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Senior High School Students' Difficulties in Writing Structural Formulae of Organic Compounds from IUPAC Names

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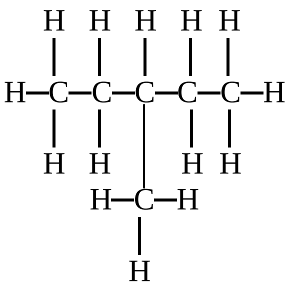
Abstract

The difficulties of the Chemistry students from Kumasi Metropolis in writing structural formulae of organic compounds were studied using cross-sectional survey design. The quantitative survey used percentages and graphs to analyse the quantitative data obtained from an achievement test and interview and the qualitative survey was used to analyse the explanations given by students on the structural formulae provided for the organic compounds. Students had difficulties in writing structural formulae of alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoates. The difficulties of students in writing structural formulae of organic compounds from the IUPAC names could be attributed to students' inability to identify from the IUPAC names 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 students' difficulties in writing the structural formulae of organic compounds having been identified, Chemistry teachers are therefore encouraged to hold class discussion with students after each class exercise on IUPAC nomenclature to enable them identify these weaknesses and work on them.

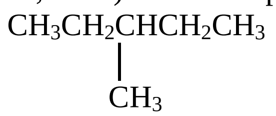
Keywords: Chemistry students, difficulties, IUPAC names, organic compounds, structural formulae

Introduction

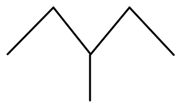
Gillette (2004) revealed that there are three ways of representing the IUPAC names of organic compounds with structural formulae. The first is the Lewis structure (referred to as expanded structural formula). The Lewis structure shows all the carbon and hydrogen atoms together with any other atom or 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).

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).

Cracking the Code

According to Gillette (2004), "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/are happening on the first and second carbon atoms in the longest continuous carbon chain (Clark, 2000).

Counting the Carbon Atoms

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 Eight Groups of Carbon Atoms

Code	Number of Carbons
Meth	1
Eth	2
Prop	3
But	4
Pent	5
Hex	6
Hept	7
Oct	8

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

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. According to Clark (2000), 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.

The findings of Baah (2009) from his study conducted at the New Juaben Municipality of the Eastern Region of Ghana with 334 Senior High School form 3 Chemistry students 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 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 trioxocarbonate(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.

Wu, Krajcik, and Soloway (2001) have revealed that Chemistry students have difficulty in writing structural formulae of organic compounds such as CH_3CH_2OH because they see them as a combination of letters and numbers. After a 6 week period of the use of eChem with 71 eleventh grade students of small public high school in a midsize university town in the Midwest, Wu, et al. (2001) found that students' difficulty in writing structural formulae of organic compounds has minimised. This is because 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).

The WAEC Chief Examiner's Reports in Ghana have showed that students found it difficult to answer 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 show that Ghanaian students are faced with a challenge in writing structural formulae of organic compounds from IUPAC names. It is important therefore to investigate why students are unable to write structural formulae of organic compounds from IUPAC names.

Purpose of the Study

The study sought to diagnose the difficulties of students in writing structural formulae of organic compounds from IUPAC names. This was done by determining the knowledge level of students in IUPAC nomenclature of organic compounds using five test items. The nature of the difficulties and why students have those difficulties were then investigated. The study was guided by the following research questions:

1. What difficulties do students have in writing structural formulae of organic compounds by IUPAC nomenclature?
2. What accounts for students' difficulty in writing structural formulae of organic compounds by IUPAC nomenclature?

Methodology

Sample

In this study, the sample was drawn from four out of the 18 schools who offered elective science for the academic year, 2010/2011 in Kumasi Metropolis. The number of students present in each school who participated in the study is presented in Table 3. A total of 245 students were involved in the study.

Table 3: Number of Students from each School who participated 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

Six students each were further selected from each of the four schools to participate in an interview section of the study. The selection of the 24 students for interview was done by stratifying the scores of students in each school into two groups as: below the score of three marks and score of three marks and above. The maximum score was five marks.

Instrument

The instruments for the study were achievement test and interview. The achievement test was designed by the researchers and given to two Chemistry teachers from Obuasi Senior High School where the instrument was pilot-tested for the face and content validation. The instrument was pilot-test with 10 SHS 4 Chemistry students. The Kuder-Richardson (KR) 21 coefficient of reliability was established as 0.8. There were five test items on the achievement test which was administered to the 245 students. Any correct response to each item carried one mark.

