Students' Difficulties in IUPAC Naming of Organic Compounds

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Abstract

This paper reports on a study that diagnosed the difficulties of chemistry students in using IUPAC nomenclature to name organic compounds. This was done by determining the knowledge level of students in IUPAC nomenclature of organic compounds. Students at the senior high school (SHS) level were involved in the study. A cross-sectional survey that employs mixed method approached provided the study with both quantitative and qualitative data. In all, 245 SHS4 chemistry students selected from four out of 18 schools who offered 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 from the study showed that students had difficulties in naming structural formulae of branched- and substituted-chains of alkanes and alkenes, geometrical isomers, dienes, unbranched alkynes, primary and tertiary alkanols, diols, alkanoic acids, and alkyl alkanoates. 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.

Keywords: Difficulties in IUPAC Naming, High School Chemistry Students, Organic Compounds, Structural Formulae

Introduction

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 (Mirzaie, Shahmohammadi, & Kouhi, 2010), 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_3OH or C_2H_6O) as a combination of letters and numbers rather than chemical formula (Wu, Krajcik, & Soloway, 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).

With respect to IUPAC nomenclature of organic compounds, the system has evolved with time and each molecule of organic compound is said to have a unique name. Gillette (2004) explained that the IUPAC system is built basically on atom or group of atoms which defines the chemical behaviour of the compound (that is the functional group). Skonieczy (2006) therefore identified that the first most important step in naming organic compound is to identify the presence of any functional group in the molecule of that compound. And in cases where there are more than one functional groups, recognition must be given to the principal group. Gillette (2004) wrote that any written IUPAC name of organic compound has three aspects. The root indicates the number of carbon atoms in the longest continuous carbon chain, which usually forms the parent name; the ending indicates the family or the functional group of the given organic compound; and the prefix indicates the number, position, and identity of any atoms or group of atoms in place of the hydrogen atom in a hydrocarbon. Gillette (2004) was emphatic about the fact that when students are able to learn to apply and

interpret these three aspects very well, they can name any given organic compound.

Wu, et al. (2001) 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 asked to name and draw the structure of a six-carbon atom compound with a side group. The difficulty of the high school chemistry students who participated in the study was said to have reduced reasonably resulting in high performance on IUPAC nomenclature of organic compounds. This is based on the fact that there was a 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).

The WAEC Chief Examiner's Reports in Ghana have repeatedly lamented on the difficulty of most students in answering examination's questions on IUPAC nomenclature of organic compounds in the West Africa Senior Secondary Certificate Examination (WAEC, 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2010). These reports suggest that Ghanaian SHS Chemistry students have challenges with the IUPAC naming of organic compounds. An empirical study of Adu-Gyamfi, Ampiah, and Appiah (2013) with Ghanaian SHS Chemistry students confirm that indeed students at the high school level show weak performance in IUPAC nomenclature of organic compounds. The students did show weak performance in naming and writing structural formulae of alkenes, alkynes, alkanols, alkanoic acids, and alkyl alkanoates. Such weak performance cannot be attributed to the school-type attended by the students. This is because there was no difference between the performance of the students from endowed and less-endowed schools in naming and writing structural formulae of organic compounds statistically. An endowed school in Ghana is a high school with high prestige, competitive academically and

capable of attracting students from all part of the country and a less-endowed school is a high schools considered to be less prestigious and weak in academics (Adu-Gyamfi et al., 2013). In a similar study, Adu-Gyamfi et al. (2012) reported that students had difficulties in writing structural formula of organic compounds. The difficulty is associated with students' inability to identify the carbon atoms in the parent or side chain, chemical symbol or formula of substituent groups from the given name. It was important therefore to find out whether such difficulty exist in naming of organic compounds using the IUPAC nomenclature and why Chemistry students are unable to use IUPAC nomenclature to name structural formulae of organic compounds for this problem to be addressed in a much broader perspective.

