could not provide any response on the IUPAC name of the compound, $HOCH_2CH_2CH_2CH_2OH$. The names in Table 16 show that only 8.3% of the students could not identify the compound, $HOCH_2CH_2CH_2CH_2OH$ as belonging to the alkanol family of organic compounds. This is because the students thought that presence of the two –OH groups make the compound an alkanoic acid type. Out of the 24 students interviewed, 45.8% of the students identified $HOCH_2CH_2CH_2CH_2OH$ as a member of alkanol family because of the presence of the –OH functional groups. However, from Table 16, 25.0% of the students could not name the compound as a diol (for the presence of the two –OH groups).

In the case of assigning positional values to the two –OH functional groups, 8.3% of the students among the 11 students who identified the two –OH groups could not state the correct positions of the two –OH groups. They used 2- to show that there were two groups of the –OH functional group. Even amongst the nine out of the 24 students who assigned the correct positions to the two –OH functional groups as 1,4-, 16.7% of the students failed to name the compound as a diol. This could be attributed to the fact that naming diols is an unusual thing to them.

In summary the main difficulties of Chemistry students who could not provide the correct IUPAC name of $HOCH_2CH_2CH_2CH_2OH$ were their inability to:

1. identify the compound as a diol, and
2. assign correct positions to the two –OH functional groups.

Alkanoic Acids

The difficulties of students in naming alkanoic acids were determined with items q17, HCOOH and q18, $(CH_3)_2C(Br)COOH$ on the achievement test. From Figure 6, the findings show that it was difficult for majority of the students to provide the correct IUPAC names for the two alkanoic acid compounds used in the study.

With respect to the compound, HCOOH, out of the 245 students who participated in the study, only 47.8% of the students provided the correct IUPAC name of the compound as methanoic acid. Hence, 52.2% of the students found it difficult to provide the correct IUPAC name of HCOOH. This could be said to be moderately difficulty as the difficulty index of the item was calculated as 0.5. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of HCOOH are presented in Table 17.

Table 17: Wrong Names of HCOOH given by Some Students (N = 7)

Name given by students	N	%
Alkanoic acid	3	12.5
Ethanoic acid	2	8.3
Methanoic	1	4.2
Methanol	1	4.2

Out of the 24 students interviewed, only 16.7% of the students could not provide any response on the IUPAC name of the compound HCOOH. From Table 17, an overall 20.8% of the students could not identify the number of carbon atoms in the longest continuous carbon chain. This is because 12.5% of the students named the compound as alkanoic acid as the given structure (HCOOH) seemed to them as the functional group of alkanoic acids. However, this cannot be the case because the functional group of alkanoic acids is the carboxyl group, which is written as –COOH.

Two students named the compound as eth**-** (for two carbon atoms in the parent chain). Two students identify the correct number of carbon atoms in the longest chain as one and named the compound as meth**-**. However, they could not provide the correct name of the compound, HCOOH because of the wrong suffixes used to indicate the family of organic compounds that the compound, HCOOH belongs to. For example, to one student, the suffix **–**ol means the compound is an alkanol for the presence of –OH functional group but this is not necessarily the case; and another student omitted the suffix acid was as he or she forgot to write it.

In summary, the main difficulties of students who could not name HCOOH by IUPAC nomenclature were their inability to identify:

1. the correct number of carbon atoms in the parent chain,
2. HCOOH as a compound but not as the functional group of alkanoic acids, and
3. the **–**COOH group as the functional group of alkanoic acids but not alkanols.

With the compound $(CH_3)_2C(Br)COOH$, the item's difficulty index was 0.2. The findings in Figure 6 show that only 20.4% of the students provided the correct IUPAC name as 2-bromo-2-methylpropanoic acid. Hence, majority of the students (79.6%) found it difficult to name the compound using the IUPAC nomenclature system. Table 18 presents some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $(CH_3)_2C(Br)COOH$.

Table 18: Wrong Names of $(CH_3)_2C(Br)COOH$ given by Some Students (N = 12)

Name given by students	N	%
2-bromo-2-propanoic acid	6	25.0
2-bromo-2-methylpropanone	1	4.2
2-bromobutan-2-oic acid	1	4.2
2-bromopropanoic acid	1	4.2
2-bromomethyl-2-ol	1	4.2
2-bromo-2-methylbutanoic acid	1	4.2
2-bromo-2-methanoic propane	1	4.2

Out of the 24 students interviewed, only 25.0% could not respond to the IUPAC name of the compound $(CH_3)_2C(Br)COOH$. From Table 18, only 12.5% of the students could not identify the correct number of carbon atoms in the longest continuous carbon chain. This is because 8.3% of the students name the compound, $(CH_3)_2C(Br)COOH$ as but- (for four carbon atoms in the parent chain) because they counted all the carbon atoms in structure of the compounds without considering the substituent group. Two students named the compound as meth- (for only one carbon atom in the parent chain) as they considered only the carbon atom of the –COOH group as written (Appendix B).

With respect to the suffix that indicate the family of organic compound that the compound, $(CH_3)_2C(Br)COOH$ belongs to, 12.5% of the student could not state that. This is because one student used a suffix –one, which is a suffix for ketones. The suffixes –ane and –ol were used respectively for alkane and alkanol compounds by two other students. The –ane was used because the student took the –COOH functional group as a substituent group, and the –ol was used because the student took –OH as the functional group for the compound, $(CH_3)_2C(Br)COOH$.

In the case of the substituents on the compound, $(CH_3)_2C(Br)COOH$, the names in Table 18 show that 50.0% of the students identified the Br as substituent and named it correctly as bromo. An overall proportion of 33.3% of the students could not identify CH_3- as a substituent because they either counted all the carbon atoms in the structure as part of the parent chain or took the –COOH group as a substituent. Half of the students interviewed assigned the correct positional value to the Br substituent as 2- whereas 33.3% of the students could not assigned the correct positional value to the CH_3- substituent because they never identified it.

In summary, the main difficulties of Chemistry students who could not provide the IUPAC name of $(CH_3)_2C(Br)COOH$ were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. identify –COOH group as the functional group of alkanoic acids, and
3. differentiate between a substituent group (such as Br) and functional group (such as –COOH) in the compound, $(CH_3)_2CBrCOOH$).

Alkyl Alkanoates

Students' difficulties in naming alkyl alkanoates were measured with items q19, CH_3COOCH_3 and q20, $(CH_3)_2CHCH_2COOCH_2CH_3$ on the achievement test. The findings in Figure 6 show that majority of the students found it difficult to provide the correct IUPAC names of alkyl alkanoates. This is because the difficulty indices of the two items were calculated as 0.2 and less than 0.1 (that is 0.04) respectively.

In the case of the compound, CH_3COOCH_3 the findings in Figure 6 show that only 18.4% of the students out of 245 students who took part in the study provided the correct IUPAC name of CH_3COOCH_3 as methyl ethanoate. Hence, majority of the students (81.6%) found it difficult to name CH_3COOCH_3 using the IUPAC nomenclature system. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of CH_3COOCH_3 are presented in Table 19.

Table 19: Wrong Names of CH_3COOCH_3 given by Some Students (N = 13)

Name given by students	N	%
Propanoic acid	4	16.7
Methyl methanoate	3	12.5
2-propanone	2	8.3
1-ethanoate acid	1	4.2
Ethyl ethanoate	1	4.2

Table 19 Cont'd

Name given by students	N	%
Propanoate	1	4.2
Methanoate	1	4.2

Out of the 24 students interviewed, 25.0% of the students could not respond to the IUPAC name of the compound, CH_3COOCH_3. From Table 19, an overall 37.5% of the students could not identify the compound, CH_3COOCH_3 as an alkyl alkanoate compound, which is of the form RCOOR'. This is because 20.8% of the students identified the compound as alkanoic acid because of the presence of the –COO group, which they referred to as a carboxyl group, the functional group of alkanoic acids, which is necessarily not the case. Two students identified the compound as a ketone and alkanoate respectively because of the presence of the –COO group.

With respect to the 16.7% of the students who identified the compound as an alkyl alkanoate (RCOOR'), one student could not identify the number of carbon atoms in the alkyl (R') group because he or she named it as ethyl whereas it was methyl for CH_3-. This could be attributed to the fact that the student counted one of the carbon atoms in the alkanoate group in addition to the alkyl group. In the case of the alkanoate (RCOO) group, 12.5% of the students could not identify the correct number of carbon atoms in the group because they did count the carbon atom bonded directly to the two oxygen atoms. The students thought it was a functional group, and that it should not be counted.

In summary, the main difficulties of students who could not provide the correct IUPAC name of CH_3COOCH_3 were their inability to identify the:

1. compound as an alkyl alkanoate with RCOOR' as the functional group, and
2. correct number of carbon atoms in either the alkanoate (RCOO) group or the alkyl (R') group.

In the case of the compound $(CH_3)_2CHCH_2COOCH_2CH_3$, the findings in Figure 6 show that only 4.1% of the students out of the 245 students who participated in the study gave the correct IUPAC name as ethyl 3-methylbutanoate. Hence, an overall 95.9% of the students found it difficult to name the compound $(CH_3)_2CHCH_2COOCH_2CH_3$ using the IUPAC nomenclature system. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $(CH_3)_2CHCH_2COOCH_2CH_3$ are presented in Table 20.

Out of the 24 students interviewed, an overall 41.7% of the students could not respond to the IUPAC name of the compound, $(CH_3)_2CHCH_2COOCH_2CH_3$. The names given in Table 20 show that 25.0% of the students could not identify the compound, $(CH_3)_2CHCH_2COOCH_2CH_3$ as an alkyl alkanoate which is of the form RCOOR'. This is because 16.7% of the students identified the compound as alkanoic acid because of the presence of the –COO group, which they referred to as a carboxyl group, the functional group of alkanoic acids, which is necessarily not the case. Two students identified the compound as just a methyl.