An interview with one student at a time was conducted with six students from each school a week after the scripts have been scored. The purpose was to find out the students' reasons for supplying such answers to the test items using the IUPAC nomenclature system.

Data Analysis

Quantitative data were generated from the scores of the students while qualitative data were generated from the explanations given by the students who were interviewed on the structural formulae provided based on the IUPAC names. Hence, the study used mixed methods in the data analysis. The quantitative data were analysed with percentages and graphs. Qualitative analysis was done on the explanations provided by the 24 students on the structural formulae provided for each IUPAC name.

Results

The results of the study were presented in two stages. The difficulties of students in writing structural formulae of organic compounds from IUPAC names were determined through the scores obtained by the students and the number of students who scored each item on the achievement test at stage one. The explanations given by students on structural formulae provided for each compound during the interview were presented and discussed at stage two.

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

The test items sought to find out the SHS Chemistry students' difficulties in writing structural formulae of organic compounds from IUPAC names. The IUPAC names of the compounds used 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 1 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.

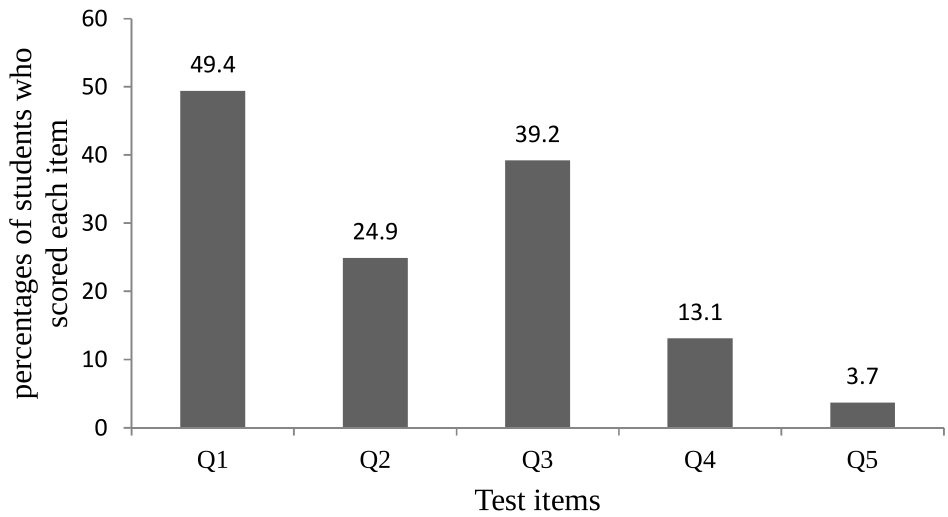


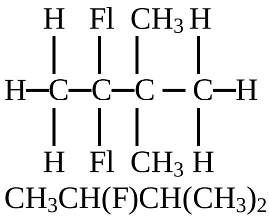
Figure 1. Bar chart of students' performance on writing structural formulae of organic compounds using the IUPAC nomenclature system.

2-fluoro-3,3-dimethylbutane

The findings in Figure 1 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 4.

Table 4: Wrong Structural Formulae of 2-fluoro-3,3-dimethylbutane given by Some Students (N = 2)

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

N is the number of students among the 24 students interviewed who could not provide the correct structural formula of the compound.

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 4, 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 4, 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.

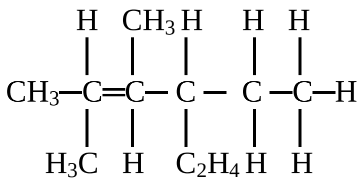
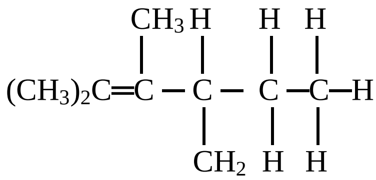
In summary, the main difficulties of students who could not write the correct structural formula of 2-fluoro-3,3-dimethylbutane were their inability to:

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 1, 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 5.

Table 5: 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

The formulae given in Table 5 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.