In this study therefore, students' difficulties in naming organic compounds using the IUPAC nomenclature system was diagnosed. To be able to achieve this, 20 test items were used to ascertain the knowledge level of the students in IUPAC nomenclature of organic compounds. This helped to recognise the nature of the difficulties and the reasons for such students' difficulties. The following research questions were used to guide the study:

1. What are students' difficulties in using the IUPAC nomenclature system to name structural formulae of organic compounds?
2. What is the basis of students' difficulty in using the IUPAC system to name structural formulae of organic compounds?

Methodology

Research Design

The study used the mixed method design employing both qualitative and quantitative methods (Cohen, Manion, & Morrison, 2005) 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. A quantitative methodology aspect of the design was used to collect data to answer research question on students' difficulty in using the IUPAC nomenclature system to name structural formulae of organic compounds. The qualitative methodology aspect of the design was to collect data to answer the research question on the reason behind students' difficulty in using the IUPAC nomenclature system to name structural formulae of organic compounds.

The survey design used for the study involves three stages. The achievement test and the basic interview items were constructed by the first author at the first stage of the survey. After the construction of the instrument, it was pilot-tested with SHS4 Chemistry students from one of the schools in Obuasi Municipality. The purpose was to help determine the level of difficulty of test items and to establish the reliability of the instruments. At the second stage of the survey, the achievement test was administered to SHS4 Chemistry students 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 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 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 in relation to the four-year SHS curriculum and they were in the better position to contribute to the study.

Sample

The sample consisted of 245 SHS4 elective science students. The sample was selected from four schools which offered elective science for the academic year, 2010/2011 in Kumasi Metropolis of Ashanti Region of Ghana. In each school, six students who took part in the study were further randomly 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 students in each school into three groups as: below the score of 10 marks, between the scores of 10-15 marks, and above the score of 15 marks out of 20 scores.

Instrument

The instruments for the study were achievement test and interview constructed by author$_1$. The achievement test consisted of 20 items, which were based on structural formulae of alkane, alkene, alkyne, alkanol, alkanoic acid, and alkyl alkanoate areas of organic compounds (Appendix A). Each correctly named structural formula was awarded one score. These test items were aimed at finding out the performance of students on naming structural formulae of organic compounds by IUPAC nomenclature. To ensure the validity of the achievement test, the items were compared to standardised questions on IUPAC nomenclature of organic compounds constructed by the WAEC for the West African Secondary School Certificate Examinations. The achievement test was further given to two experienced chemistry teachers for review. The purpose was also to ensure that the instrument was valid. The Kuder-Richardson (KR) 21 coefficient of reliability was established as 0.8. This was done after the instrument has been pilot-tested with 10 SHS4 Chemistry students from another high school outside the study zone.

Six students from each school were interviewed (Appendix B). A week after the scripts have been scored, author$_1$ returned to each school and interviewed the selected students. The students' interviews helped to establish the nature of the difficulties and the reasons for such difficulties in IUPAC naming of organic compounds.

Data Analysis

Both quantitative and qualitative data were obtained from the research instruments. The students' scores from the achievement test were used as quantitative data and the outcomes of the students' interviews in the form of explanations given by the students on the IUPAC names they provided to the compounds were used as the qualitative data. Percentages and graphs were used to analyse the quantitative data. The item difficulty index for each item was calculated to determine how difficulty each item was. The difficulty index of each item was calculated by relation $P = R/T$. Where R is the correct number of responses under each item and T is the overall total number of responses (which were correct, incorrect, and blank responses). It was therefore considered that the higher the index value the less difficult the item and the lower the index value the difficult the item (Matlock-Hetzel, 1997; Mitra, Nagaraja, Ponnudurai, & Judson, 2009; Sim & Rasiah, 2006). For the purposes of this study, an index below 0.4 showed the item was difficult and an index of 0.8 was a less difficult item.

Under the qualitative data, the students' explanations were transcribed and meanings were made from them. From the meanings we made, themes were formed which helped to appreciate the nature and reasons for students' difficulties in IUPAC naming of organic compounds.