Table 20: Wrong Names of $(CH_3)_2CHCH_2COOCH_2CH_3$ given by Some Students (N = 11)

Name given by students	N	%
5-methylethyl butanoate	3	12.5
5-methyl	2	8.3
2-methylpentatonic acid	2	8.3
Ethyl 2-methylbutanoate	1	4.2
3-methylheptanoate	1	4.2
2-methyl-2-hexanoic acid	1	4.2
4-methyl-2-pentatonic acid	1	4.2

With respect to the 20.8% of the students who identified the compound as an alkyl alkanoate (RCOOR'), the names in Table 20 show that 12.5% student identified the correct number of carbon atoms in the alkyl (R') and named it as eth-. They however failed to place the ethyl group at the right place of the IUPAC name (that is the left hand side when written before the name the alkanoate group). One student could not identify the correct number of carbon atoms in the alkyl group because he or she counted it among the carbon atoms in the alkanoate group. In the case of the alkanoate group, one student could not identify the correct number of carbon atoms in the group because he or she counted the carbon atom of the alkyl group in addition and therefore named it as hept- (for seven carbon atoms in the alkanoate group).

From Table 20, 45.8% of the students identified one of the two methyl groups written as $(CH_3\text{-})_2$ as a substituent. However, 41.7% of the students could not identify the right position of the substituent. Examples of such wrong positions stated for the methyl substituent were 2- and 5-. In the case of the 2-methyl substituent, the students counted the carbon atoms from the left hand side of the alkanoate group instead of the carbon atom in the RCOOR' functional group. In the case of the 5-methyl, the students thought all the carbon atoms present in the molecule should be part of the longest continuous chain, which does not conform to the IUPAC rules for naming an alkyl alkanoate.

In summary, the main difficulties on the part of the students who could not provide the correct IUPAC name of $(CH_3)_2CHCH_2COOCH_2CH_3$ were their inability to:

1. identify the compound as an alkyl alkanoate with RCOOR' as the functional group,
2. identify the correct number of carbon atoms in either the alkanoate (RCOO) group or the alkyl (R') group, and
3. assign to the substituent group its correct position in the chain.

Students' Difficulties and Reasons for Writing Condensed and Graphical Formulae of Organic Compounds

Research question 2 further sought to find students' difficulties in writing the condensed and graphical formulae of organic compounds using IUPAC nomenclature. To show the difficult areas, students' performance is presented for each of the five test items on the achievement test (Appendix B). The distributions of the scores on the five test items in Figure 7 show that some items were not difficult whereas others were difficult.

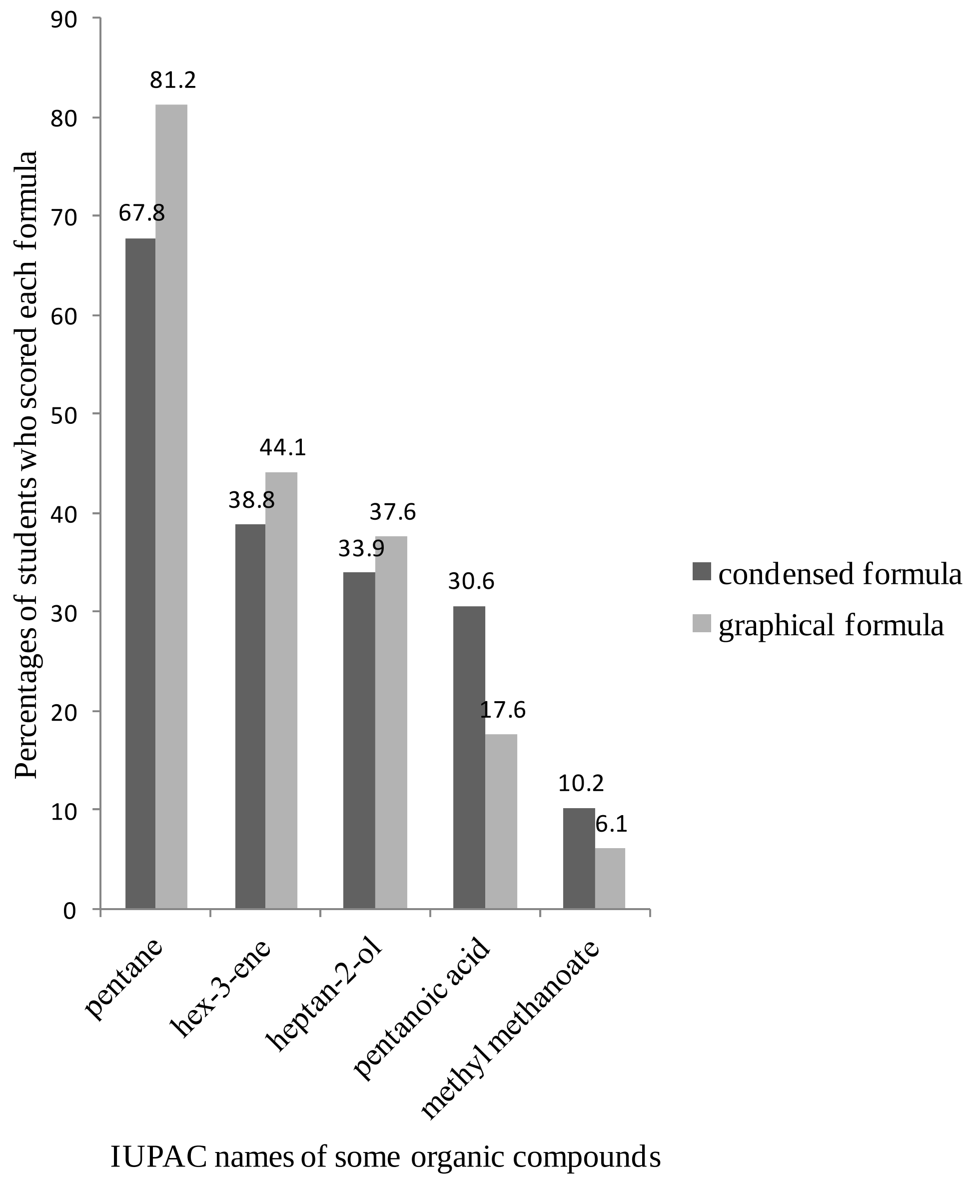


Figure 7. Bar chart of students' performance on writing condensed and graphical formulae of organic compounds.

The findings in Figure 7 show that generally, students show little or no difficulty in providing the correct graphical formula of a compound than the correct condensed formula of the same compound. For example, 81.2% of the students provided the correct graphical formula of pentane as compared to 67.8% of the students who provided the correct condensed formula of the same compound. This could be attributed to the fact that usually the examples used in teaching the IUPAC nomenclature of organic compounds are written in the graphical formula form.

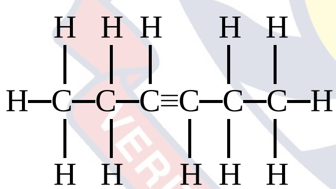
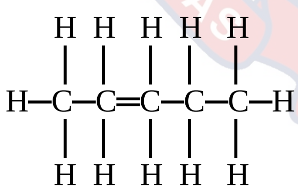
The findings in Figure 7 show those students' difficulties in writing condensed and graphical formulae of organic compounds from the IUPAC names increased from pentane, hex-3-ene, heptan-2-ol, pentanoic acid through to methyl methanoate. This could be attributed to the relatively enough time and attention given to the teaching of IUPAC nomenclature alkanes compared to other areas of organic compounds.

From Figure 7, the bars show that majority of the students (67.8%) and (81.2%) respectively found it not difficult to translate pentane into its condensed and the graphical formulae. However, majority of the students found it difficult to write the condensed and graphical formulae of hex-3-ene, heptan-2-ol, pentanoic acid, and methyl methanoate.

Hex-3-ene

From Figure 7, only 38.8% of the students wrote the correct condensed formula of hex-3-ene as $CH_3CH_2CH{=}CHCH_2CH_3$, and 44.1% of the student wrote the correct graphical formula of hex-3-ene (Appendix E). Hence, 61.2% and 55.9% of the students could not write respectively the correct condensed and graphical formulae of hex-3-ene using the IUPAC nomenclature system. This is because the difficulty indices of the item in terms of condensed and graphical formulae were calculated approximately as 0.4. Some wrong formulae provided and the percentages of the 24 students who were interviewed on the condensed and graphical formulae of hex-3-ene are presented in Table 21.

Table 21: Wrong Condensed and Graphical Formulae of Hex-3-ene given by Some Students (N = 14)

Formula given by students	N	%
Condensed		
C_6H_{12}	5	20.8
$CH_3CH_2C{\equiv}CCH_2CH_3$	3	12.5
$CH_3CH_2CH{=}CHCH_3$	1	4.2
Graphical		
C_6H_{12}	2	8.3
$CH_3CH_2CH_2{=}CH_2CH_2CH_3$	1	4.2
	1	4.2
	1	4.2

N is the number of students who provided wrong structural formulae from the IUPAC names.

Out of the 24 students who were interviewed, 8.3% of the student could not write the condensed formula of hex-3-ene and 25.0% of the students could not write the graphical formula of hex-3-ene. With respect to the number of the carbon atoms in the longest chain, only one student could not decode the code, hex- (for six carbon atoms in the parent chain). He or she said: “it was a mistake”. Amongst those students who decoded correctly the code hex-, one student could not provide the correct graphical formula of hex-3-ene because he or she used a condensed formula. Also, this is because the student assigned more than four covalent bonds to the two carbon atoms at the site of the double bond.

From Table 21, 33.3% and 12.5% of the students respectively for condensed and graphical formula of hex-3-ene could not decode the code –ene for double bonded hydrocarbon (that is alkene). This is because 20.8% of the students for condensed and 8.3% of the students for graphical wrote the molecular formula for hex-3-ene instead of the structure. Also, 12.5% of the students for condensed and one student for graphical thought the –ene mean a triple bond.

In summary, the main difficulties of the students who could not write the correct condensed and graphical formulae of hex-3-ene were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. assign the right number of covalent bonds to the carbon atoms at the site of the double bond, and
3. use double bond instead of triple bond for –ene.