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 1 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 6 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 6: 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
H H H | | | H–C–C–C–OH | | | H H H	2	8.3
H CH_3 H | | | H–C–C– C–OH | | | H CH_3 H	1	4.2
$CH_2(OH)CH(CH_3)CH_2CH_3$	1	4.2
H H | | H–C≡C–OH | | H CH_3	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 6, 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 6, 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 1, 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 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 7.

Table 7: 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 7, 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 7, 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 1 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 8 presents some wrong formulae provided and the percentages of the 24 students who were interviewed on the structure formulae of propyl 2-chloroethanoate.

Table 8: Wrong Structural Formulae of Propyl 2-chloroethanoate given by Some Students (N = 4)

Formula given by students	N	%
$\begin{array}{ccccccc} & & \mathrm{Cl} & & \mathrm{O} & & \\ & & \vert & & \Vert & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{OH} \\ & & \vert & & & & \\ & & \mathrm{H} & & & & \end{array}$	2	8.3
$\begin{array}{ccccc} & & \mathrm{O} & & \\ & & \Vert & & \\ \mathrm{CH_3} & - & \mathrm{C} & - & \mathrm{OCH_2CH_2CH_3} \end{array}$	1	4.2
$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & \vert & & \vert & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C{\equiv}COOH} \\ & & \vert & & \vert & & \\ & & \mathrm{H} & & \mathrm{Cl} & & \end{array}$	1	4.2

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 8, 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.

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.

Conclusions

The study has shown that the students had difficulties in writing structural formulae of organic compounds from the IUPAC names of alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoates. This could be that students are not conversant with the names of the three parts of each organic molecule. Chemistry teachers should therefore provide students with the opportunity to learn to apply and interpret the names of the three parts of organic molecules using the IUPAC nomenclature system.

In this study, what accounts for 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 students could not work backwards from the IUPAC name to the structural formula of any given organic compound.

Recommendations

As students had difficulties in writing structural formulae of organic compounds from IUPAC names of alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoates, it is therefore recommended that Chemistry teachers should provide students with more worked examples in these areas.

Since the students' difficulty in writing structural formulae of organic compounds from IUPAC names was partly due to their inability to identify the correct number of carbon atoms in the carbon chain, Chemistry teachers are therefore encouraged to hold class discussion with students after each class exercise on IUPAC nomenclature to enable them identify this weakness and work on it.

References

Baah, R. (2009). *Senior secondary school students' understanding of chemical formulae and chemical equations.* Unpublished master's thesis, University of Cape Coast, Cape Coast.

Bello, O. O. (1988). An analysis of students' error in stoichiometric problems. *Nigerian Education Forum, 11*(2), 181-186.

Clark, J. (2000). *The names of organic compounds.* Retrieved October 14, 2010, from http://www.chemguide.co.uk/basicorg/conventions/names.html.

Gillette, M. L. (Ed.). (2004). *Introducing IUPAC nomenclature for organic chemical compounds.* Retrieved October 08, 2010, from http://www.cerlabs.com/ experiments/1053447599X.pdf.

Hines, C. (1990). Students' understanding of chemical equations in secondary schools in Botswana. *School Science Review, 72*(285), 138-140.

The West African Examinations Council [WAEC]. (2000). *Chief examiners' reports: November/December senior secondary school certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2001). *Chief examiners' reports: July/August senior secondary school certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2002). *Chief examiners' reports: July/August senior secondary school certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2003). *Chief examiners' reports: July/August senior secondary school certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2004). *Chief examiners' reports: November/December senior secondary school certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2005). *Chief examiners' report. General science programme*: *July senior secondary school certificate examination.* Accra: WAEC.

The West Africa Examinations Council [WAEC] (2006). *Chief examiner's report. General science programme: May/June west africa senior secondary certificate examination.* Accra: WAEC.

The West Africa Examinations Council [WAEC]. (2007). *Chief examiner's report. General science programme: May/June west africa senior secondary certificate examination*. Accra: WAEC.

The West African Examinations Council [WAEC]. (2010). *Chief examiners' reports: November/December west africa senior secondary certificate examination.* Accra: WAEC.

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38* (7), 821-842.

Woodcock, D. (1996). *An introduction to basic organic nomenclature*. A paper presented at the Department of Chemistry, Okanagan University College, Okanagan.