Results

The results of the study were presented in two stages. At the first stage, the difficulties of students in naming structural formulae of organic compounds were determined through the scores obtained by the students in the achievement test. The explanations given by students on the names they provided for each compound were presented and discussed at stage two.

Research Question 1 sought to find out students' difficulties in naming of 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 1 show that some items were not difficult whereas others were difficult.

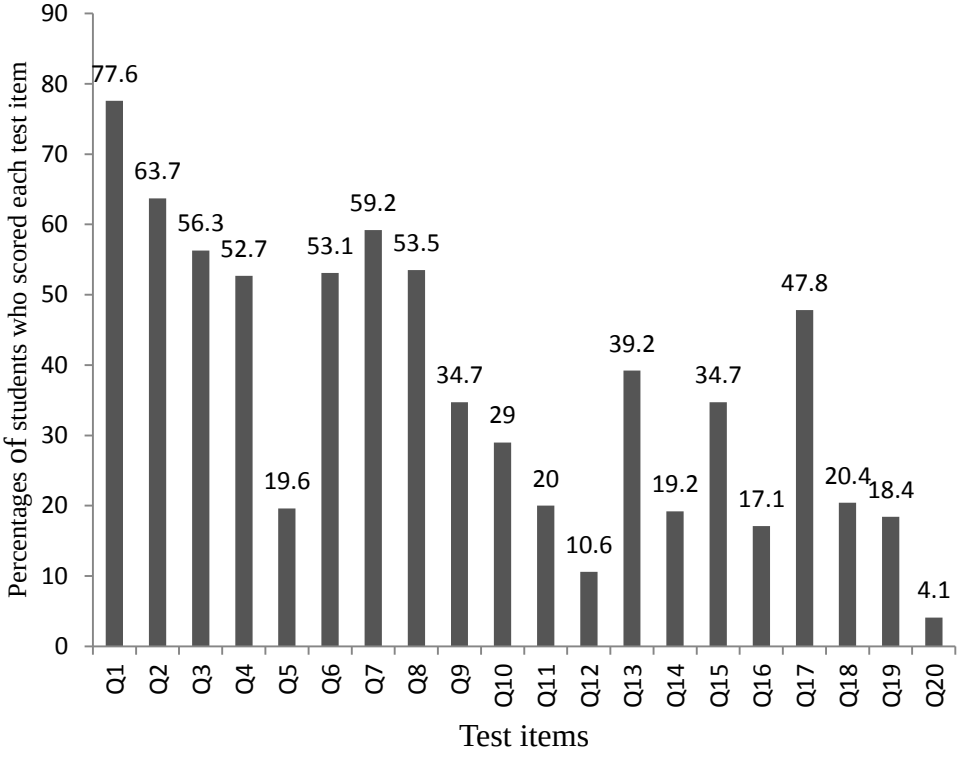

Figure 1. Bar chart of students' performance on naming organic compounds using the IUPAC nomenclature system.

The difficult items were those where less than 50.0% of the students provided the correct IUPAC names. As seen in Figure 1, 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. The findings show that students found it difficult to name any branched- and substituted-chain alkane, alkene, diene, geometrical isomer, unbranched alkyne, alkanol, diol, alkanoic acid, and alkyl alkanoate.

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. For the purpose of this paper, students' difficulties and the reasons for the difficulties in naming organic compounds were presented and discussed in the areas of alkanes, alkenes (as hydrocarbons), and alkanols (non-hydrocarbons) after which a generalisation was made to cover the other areas of organic compounds.

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 1, 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 the 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. Table 1 presents the wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of $(CH_3)_2CHCH(Cl)CH(CH_3)CH_2CH_3$.

Table 1: 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

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 1, 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.

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 identify the Cl as a substituent and only 8.3% of the students could not identified 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 substituent 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-CH=$CHCH_3$. The findings from Figure 1 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 approximately as 0.4. This is because 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 2.