Heptan-2-ol

The findings in Figure 7 show that only 33.9% of the students involved in the study wrote the correct condensed formula of heptan-2-ol as $CH_3(CH_2)_4CHOHCH_3$ and only 37.6% of the students provided the correct graphical formula of heptan-2-ol (Appendix E). These findings show that an overall 66.1% and 62.4% of the Chemistry students who participated in the study found it difficult to write respectively the correct condensed and graphical formulae of heptan-2-ol. This is because the item's difficulty index was 0.3 for condensed formula and 0.4 for graphical formula. Table 22 presents some wrong formulae and the percentages of the 24 students who were interviewed on writing condensed and graphical formulae of heptan-2-ol. Out of the 24 students interviewed, 25.0% and 33.3% of the students could not provide the correct condensed and graphical formulae respectively for heptan-2-ol.

Table 22: Wrong Condensed and Graphical Formulae of Heptan-2-ol given by Some Students (N = 10)

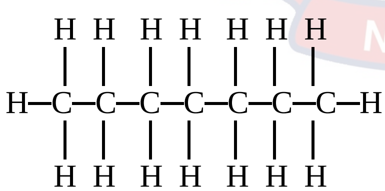
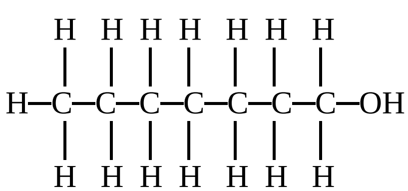
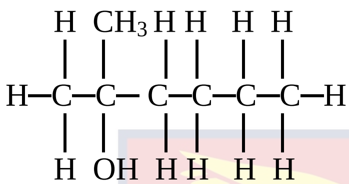
Formula given by students	N	%
Condensed		
$C_7H_{15}OH$	3	12.5
$CH_3(CH_2)_5CH_2OH$	2	8.3
Graphical		
$C_7H_{16}O$	2	8.3
	1	4.2
	1	4.2

Table 22 Cont'd

Formula given by students	N	%
	1	4.2

The formulae given in Table 22 show that only one student could not identify the correct number of carbon atoms in the longest continuous chain in the case of the graphical formula. This is because he or she used one of the carbon atoms to form a substituent. In the case of those students who identified the correct carbon atoms from the name, hept- (for seven carbon atoms in the parent chain), 12.5% and 8.3% of the students stated the molecular formula of heptan-2-ol as $C_7H_{16}O$ instead of the structure because they could not differentiate between condensed, graphical, and molecular formulae of organic compounds.

The formulae in Table 22 show that one student could not introduce the –OH functional group into the graphical formula of heptan-2-ol. This is because he or she could not decode the name, -ol as the suffix of alkanols. In the case of 2-ol, the names in Table 22 show that 4.2% and 8.3% of the students respectively attached the –OH functional group to the first carbon atom of the parent chain.

In summary, the main difficulties of the students who could not write the correct condensed and graphical formulae of heptan-2-ol were their inability to:

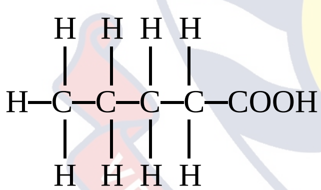
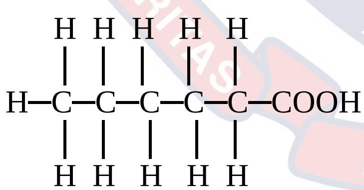
1. differentiate between condensed, graphical, and molecular formulae of heptan-2-ol,
2. identify the correct number of carbon atoms in the parent chain,
3. decode the suffix that show the functional group of heptan-2-ol, and
4. attach the –OH functional group to the right carbon atom of the parent chain.

Pentanoic Acid

The difficulty indices of pentanoic acid were 0.3 and 0.2 respectively for condensed and graphical formulae. The findings in Figure 7 show that out of the 245 students who participated in the study, only 30.6% of the students wrote the correct condensed formula of pentanoic acid as $CH_3CH_2CH_2CH_2COOH$ and 17.6% of the students provided the correct graphical formula of pentanoic acid (Appendix E). Hence, an overall 69.4% and 82.4% of the students found it very difficult to write respectively the condensed and graphical formulae of pentanoic acid. Some wrong formulae provided and the percentages of the 24 students who were interviewed on the writing of condensed and graphical formulae of pentanoic acid are presented in Table 23.

Out of the 24 students interviewed, 25.0% and 33.3% of the students could not respond to writing condensed and graphical formulae of pentanoic acid respectively. The formulae in Table 23 show that 12.5% of the students each for the condensed and the graphical formulae could not identify the correct number of carbon atoms in the longest continuous carbon chain. This is because they wrote six carbon atoms in the parent chain for pent-, saying that the carbon atom of the carboxyl (-COOH) functional group was not considered to be part of the longest chain.

Table 23: Wrong Condensed and Graphical Formulae of Pentanoic Acid given by Some Students (N = 20)

Formula given by students	N	%
Condensed		
$CH_3(CH_2)_4COOH$	3	12.5
C_4H_9COOH	3	12.5
$CH_3(CH)_3COOH$	2	8.3
$CH_3COOHCH_2CH_2CH_3$	1	4.2
$CH_3(CH)_3CH_3$─OH	1	4.2
Graphical		
	6	25.0
	2	8.3
$C_5H_{10}O_2$	1	4.2
$C_6H_{11}O_2$	1	4.2

In the case of those students who identify the correct number of carbon atoms in the parent chain as five for pent, an overall 29.2% and 25.0% of the students could not write the correct condensed and graphical formulae respectively for pentanoic acid. This is because the students either stated molecular formula such as C_4H_9COOH, or CH in place of the methylene (CH_2) group, or positioned the –COOH group in the midway of the parent chain for the condensed formula of pentanoic acid. In the case of the graphical formula of pentanoic acid, the students failed to show the bonds in the –COOH functional group (as done in Appendix E). Only one student thought that the presence of an –OH functional group shows that the organic compound is an acid, which is not necessarily the case.

In summary, the main difficulties of students who could not write the correct condensed and graphical formulae of pentanoic acid were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. differentiate between condensed, graphical, and molecular formulae of pentanoic acid,
3. identify the functional group of pentanoic acid as –COOH, and
4. show the bonds in –COOH functional group for the graphical formula.

Methyl Methanoate

From Figure 7, only 10.2% of the students wrote the correct condensed formula of methyl methanoate as $HCOOCH_3$ and only 6.1% of the students out of the 245 students involved in the study provided the correct graphical formula of methyl methanoate (Appendix E). Hence, an overall 89.8% of the students found it difficult to write the correct condensed formula of methyl methanoate and an overall 93.9% of the students also found it difficult to provide the correct graphical formula of methyl methanoate. This is because the item's difficulty index was calculated as 0.1 approximately for both condensed and graphical formulae. Table 24 presents some wrong formulae provided and the percentages of the 24 students who were interviewed on the condensed and graphical formulae of methyl methanoate.

Out of the 24 students interviewed, majority of the students (58.3%) could not respond to writing condensed and graphical formulae of methyl methanoate. From Table 24, the formulae provided show that only one student could identify that methyl methanoate is a member of alkyl alkanoate compounds, which have RCOOR' as their functional group. This is because he or she thought the functional group for methyl methanoate is –COOH.

Table 24: Wrong Condensed and Graphical Formulae of Methyl Methanoate given by Some Students (N = 9)

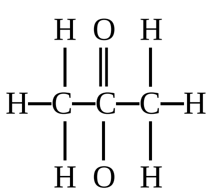
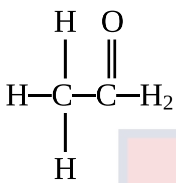
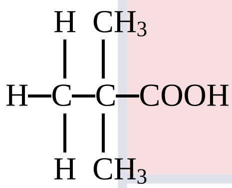
Formula given by students	N	%
Condensed		
CH_3COOCH_3	2	8.3
$CH_3CHCOOCH$	1	4.2
$COOCH_3$	1	4.2
CH_3COOH	1	4.2
Graphical		
	2	8.2

Table 24 Cont'd

Formula given by students	N	%
	1	4.2
	1	4.2

From Table 24, with respect to the number of carbon atoms in the longest chain, 12.5% of the students could not identify the correct number of carbon atoms from the IUPAC name, methyl methanoate. In the case of the alkyl (R') group, 12.5% of the students identified the methyl group but they thought of it as a substituent group on the parent chain in the graphical formula form of methyl methanoate. From Table 24, 12.5% and 8.3% of the students respectively could not write the correct number of carbon atoms in the methanoate group. This is because the students failed to consider the carbon atom of the functional group as part of the alkanoate (RCOO) group. The only student who identified the correct number of carbon atoms in the methyl group failed to complete the four covalent bonds that carbon atom in the functional group must have for the condensed formula form.

In summary, the main difficulties of students who could not write the correct condensed and graphical formulae of methyl methanoate were their inability to:

1. identify the correct number of carbon atoms in both the alkyl and the alkanoate groups,
2. identify the functional group of alkyl alkanoate as RCOOR’,
3. write the correct number of covalent bonds for the carbon atom of the functional (RCOOR’) group, and
4. use the methyl group as the R’ group for RCOOR’ but not as a substituent group.

Students’ Difficulties and Reasons for Writing Structural Formulae of Organic Compounds

The next five test items of section 2 of the achievement test sought to find out the SHS Chemistry students’ difficulties in writing structural formulae of organic compounds from IUPAC names. The compounds used for this section were:

Q1. 2-fluoro-3,3-dimethylbutane

Q2. 4-ethyl-2,3-dimethylhex-2-ene

Q3. 2-methylpropan-1-ol

Q4. 5-chloro-2-methylhexanoic acid

Q5. Propyl 2-chloroethanoate

To show the difficult areas, students’ performance is presented for each of the five test items. The distributions of the scores on the five test items in Figure 8 show that all the items were difficult. This is because majority of students could not write the correct structural formulae of the given IUPAC names. This could be attributed to the presence of one or more substituent groups in each compound.