Table 2: 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

The names in Table 2 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. 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 of the molecule 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. According to one of the students, *the least position should always be given to the substituent groups*. 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 1, 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 3 presents the

wrong names and percentages of the 24 students who were interviewed on the IUPAC name of cis isomer of BrCH═CHBr.

Table 3: 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, only 12.5% of the students did not provide any name for the cis isomer of BrCH═CHBr. One of the students among those who could not provide the correct IUPAC name said: *I just cannot answer this question. It is difficult to me*. 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 3, 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 demanded 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 1, only 20.0% of the 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 4 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 4: 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 4, 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 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 same 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-CH=$CHCH_3$. The findings in Figure 1 mean that only 10.6% of the students gave the correct IUPAC name of CH_2=CH-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-CH=$CHCH_3$. This is because the item's difficulty index was calculated as 0.1. Some wrong names provided and the percentages of the 24 students who were interviewed on the IUPAC name of CH_2=CH-CH=$CHCH_3$ are presented in Table 5.

Table 5: 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

An overall 33.3% of the students failed to provide any response on the IUPAC name of CH_2=CH-CH=$CHCH_3$. The names in Table 5 show that half of the students (50.0%) interviewed identified correctly the number of carbon atoms in the longest continuous carbon chain. 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% of the 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.

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 1, 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 1 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 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 6.

Table 6: 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

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 and from the interviews it was realised that the students were comfortable with the structure of the molecule as 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.

In the case of the –OH functional group, from Table 6, 83.3% students identified it correctly as hydroxyl group and therefore named it as –ol. However, 50.0% of the 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 1, 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 7.

Table 7: 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 7, 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 1 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 8 presents wrong names provided and the percentages of the 24 who were interviewed on the IUPAC name of $HOCH_2CH_2CH_2CH_2OH$.

Table 8: 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 8 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 8, 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.

Discussion

The findings that the students have difficulty in naming the various classes of structural formulae of organic compounds used in this study show that indeed Ghanaian students achieve low in IUPAC nomenclature of organic compounds (Adu-Gyamfi et al., 2013). Such students' low achievement is not limited to one particular class of organic compounds but across most of the classes. Chemistry educators are therefore encouraged to take a critical look at the nature and reasons of the students' difficulties identified by the current study in order to adopt the appropriate instruction to help students overcome the difficulties in naming structural formulae of organic compounds.

The findings from the study reveal that the students' difficulties in naming structural formulae of organic compounds are in three areas as the root, ending, and prefix (Gillette, 2004); which from the current study are respectively seen as number of carbon atoms in the continuous carbon chain, functional groups, and substituents. This means that the students could not appreciate that IUPAC names are formed from the three parts of organic molecules. With a good knowledge of the concept of the parent chain, one could name the parent molecule with respect to the number of carbon atoms in the longest continuous carbon chain. The difficulty in identify the continuous carbons chain usually occurred with branched-chain molecules, which are organic compounds with substituent groups.

Students being able to identify the family (ending) of the given molecule gives an indication that the students have identify the functional group present in the molecule, which is said to be an important first step in naming organic compound (Skonieczy, 2006). A difficulty in identifying the functional group of an organic compound means that the individual student will fail to provide the correct parent name of such compound as well as the locant of the functional group.

The findings that students are unable to identify and name substituent groups correctly with respect to its number and position could suggest that branched-chain organic molecules are difficult for students to conceptualise and that the students usually meet simple structural formulae of organic compounds without the substituent groups in their teacher-led examples. The difficulty with identification and naming of the substituent is more apparent when the given structure is of condensed formula type where all covalent bonds connecting all atoms are removed and parenthesis is used to show substituent groups.

Conclusions

The study has confirmed the study of Adu-Gyamfi et al. (2012) where students show difficulty in using IUPAC nomenclature under organic compounds. The previous study is on writing structural formulae of organic compounds and the current study is on naming structural formulae of organic compounds. This is an indication that there is similar student difficulty in naming and writing structural formulae of organic compounds using the IUPAC nomenclature system. The study has showed that the 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. This could be that students are not exposed to more examples on these areas with varying degree of difficulty. Therefore chemistry teachers should provide students with varying examples of structural formulae of organic compounds to reduce students' difficulties in naming these areas.