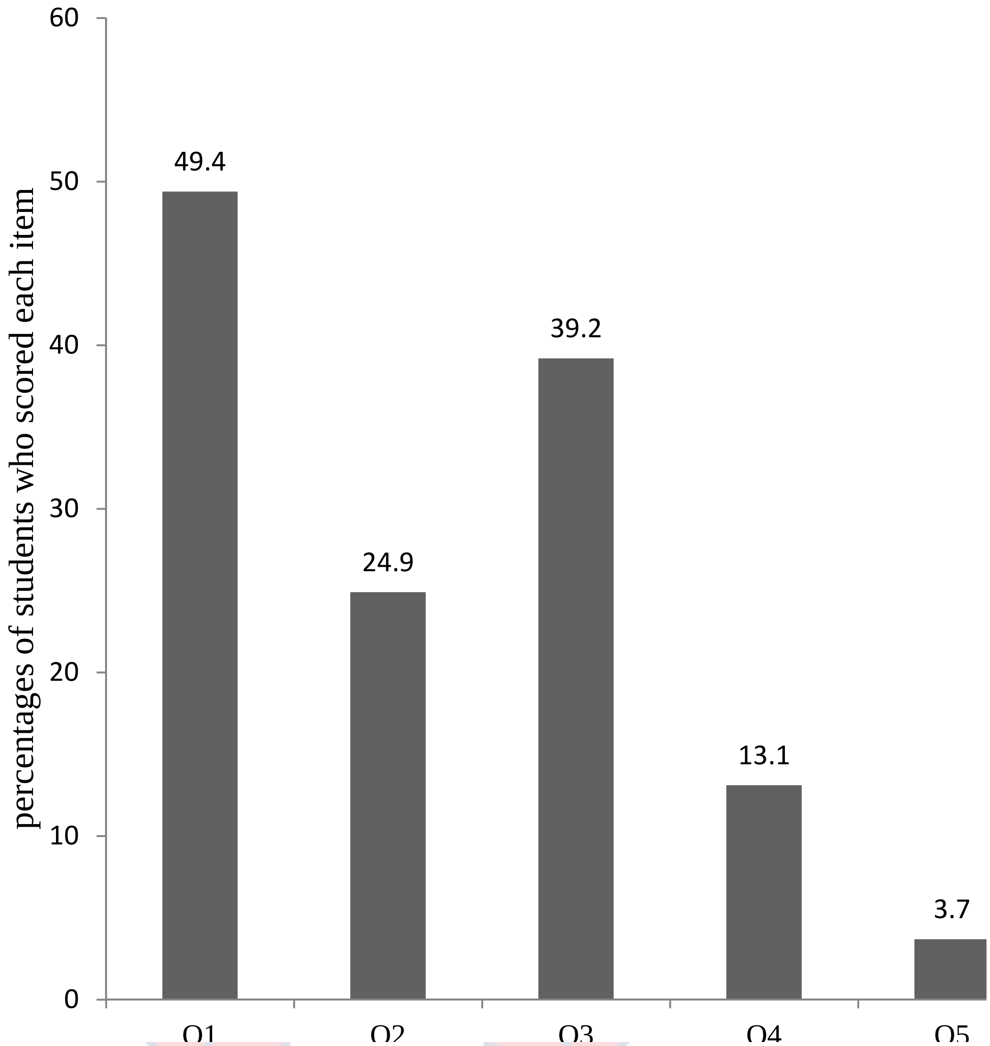


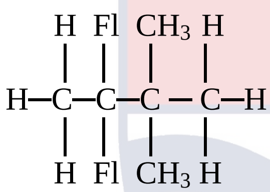
Figure 8. **Bar chart of students' performance on writing structural formulae of organic compounds using the IUPAC nomenclature system**.

2-fluoro-3,3-dimethylbutane

The findings in Figure 8 show that out of the 245 students involved in the study, 49.4% of the students wrote the correct structural formula of 2-fluoro-3,3-dimethylbutane as $CH_3CH(F)C(CH_3)_3$. Hence, an overall 50.6% of the students found it difficult to write the structural formula of 2-fluoro-3,3-dimethylbutane.

This is because the difficulty index of the item was calculated as 0.5. Some wrong formulae provided and the percentages of the 24 students who were interviewed on writing structural formula of 2-fluoro-3,3-dimethylbutane are presented in Table 25.

Table 25: Wrong Structural Formulae of 2-fluoro-3,3-dimethylbutane given by Two Students (N = 2)

Formula given by students	N	%
	1	4.2
$CH_3CH(F)CH(CH_3)_2$	1	4.2

Out of the 24 students interviewed, 20.8% of the students could not write any structural formula for 2-fluoro-3,3-dimethylbutane. From Table 25, the 8.3% of the students who could not provide the correct formula of 2-fluoro-3,3-dimethylbutane using the IUPAC nomenclature system identified the correct number of carbon atoms in the longest continuous carbon chain.

From Table 25, in the case of the substituent groups, one student could not identify the two CH_3- substituents for the prefix di- because he or she thought that having the methyl substituents written as $(CH_3)_2$ means he or she had catered for both methyl substituents. This is not necessarily the case as that reduces the carbon atoms in the longest chain, and that methyl group written as (CH_3) does not necessarily mean a substituent group. With respect to the fluoro substituent, one student could not provide the correct chemical symbol and the number for it. This is because he or she stated two of Fl instead of one of F.

In summary, the main difficulties of students who could not write the correct structural formula of 2-fluoro-3,3-dimethylbutane were their inability to:

1. identify the right number of the substituent groups, and
2. use the correct chemical symbol for the fluoro substituent.

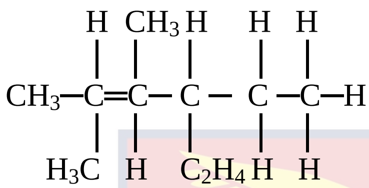
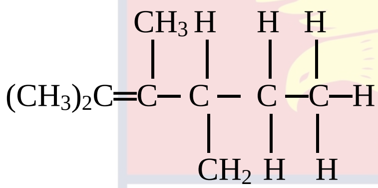
4-ethyl-2,3-dimethylhex-2-ene

The item difficulty index of the compound, 4-ethyl-2,3-dimethylhex-2-ene was 0.3. From Figure 8, only 24.9% of the students wrote the correct structural formula of 4-ethyl-2,3-dimethylhex-2-ene as $(CH_3CH_2)_2CHC(CH_3){=}C(CH_3)_2$. Hence, an overall 75.1% of the students found it difficult to write the correct structural formula of 4-ethyl-2,3-dimethylhex-2-ene. Some wrong formulae provided and the percentages of the 24 students who were interviewed on writing structural formula of 4-ethyl-2,3-dimethylhex-2-ene are presented in Table 26.

The formulae given in Table 26 show that 20.8% of the students identified the correct number of carbon atoms in the longest continuous carbon chain as six for the root name hex-. However, one student could not state double bond for the suffix –ene because he or she thought –ene shows the presence of a triple bond. Two students could not assign the right number of covalent bonds to the two carbon atoms at the site of the double bond.

In the case of the substituent groups, 16.7% of the students identified the correct numbers and positions of the two substituent groups (ethyl and methyl). However, 8.3% of the students could not write the correct formula for the ethyl substituent because they wrote CH_2 or C_2H_4 in place of C_2H_5.

Table 26: Wrong Structural Formulae of 4-ethyl-2,3-dimethylhex-2-ene given by Some Students (N = 5)

Formula given by students	N	%
	2	8.3
	2	8.3
$(CH_3)_2CHCH(CH_3)CH{\equiv}CH_2CH_3$	1	4.2

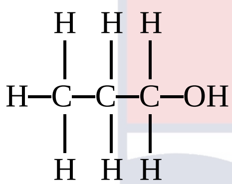
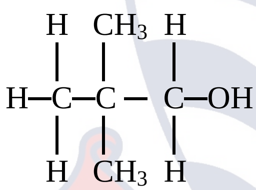
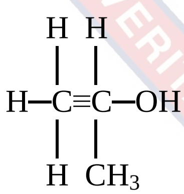
In summary, the main difficulties of students who could not write the correct structural formula of 4-ethyl-2,3-dimethylhex-2-ene were their inability to:

1. assign the right number of bonds to the carbons at the site of the double bond, and
2. identify the number of carbon or hydrogen atoms in the ethyl substituent group.

2-methylpropan-1-ol

The findings in Figure 8 show that only 39.2% of the students wrote the correct structural formula of 2-methylpropan-1-ol as $(CH_3)_2CHCH_2OH$. Hence, an overall 60.8% of the students found it difficult to write the correct structural formula of 2-methylpropan-1-ol using the IUPAC nomenclature system. This is because the difficulty index of the item was calculated as 0.4. Table 27 presents some wrong formulae provided and the percentages of the 24 students who were interviewed on the structural formula of 2-methylpropan-1-ol.

Table 27: Wrong Structural Formulae of 2-methylpropan-1-ol given by Some Students (N = 7)

Formula given by students	N	%
$CH_3CH(OH)CH_3$	2	8.3
	2	8.3
	1	4.2
$CH_2(OH)CH(CH_3)CH_2CH_3$	1	4.2
	1	4.2

Out of the 24 students interviewed, 16.7% of the students could not provide any response on writing structural formula of 2-methylpropan-1-ol. From Table 27, only 8.3% of the student could not identify the correct number of carbon atoms in the longest continuous chain because one of them used four carbon atoms in the parent chain for prop-. The other student stated two carbon atoms in the parent chain for prop- because he or she thought the methyl group was part of the parent chain.

In case of the functional group of the compound, 2-methylpropan-1-ol, 29.2% of the students identified the suffix –ol as showing the presence of the –OH functional group. However, 16.7% of the students could not decode the name -1-ol as the presence of the –OH on the first carbon atom of the parent chain. This could be attributed to how the students positioned the substituent group.

With respect to the substituent group, only 16.7% of the students could not write CH_3- for methyl because they thought it was already part of the parent chain, which is necessarily not the case. From Table 27, amongst the 8.3% of the students who identified the methyl substituent, one student wrote two CH_3- groups as he or she thought the 2- that came before the name methyl means there are two methyl groups on the parent chain. This could be attributed to the fact that some students are not used to the prefixes di, tri, tetra and others which are used to give an indication of the number of the same substituent group present.

In summary, the main difficulties of students who could not write the correct structural formula of 2-methylpropan-1-ol were their inability to:

1. identify the correct number of carbon atoms in the parent chain,
2. attach the –OH functional group to the right carbon atom of the parent chain, and
3. attach the CH_3- substituent group to the right carbon atom of the parent chain.

5-chloro-2-methylhexanoic Acid

From Figure 8, out of the 245 students who took part in the study, only 13.1% wrote the correct structural formula of 5-chloro-2-methylhexanoic acid as $CH_3CH(Cl)CH_2CH_2CH(CH_3)COOH$. The item's difficulty index was 0.1 and hence, an overall 86.9% of the Chemistry students found it difficult to write the correct structural formula of 5-chloro-2-methylhexanoic acid. Some wrong formulae provided and the percentages of the 24 students who were interviewed on the structural formula of 5-chloro-2-methylhexanoic acid are presented in Table 28.

Table 28: Wrong Structural Formulae of 5-chloro-2-methylhexanoic Acid given by Some Students (N = 9)

Formula given by students	N	%
$(CH_3)_2CHCH_2CH_2CH(Cl)COOH$	5	20.8
$(CH_3)_2CHCH_2CH_2CH(Cl)CH_2COOH$	2	8.3
$CH_3CH(Cl)CH_2CH_2CH(CH_3)CH_2COOH$	1	4.2
$(CH_3)_2CHCH_2CH_2COOH$	1	4.2

Out of the 24 students interviewed, 29.2% could not respond to writing structural formula of 5-chloro-2-methylhexanoic acid using the IUPAC nomenclature system. From the formulae given in Table 28, 16.7% of the students could not identify the correct number of carbon atoms in the longest continuous carbon chain. This is because 8.3% of the students thought the carbon atom of the –COOH functional group was not part of the parent chain. The students stated that this carbon atom just give an indication that the compound is an alkanoic acid. One student wrote five carbon atoms in the parent chain because he or she considered the methyl groups written as $(CH_3)_2$ as part of the parent chain.

With respect to the substituent groups in the compound, 5-chloro-2-methylhexanoic acid, only one student could not identify and write Cl as part of the structure of the compound for the chloro substituent. From Table 28, the 20.8% of the students who wrote the correct number of carbon atoms in the parent chain could not position the Cl and CH_3- substituents respectively at positions 5 and 2 because they started the counting of the carbon atoms in the parent chain not from the carbon atom of the –COOH functional group.

In summary, the main difficulties of the Chemistry students who could not write the correct structural formula of 5-chloro-2-methylhexanoic acid were their inability to:

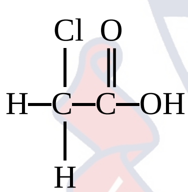
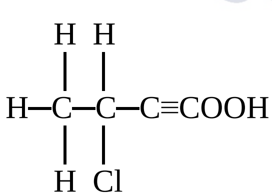
1. identify the correct number of carbon atoms of the parent chain,
2. identify all substituent groups from the IUPAC name, and
3. attach the substituent groups to the right carbon atoms in the parent chain.

Propyl 2-chloroethanoate

Out of the 245 students involved in the study, it is seen from Figure 8 that only 3.7% of the students wrote the correct structural formula of propyl 2-chloroethanoate as $CH_2(Cl)COOCH_2CH_2CH_3$. The findings show that an overall 96.3% of the students found it difficult to write the correct structural formula of propyl 2-chloroethanoate. This is because the difficulty index of the compound was calculated to be less than 0.1 (that is 0.04). Table 29 presents some wrong formulae provided and the percentages of the 24 students who were interviewed on the structure formulae of propyl 2-chloroethanoate.

Majority of the students (66.7%) who were interviewed could respond to writing structural formula of propyl 2-chloroethanoate using the IUPAC nomenclature system. From Table 29, 12.5% of the students could not identify that the compound, propyl 2-chloroethanoate belongs to the family of the alkyl alkanoates (RCOOR') because they wrote the –COOH functional group as the functional group of the compound.

Table 29: Wrong Structural Formulae of Propyl 2-chloroethanoate given by Some Students (N = 4)

Formula given by students	N	%
	2	8.3
	1	4.2
	1	4.2

In terms of the number of carbon atoms in the parent chain, only one student identified all the three carbon atoms in the R' group for prop-, and the two carbon atoms in the RCOO group for eth-. He or she however forget to add the Cl atom to the second carbon atom of the RCOO group for the name 2-chloro.

In summary, the main difficulties of students who could not write the correct structural formula of propyl 2-chloroethanoate were their inability to identify the:

1. correct number of carbon atoms in the parent chain,
2. correct functional group for alkyl alkanoates, and
3. substituent group from the IUPAC name.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the key findings are highlighted and recommendations given that may enable Chemistry teachers improve on the teaching of organic Chemistry in the schools.

Summary

This study tested the knowledge level of the SHS Chemistry students in IUPAC nomenclature of organic compounds in the Kumasi Metropolis. This assisted in diagnosing the difficulties students have with naming and writing structural formulae of organic compounds. Also, the nature of the difficulties and why students have those difficulties were investigated. The sample used was 245 SHS4 Chemistry students for the 2010/2011 academic year drawn from four schools in the Kumasi Metropolis. The instruments used for data collection were achievement test and interview.

A cross-sectional survey was used to collect quantitative data on students' general performance on naming and writing structural formulae of organic compounds at the second stage of the study. In stage three, interviews with 24 selected students were used to find out qualitatively what accounted for the students' difficulties in the achievement test.

Key findings

1. a. The performance of students on naming structural formulae of organic compounds was low as only 25.7% of students scored more than half of the total marks.

   b. Students' performance on writing structural formulae of organic compounds from IUPAC names was very low as only 21.6% of students scored more than half the total marks.

2. a. 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.

   b. Students had difficulties in writing structural formulae (either condensed or graphical) of branched- and unbranched-chain alkenes, alkanols, alkanoic acids, and alkyl alkanoates from IUPAC names.

3. The difficulties of the Chemistry students in naming organic compounds using the IUPAC nomenclature system were as a result of their inability to:

   a. identify the correct number of carbon atoms in the parent chain.
   b. identify some of the atoms or groups in the structural formula of a compound as substituent groups.
   c. assign the substituent groups the correct positions in the structure of a compound.
   d. arrange the names of the substituent groups in alphabetical order.
   e. identify and use the correct position of a multiple bond.

f. state the correct suffix for a particular multiple bond.

g. use the correct prefix for two or more identical substituents.

h. use the prefix trans- or cis- in IUPAC name of a geometrical isomer.

i. identify a functional group in a structural formula of a compound.

j. assign correct position to a carbon atom to which a functional group is bonded.

k. state the right suffix for an identified functional group.

l. state the position of a functional group (such as –OH) in the IUPA name.

m. differentiate between a substituent group (such as Br) and functional group (such as –COOH) in a molecule.

Chemistry students' difficulties in writing structural formulae of organic compounds from IUPAC names were as a result of their inability to:

a. differentiate between condensed, graphical, and molecular formulae of an organic compound.

b. assign each carbon atom the correct number of covalent bonds.

c. identify the correct number of carbon atoms in the parent chain.

d. identify a functional group from the suffix of the IUPAC name.

e. attach a functional group (such as –OH) to the right carbon atom of the parent chain.

f. identify the right number of the substituent groups from an IUPAC name.

g. use the correct chemical symbol or a formula for a particular substituent.

h. attach a substituent group to the right carbon atom of the parent chain.

4. a. There was no statistical significant difference between the scores of students from well-endowed and less-endowed schools on naming organic compounds using the IUPAC nomenclature system. This is because the mean score for the students from well-endowed schools (M = 7.0, SD = 3.9) on naming organic compounds using the IUPAC nomenclature system was not statistically significantly different from the mean score for students from less-endowed schools (M = 7.7, SD = 4.6, t(243) = 1.3, p = 0.211) with relatively small effect size (d = 0.006).

   b. There was no statistical significant difference between the scores of students from well-endowed and less-endowed schools on writing structural formulae of organic compounds using the IUPAC nomenclature system. This is because the mean score for students from well-endowed schools (M = 4.9, SD = 2.9) on writing structural formulae of organic compounds using the IUPAC nomenclature system was not significantly different from the mean score for students from less-endowed schools (M = 5.1, SD = 3.6, t(243) = 0.5, p = 0.649) with relatively small effect size (d = 0.0009).

Conclusions

The study has shown that the Chemistry students examined generally show low level of understanding in IUPAC nomenclature of organic compounds and this confirms the WAEC Chief Examiner's Reports on the general weakness of Chemistry students at the SHS level in IUPAC nomenclature of organic compounds. The students showed high level of understanding in naming and writing structural formulae of alkanes using the IUPAC nomenclature system. However, the students showed weakness in IUPAC naming and writing of structural formulae of alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates.

The Chemistry students' difficulty in naming organic compounds using the IUPAC nomenclature system is due to their inability to identify the correct number of carbon atoms in the parent chain, identify substituent or functional groups, assign the right positions to the substituent group, functional group, or multiple bond, use the right suffix for multiple bond or any other functional group, and use the right prefix for identical substituent or functional groups. It seems the students are not conversant with the root names of the number of carbon atoms in the longest chain. It could also be that the students counted the carbon atoms of the alkyl substituents as part of the longest continuous carbon chain and that students assigned positions to the carbon atoms in a particular chain without considering assigning the least position to any carbon atom that is directly bonded to any substituent or the functional group.