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 (the root), identify substituent or functional groups (the ending), assign the right positions to the substituent group (the prefix), 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 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.

Some of the students' difficulties could have been minimised or eliminated completely if students encounter more than one form of the structure. For instance, when a number of examples of dienes or diols are used, students would appreciate that more than one multiple bond or hydroxyl group (or functional group) can occur in some molecules of organic compounds. And that not all groups in parenthesis such as (CH_3-) and (-OH) attach to the molecule of organic compounds are substituents.

Recommendations and Suggestions

As the Chemistry students had difficulty in naming the root, ending, and prefix of organic, students should be provided with opportunities to enable them attempt to name structural formulae of varying examples of organic compounds that could help them to identify the correct number of carbon atoms in a parent chain, use the correct root and substituent names, correct positions, suffixes, and prefixes of substituents and functional groups in new situations. Class and group discussions on correct IUPAC name of any given structural formula of organic should be held to enable students consolidate their strengths and polish on their weaknesses.

The current study only diagnosed the students' difficulties in naming structural formulae of organic compounds. However, the study did not consider the Chemistry teachers' difficulties in teaching and their own understanding of IUPAC nomenclature of organic compounds. It is therefore recommended that a future research work is conducted into these issues.

Since the current study was across sectional survey and only identified students' difficulties, it is recommended that Chemistry educators and researchers should develop (if possible) some instructional materials that could be used to instruct SHS Chemistry students to help overcome the identified difficulties in naming structural formulae of organic compounds.

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APPENDIX A

ACHIEVEMENT TEST ON IUPAC NOMENCLATURE OF ORGANIC COMPOUNDS

Biographic Data

Gender: Male ☐ Female ☐

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.

Give the correct IUPAC names of the following organic compounds:

1. $CH_3CH_2CH_2CH_3$

   ……
   ……

2. $CH_3(CH_2)_6CH_3$

   ……
   ……

3. CH_3CHCH_3
   $\quad\quad\;\;|$
   $\quad\quad CH_2$
   $\quad\quad\;\;|$
   $\quad\quad CH_3$

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   ……

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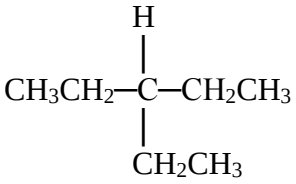
4. 

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

6. $CH_2{=}CHCH_2CH_2CH_3$
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7. $CH_3CH_2CH_2CH{=}CHCH_3$
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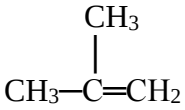
…….

8. 

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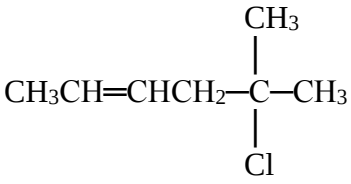
9. 

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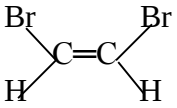
10. 

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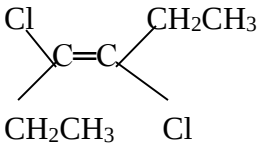
11. 

……
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12. $CH_2{=}CH{-}CH{=}CHCH_3$

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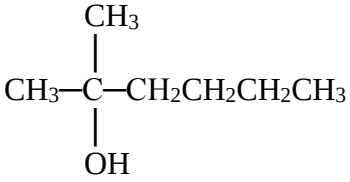
13. $HC{\equiv}CCH_2CH_3$

……
……

14. $CH_3CH_2CH_2OH$

……
……

15. 

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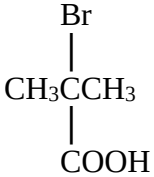
16. $HOCH_2CH_2CH_2CH_2OH$

……
……

17. HCOOH

……

18. 

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19. CH_3COOCH_3

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20. 

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APPENDIX B

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.