In this study, what accounts for the Chemistry students' difficulty in writing structural formulae of organic compounds using the IUPAC nomenclature system has been shown. This includes their inability to identify from the IUPAC name the correct number of carbon atoms in the parent chain, the chemical symbol or formula of any substituent or functional group, the correct position of and number of multiple bonds, functional, or substituent group. This means that the students could not work backwards from the IUPAC name to the structural formula of any given organic compound. These difficulties having been identified could help Chemistry teachers at the SHS level to deploy more effectively their pedagogical content knowledge in teaching organic Chemistry.

Recommendations

The following recommendations are made based on the findings of the study:

1. As the students had difficulties in IUPAC nomenclature of alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates, Chemistry teachers should give more worked examples on IUPAC nomenclature in these areas.
2. Since the students' difficulty in IUPAC nomenclature of organic compounds was due partly to their inability to identify the correct number of carbon atoms in a parent chain from either an IUPAC name or a structural formula, Chemistry teachers should therefore hold class discussion with students after each class exercise on IUPAC nomenclature to enable them identify this weakness and work on it.
3. Any assistance to be provided by the Ghana Education Service to help the students to improve on their understanding in IUPAC nomenclature of organic compounds should be independent of the school-type as there was no statistical significant difference between the performance of the students from well-endowed and less-endowed schools.

Suggestion for Future Research

The study tested the knowledge level and difficulties of the Chemistry students in IUPAC nomenclature of organic compounds. However, the study did not consider the Chemistry teachers' difficulties in teaching and their own understanding of the content and how they present it to the students. It is therefore recommended that a future research is conducted to look into these issues.

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APPENDIX A

NAMING ORGANIC COMPOUNDS USING THE IUPAC NOMENCLATURE SYSTEM

Naming Unbranched Alkanes

To name an unbranched alkane,

1. Count the length of the continuous carbon chain. For example, one, two, three, four, five, six, seven, eight, nine, and ten and respectively name as meth, eth, prop, but, pent, hex, oct, non, and dec (Solomons & Fryhle, 2008).
2. Add –ane to the length of the continuous carbon chain as the ending of all alkanes (Solomons & Fryhle, 2008). Some examples are given in Table 30.

Table 30: Names and Formulae of the First Six Members of Alkanes

Chain Length	Formula	IUPAC Nomenclature
1	CH_4	Methane
2	CH_3CH_3	Ethane
3	$CH_3CH_2CH_3$	Propane

Table 30 Cont'd

Chain Length	Formula	IUPAC Nomenclature
4	$CH_3CH_2CH_2CH_3$	Butane
5	$CH_3CH_2CH_2CH_2CH_3$	Pentane
6	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane

Naming Unbranched Alkyl Groups

An alkyl group is formed when terminal hydrogen is removed from an alkane. The alkyl groups have their endings with –ly. Naming alkyl groups is straight forward like the unbranched alkanes. Some examples of alkyl groups are presented in Table 31.

Table 31: Some Alkanes and their Corresponding Alkyl Groups

Alkane	Alkyl Group	Abbreviation
CH_3—H	CH_3—	Me
Methane	Methyl	
CH_3CH_2—H	CH_3CH_2—	Et
Ethane	Ethyl	
$CH_3CH_2CH_2$—H	$CH_3CH_2CH_2$—	Pr
Propane	Propyl	
$CH_3CH_2CH_2CH_2$—H	$CH_3CH_2CH_2CH_2$—	Bu
Butane	Butyl	

Naming Branched-Chain Alkanes

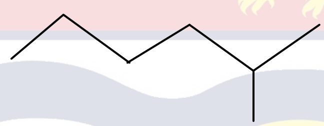
According to Solomons and Fryhle (2008, pp. 135-137), branched-chain alkanes are named according to the following rules:

1. Locate the longest continuous chain of carbon atoms; this chain determines the parent name for the alkane. For example,

$CH_3CH_2CH_2CH_2CHCH_3$
|
CH_3

Hexane

or



The longest continuous carbon chain may not be obvious from the way the formula is written. For example, heptane

$CH_3CH_2CH_2CH_2CHCH_3$
|
CH_2
|
CH_3

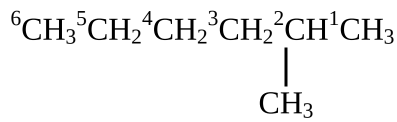
2. Number the longest chain beginning with the end of the chain nearer the substituent. For example,

$^{6}CH_3{}^{5}CH_2{}^{4}CH_2{}^{3}CH_2{}^{2}CH^{1}CH_3$
|
CH_3

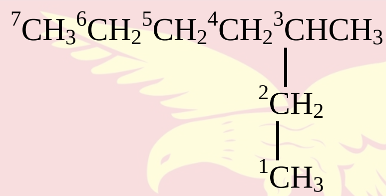
$^{7}CH_2{}^{6}CH_2{}^{5}CH_2{}^{4}CH_2{}^{3}CHCH_3$
|
$^{2}CH_2$
|
$^{1}CH_3$

It should be noted that the CH_3 is substituent in the two examples.

3. Use the numbers obtained by application of rule 2 to designate the location of the substituent group. Numbers are separated from words by a hyphen. For example,

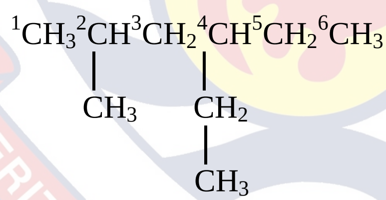


2-methylhexane



3-methylheptane

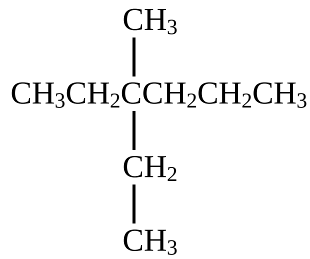
4. When two or more substituents are present, give each substituent a number corresponding to its location on the longest chain. For example,



4-ethyl-2-methylhexane

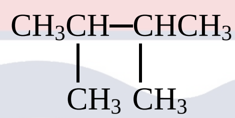
The substituent groups should be listed alphabetically. In deciding on alphabetical order, disregard multiplying prefixes such as “di” and “tri”.

5. When two substituents are present on the same carbon atom, use that number twice.

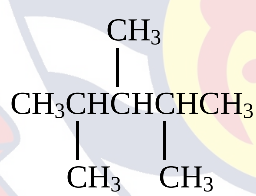


3-ethyl-3-methylhexane

6. When two or more substituents are identical, indicate this by the use of the prefixes di-, tri-, tetra-, and so on. Then make certain that each and every substituent has a number. Commas are used to separate numbers from each other. For example,

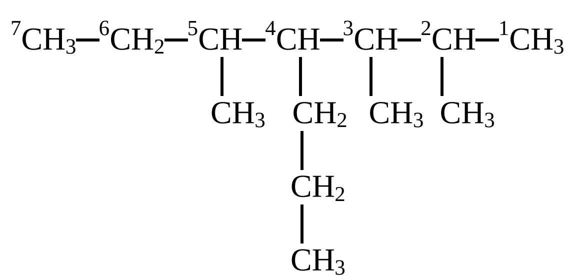


2,3-dimethylbutane



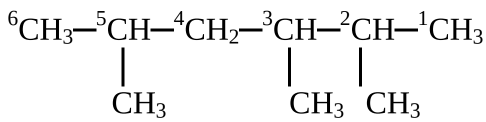
2,3,4-trimethylpentane

7. When two chains of equal length compete for selection as the parent chain, choose the chain with the greater number of substituents. For example,



2,3,5-trimethyl-4-propylheptane

8. When branching first occurs at an equal distance from either end of the longest chain, choose the name that gives the lower number at the first point of difference. For example,



2,3,5-trimethylhexane (not 2,4,5-trimethylhexane)

Naming Branched Alkyl Groups

Alkanes with more than two carbon atoms can provide more than one derived group. For example, two groups can be derived from propane; namely the propyl group is derived by removal of a terminal hydrogen, and 1-methylethyl or isopropyl group is derived by removal of hydrogen from the central atom. 1-methylethyl is the systematic name while isopropyl is the common name. Systematic nomenclature for alkyl group is the same as that for branched-chain alkanes. Note that the numbering always starts at the point where the group is attached to the main chain (Solomons & Fryhle, 2008).

Three-Carbon Groups

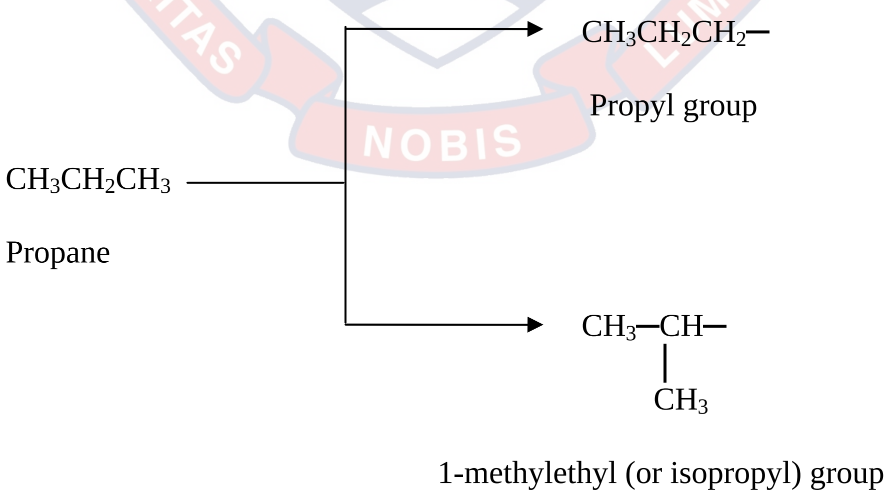


Figure 9. Derived groups of propane.

Four-Carbon Groups

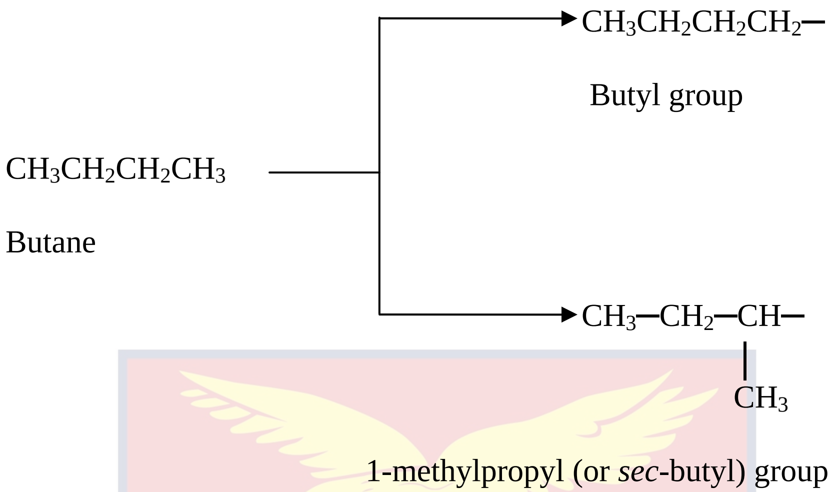


Figure 10. **Derived groups of butane**.

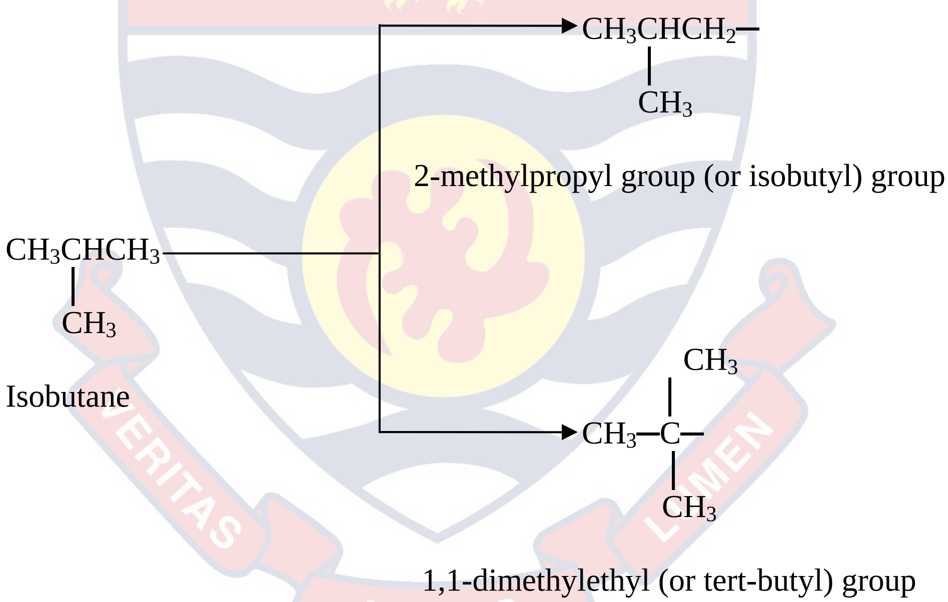
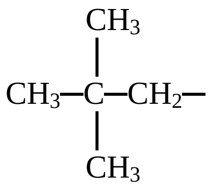


Figure 11. **Derived groups of isobutane**.

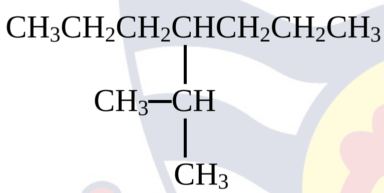
Five-Carbon Groups

There is only one five-carbon group with an IUPAC approved common name. It is commonly referred to as neopentyl group:

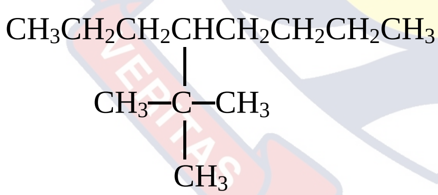


2,2-dimethylpropyl (or neopentyl) group

These common names, isopropyl, isobutyl, sec-butyl, tert-butyl, and neopentyl are approved by the IUPAC for the unsubstituted groups, and currently are still in used. On the basis of the alphabetical order the structure-defining prefixes such as sec- and tert- are not considered. Only consider the alphabetical letter that comes immediately after these prefixes (Skonieczy, 2006). The following are examples of how these common names are used in the IUPAC system.



4-(1-methylethyl) heptane (or 4-isopropylheptane)



4-(1,1-dimethylethyl) octane (or 4-tert-butyloctane)

Naming Alkyl Halides

Alkanes bearing halogen substituent groups are named in the IUPAC substitutive system as haloalkanes (Solomons & Fryhle, 2008). For example,

CH_3CH_2Cl

Chloroethane

$CH_3CH_2CH_2F$

1-fluoropropane

$CH_3CHBrCH_3$

2-bromopropane

There are some compounds that contain both a halo and an alkyl substituent group. In such cases the chain is numbered from the end nearer to the first substituent group, notwithstanding whether the group is a halo or an alkyl group. If the two substituents are at equal distance from the end of the chain, then the alphabetical order should be considered in numbering (Skonieczy, 2006). For example,

CH_3

$CH_3CHCHCH_2CH_3$

Cl

2-chloro-3-methylpentane

CH_3

$CH_3CHCH_2CHCH_3$

Cl

2-chloro-4-methylpentane

Many haloalkanes are currently using their common names. In such cases the haloalkanes are named as alkyl halides (that is, functional class nomenclature) (Solomons & Fryhle, 2008). These names are accepted by IUPAC. For example,

CH_3CH_2Cl

Ethyl chloride

CH_3CHCH_3
|
Br

Isopropyl bromide

$(CH_3)_3CBr$

tert-butyl bromide

CH_3CHCH_2Cl
|
CH_3

Isobutyl chloride

CH_3
|
CH_3CCH_2Br
|
CH_3

Neopentyl bromide

Naming Alkanols

According to Gillette (2004); Solomons and Fryhle (2008), under the IUPAC substitutive system, there are about four possible features to be identified. These are locants, prefixes, parent compound, and suffixes. For example,

$CH_3CH_2CHCH_2CH_2CH_2OH$
|
CH_3

4-methyl-1-hexanol

Where, 4 and 1 are the locants, which tell the positions of attachments of methyl and hydroxyl group respectively. The parent compound contains six carbon atoms and no multiple bonds, and hence the parent structure is hexane. The suffix –ol indicates that the compound is an alkanol (alcohol). The numbering of the continuous carbon chain must always start at the end nearer the group named as a suffix. The locant for a suffix (either alkanol or any other functional group) can either be placed before the parent name (for example, 1-hexanol) or immediately before the suffix (for example, hexan-1-ol). According to Solomons and Fryhle (2008), to name an alkanol,

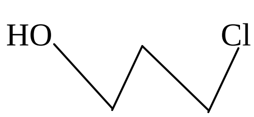
1. Select the longest continuous carbon chain to which the hydroxyl is directly attached.
2. Change the name of the alkane corresponding to this chain by dropping the final 'e' and adding the suffix –ol.
3. Number the longest continuous carbon chain so as to give the hydroxyl group the lower number.
4. Indicate the position of the hydroxyl group by using this number as a locant.
5. Indicate the positions of other substituents (as prefixes) by using the numbers corresponding to their positions along the carbon chain as locants (p. 140). For example,

$CH_3CHCH_2CH_3$
$\quad\;\; |$
$\quad\;\; OH$

2-butanol (or butan-2-ol)

$CH_3CHCH_2CH_2CH_2OH$
$\quad\;\; |$
$\quad\;\; CH_3$

4-methyl-1-pentanol (or 4-methylpentan-1-ol)



3-chloro-1-propanol (or 3-chloropropan-1-ol)

Simple Alkanols

The IUPAC system approves the use of common functional class names for simple alkanols (Solomons & Fryhle, 2008). For example,

CH_3OH

Methyl alcohol

CH_3CH_2OH

Ethyl alcohol

$CH_3CH_2CH_2OH$

Propyl alcohol

$HOCHCH_3$
|
CH_3

Isopropyl alcohol

CH_3
|
CH_3COH
|
CH_3

tert-butyl alcohol

CH_3
|
$HOCH_2CCH_3$
|
CH_3

Neopentyl alcohol

Diols

Alkanols containing two hydroxyl groups, which are usually referred to as glycols, are named as **diols** in the IUPAC substitutive system (Skonieczy, 2006; Solomons & Fryhle, 2008). For example,

CH_2-CH_2
| |
OH OH

1,2-ethanediol (or ethane-1,2-diol)

CH_3CH-CH_2
| |
OH OH

1,2-propanediol (or propane-1,2-diol)

$HOCH_2CH_2CH_2OH$

1,3-propanediol (or propane-1-3-diol)

Naming Alkenes

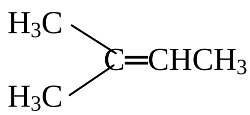
According to Solomons and Fryhle (2008, pp. 144-145), to name an alkene,

1. Determine the parent name by selecting the longest chain that contains the double bond and change the ending of the name of the alkane of identical length from –ane to –ene.
2. Number the chain so as to include both carbon atoms of the double bond, and begin numbering at the end of the chain nearer the double bond.
3. Designate the location of the double bond by using the number of the first atom of the double bond as a prefix. The locant for the alkene suffix may precede the parent name or be placed immediately before the suffix. For example,

   $CH_2=CHCH_2CH_3$

   1-butene (or but-1-ene)

4. Indicate the locations of the substituent groups by the numbers of the carbon atoms to which they are attached. For example,

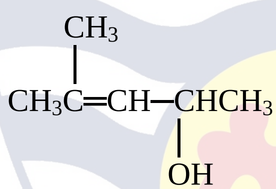


2-methyl-2-butene (or 2-methylbut-2-ene)

$BrCH_2CH{=}CHCH_3$

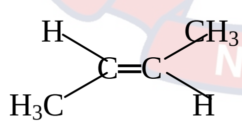
1-bromo-2-butene (or 1-bromobut-2-ene)

5. Name compounds containing a double bond and an alkanol (alcohol) group as alkenols, and give the alcohol carbon the lower number. For example,

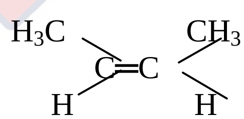


4-methyl-3-penten-2-ol (or 4-methylpent-3-en-2-ol)

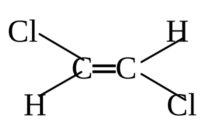
6. If two identical or substantial groups are on the same side of the double bond, the compound can be designated cis; if they are on opposite sides, it can be designated trans. For example,



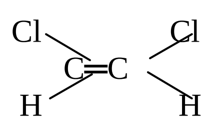
trans-2-butene



cis-2-butene



trans-1,2-dichloroethene



cis-1,2-dichloroethene

Naming Alkynes

Alkynes are named in much the same way as alkenes. According to Solomons and Fryhle (2008), to name an alkyne,

1. Replace the –ane of the corresponding alkane with the ending –yne**.**
2. Number the chain to give the carbon atoms of the triple bond the lower possible numbers.
3. Use the lower number of the two carbon atoms of the triple bond to designate the location of the triple bond. For example,

   $HC{\equiv}CH$

   Ethyne

   $CH_3CH_2C{\equiv}CH$

   1-butyne (or but-1-yne)

   $CH_3C{\equiv}CCH{=}CH_2$

   1-penten-3-yne (or pent-1-en-3-yne)

   It must be noted that where there is a choice, the double bond is given the lower number.
4. Assign numbers to the locations of substituent groups of branched alkynes.
5. Give priority to –OH group over the triple bond when numbering the continuous carbon chain. (p. 145). For example,

   $ClCH_2C{\equiv}CH$

   3-chloropropyne

   $CH_3C{\equiv}CCH_2Br$

   1-bromo-2-butyne (1-bromobut-2-yne)

$CH_3C{\equiv}CCH_2CH_2OH$

3-pentyn-1-ol (or pent-3-yn-1-ol)

Naming Carboxylic (Alkanoic) Acids

To name a carboxylic acid,

1. Select the longest continuous carbon chain containing the –COOH (solomons & Fryhle, 2008).
2. Replace the ending 'e' of the corresponding alkane name for the parent structure with 'oic' and the word 'acid' that is they are named as "alkanoic acids" (solomons & Fryhle, 2008).
3. Start the numbering from the carboxyl (-COOH) group as first carbon (solomons & Fryhle, 2008).
4. Any substituent group on the parent structure is named as usual. For example,

   HCOOH

   Methanoic acid

   CH_3COOH

   Ethanoic acid

   $CH_3CH(Br)COOH$

   2-bromopropanoic acid

   $CH_3CH{=}CHCOOH$

   2-butenoic acid

Naming Esters (Alkyl Alkanoates)

They are named by regarding them as alkyl derivatives of carboxylic (alkanoic) acids. Thus the name is obtained from a stem indicating the alcohol from which the ester is derived with suffix– 'yl'; follow by another stem indicating the acid, with the suffix- 'oate'. Hence, esters are commonly named as "alkyl alkanoates" (that is RCOOR'). Where R' is the alkyl from the alcohol and RCOO is the alkanoates from the alkanoic acid. Skonieczy (2006) explained that in naming an alkyl alkanoate, no hyphen is to be placed between the name of the alkyl group and that of the alkanoate group. For example,

$HCOOCH_3$

Methyl methanoate

CH_3COOCH_3

Methyl ethanoate

$CH_3CH_2CHCOOC_2H_5$
|
CH_3

Ethyl 2-methylbutanoate

$CH_2(Cl)COOC_6H_5$

Phenyl 2-chloroethanoate

APPENDIX B

ACHIEVEMENT TEST ON IUPAC NOMENCLATURE OF ORGANIC COMPOUNDS

Biographic Data

Gender: Male ☐ Female ☐

Age: ☐ years

Name of School: ……………………………………………………………

This achievement test seeks to find out your understanding of IUPAC nomenclature of organic compounds. Please provide the responses in the spaces provided. Your performance will be used for research purposes only. Your identity is not required, and therefore you are to respond to the items to the best of your ability. You will be given **60** minutes to respond to the items after which your paper will be collected.

SECTION 1

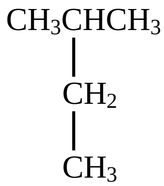
Give the correct IUPAC names of the following organic compounds:

1. $CH_3CH_2CH_2CH_3$

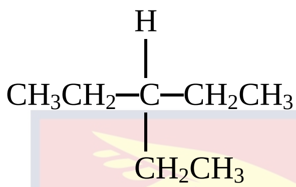
   ……………………………………………………………………………

2. $CH_3(CH_2)_6CH_3$

   ………………………………………………………………………………

3. 

……………………………………………………………………………………

4. 

……………………………………………………………………………………

5. $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$

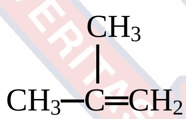
……………………………………………………………………………………

6. $CH_2{=}CHCH_2CH_2CH_3$

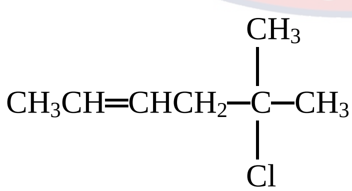
……………………………………………………………………………………

7. $CH_3CH_2CH_2CH{=}CHCH_3$

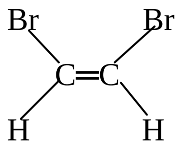
……………………………………………………………………………………

8. 

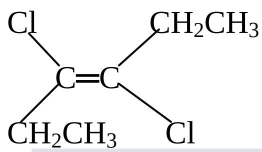
……………………………………………………………………………………

9. 

……………………………………………………………………………………

10. 

…………………………………………………………………………………....

11. 

……………………………………………………………………………………

12. $CH_2{=}CH{-}CH{=}CHCH_3$

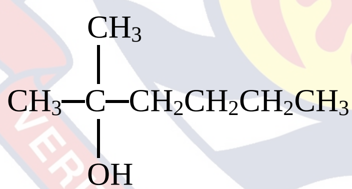
……………………………………………………………………………………

13. $HC{\equiv}CCH_2CH_3$

……………………………………………………………………………………

14. $CH_3CH_2CH_2OH$

……………………………………………………………………………………

15. 

……………………………………………………………………………………

16. $HOCH_2CH_2CH_2CH_2OH$

……………………………………………………………………………………

17. HCOOH

……………………………………………………………………………………

18.
```
       Br
       |
  CH3CCH3
       |
       COOH
```

…………………………………………………………………………………

19. CH_3COOCH_3

…………………………………………………………………………………

20.
```
       CH3
       |
  CH3CHCH2COOCH2CH3
```

…………………………………………………………………………………

SCETION 2

A. Write the correct **condensed** and **graphical** formulae for each of the following organic compounds:

1. Pentane

a. Condensed Formula **b. Graphical Formula**

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

2. Hex-3-ene

a. Condensed Formula **b. Graphical Formula**

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

3. Heptan-2-ol

a. Condensed Formula **b. Graphical Formula**

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

4. Pentanoic acid

a. Condensed Formula **b. Graphical Formula**

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

5. Methyl methanoate

a. Condensed Formula **b. Graphical Formula**

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

A. Write the structural formulae of the following organic compounds:

1. 2-fluoro-3,3-dimethylbutane

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

2. 4-ethyl-2,3-dimethylpent-2-ene

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

3. 2-methylpropan-1-ol

…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

4. 5-chloro-2-methylhexanoic acid

…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

5. Propyl-2- chloroethanoate

…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

APPENDIX C

STUDENTS' INTERVIEW GUIDE

1. Explain how you arrived at the IUPAC names you gave to the compounds.
2. Explain how you arrived at your condensed formulae.
3. Explain how you arrived at your graphical formulae.
4. Explain how you arrived at the structural formulae.

APPENDIX D

DETERMINATION OF KR 21 COEFFICIENT OF RELIABILITY

Table 32: Mean and Standard Deviation of Students' Scores

n	π	S	S^2
35	18.800	5.940	35.289

$$KR\ 21 = \left(\frac{n}{n-1}\right)\left(1 - \left\{\frac{[\pi(n-\pi)]}{nS^2}\right\}\right)$$

where n is the number of items, which is 35

π is the mean score, which is 18.800

S^2 is the variance, which is 35.289

$$KR\ 21 = \left(\frac{35}{35-1}\right)\left(1 - \left\{\frac{[18.8(35-18.8)]}{35(35.289)}\right\}\right)$$

$$= \left(\frac{35}{34}\right)\left(1 - \left\{\frac{(304.56)}{1235.115}\right\}\right)$$

$$= (1.029411765)\ (1-0.246584326)$$

$$= (1.029411765)\ (0.753415673)$$

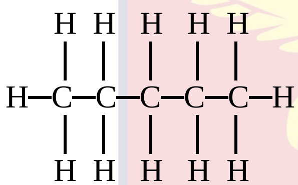
$$= 0.775574958$$

KR 21 = 0.8

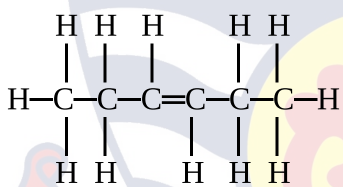
APPENDIX E

GRAPHICAL FORMULAE OF SOME ORGANIC COMPOUNDS

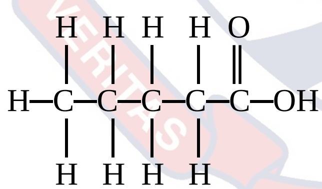
1. Pentane



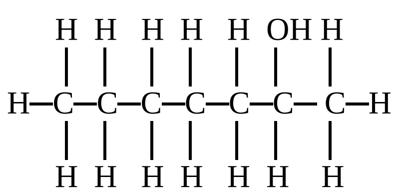
2. Hex-3-ene



3. Pentanoic acid



4. Heptane-2-ol



5. Methyl methanoate