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Teachers' Conceptual Difficulties in Teaching Senior High School Organic Chemistry

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ABSTRACT

Teachers are one of the important factors influencing students' learning of chemistry as they (teachers) transform the content for students. When teachers do not have a sound scientific understanding of the chemistry behind the organic concepts considered to be difficult, they are likely, not able to transform sound scientific understanding for their students. Hence, the need to examine the conceptual difficulties of teachers in teaching organic chemistry to senior high school students. Teachers, teaching chemistry in 31 schools were sampled through multi-stage sampling procedures and responded to a diagnostic test on organic chemistry. The data from the test were manipulated using quantitative and qualitative methods, such as means, standard deviations, percentages, and themes. The quantitative results were merged with the qualitative results to examine teachers' conceptual difficulties in organic chemistry. The findings showed that teachers have conceptual difficulties with organic chemistry. This study has added to the literature that teacher conceptual difficulties were partial understanding with misconceptions such as preconceived notions, factual misconceptions, and conceptual misunderstandings. Therefore, in order to deal with those misconceptions, chemistry educators should implement instructional approaches that will help pre-service teachers challenge and deal with their misconceptions in organic chemistry.

Keywords: conceptual difficulties, misconceptions, organic chemistry, teachers

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INTRODUCTION

One general aim of teaching chemistry in the senior high school (SHS) in Ghana is to encourage an investigative method in the teaching and learning of chemistry and make chemistry teachings, problem-solving in nature. The scope of the content of Ghana's SHS chemistry curriculum is thus designed to achieve three principal objectives providing sufficient chemistry to students who:

(a) will terminate their chemistry study at the SHS level,

(b) need chemistry knowledge in their vocational studies, and

(c) wish to pursue their chemistry studies at the tertiary institutions (Ministry of Education [MOE], 2010).

To ensure uniformity and direction toward these objectives, the content of the curriculum and textbooks is organized along the branches of chemistry as; physical, inorganic, and organic chemistry (Ameyibor & Wiredu, 2006; MOE, 2010).

The relevance of organic chemistry cannot be underestimated. Its impact on modern science and technology as well as on our ideas and on our lives and the world today is difficult to exaggerate (Chang & Goldsby, 2016). From the food we eat (carbohydrates, proteins, fats, and oils) to the clothing that we wear, plastics, and drugs that we take, all of them have their roots embedded in organic chemistry (MOE, 2010). Household items such as soaps, plastics, televisions, radios, books, and computers would not exist without organic chemistry (Ebbing & Gammon, 2017; MOE, 2010). As a result of the relevance of organic chemistry, in Ghana, it is taught to all SHS students as a core in the integrated science and as an aspect of elective chemistry (MOE, 2010). As a major science discipline, its knowledge will serve as a pre-requisite for the study of any science- or technology-related disciplines such as medicine, pharmacy, engineering, agriculture, physics, geology, and ecology (Chang & Goldsby, 2016). Simply, its teaching and learning will improve our lives and enhance sustainable development.

Although the importance of chemistry is indisputable, organic chemistry has been reported widely by researchers and chemical educators as being difficult (Chang & Goldsby, 2016; Childs & Sheehan, 2009; Salame et al., 2019). Chemistry (for that matter organic chemistry) is often considered a difficult subject and this observation has repelled learners from progressing with their studies in chemistry (Salame et al., 2019; Sibomana et al., 2021; Sirhan, 2007). Research has identified some areas of organic chemistry such as drawing and representing organic compounds (Johnstone, 2006; Taber, 2002), naming and writing structural formulae of organic compounds using the IUPAC nomenclature system (Adu-Gyamfi et al., 2012, 2017, 2020), isomerism (Schmidt, 1992), properties of organic compounds

(Anderson & Bodner, 2008), and aromatic compounds (Ealy & Hermanson, 2006) as difficult areas for students.

Consequently, the teaching and learning chemistry (organic chemistry) have become a great concern to educationists and researchers. Much research efforts have been made to identify the difficulties associated with chemistry teaching and learning so as to proffer solutions that could result in better achievement (Omwirhiren & Ubanwa, 2016; Sirhan, 2007; Uce & Ceyhan, 2019). The factors that hinder students' achievement in chemistry are student-related factors, such as their background problems, lack of interest, and/or negative attitude towards chemistry, and teacher-related factors such as poor teacher preparation and teaching strategies, and inadequate qualified chemistry teachers and instructional materials (Usman, 2011). More extensive work on the factors causing students' difficulties in studying organic chemistry is the one conducted by O'Dwyer and Childs (2017). O'Dwyer and Childs (2017) reported from summaries of several related pieces of literature that extrinsic factors (for example, the multidimensional nature of chemistry, its complex language, relationship with mathematics, laboratory work, and chemical curricula) and intrinsic factors (for example, cognitive ability, attitudes to learning, and misconceptions) contribute to students' difficulties in learning organic chemistry.

Other chemical education researchers found that the difficulties in assisting students on how they learn chemistry (organic chemistry) are associated with the subject and its concepts (Ellis, 1994; Johnstone, 1991, 2010). For instance, there are always three challenges facing those studying chemistry; a lack of algorithm, a desire for three-dimensional imagery, and an extensive new vocabulary (Ellis, 1994), and these difficulties emanate because the subject and its concepts have a distinct vocabulary (Chang & Goldsby, 2016). Chemistry concepts are abstract (with organic chemistry being no exception) and thus, require learners to think in three domains (Johnstone, 1991, 2010). These domains are the macroscopic domain (that is what is tangible and visible, for example, a beaker of an ethanoic acid or ethanol); the sub-microscopic domain (that is, what is molecular and invisible, for example, ethanoic or ethanol atoms and bonds); and the symbolic domain (that is, chemical formulas, equations, diagrams, for example CH_3COOH and C_2H_5OH displaying ethanoic or ethanol atoms and molecules). Simply, high cognitive demand is required to study organic chemistry. A learner with little or no prior knowledge of organic chemistry would have difficulty understanding a combination of these dimensions or even one of the dimensions (O'Dwyer & Childs, 2017). Teachers would be left with the hard task of drawing relations between the microscopic and macroscopic world. Thus, the teacher would have a herculean task in guiding learners to learn (Quadros et al., 2011).

Notwithstanding the aforementioned challenges associated with the subject, teachers have a role to play in addressing them (Stojanoyska et al., 2020). Because they are seen as catalysts of the expected changes (Nbina, 2012). According to Okorie and Akubuilo (2013), teachers are the classroom managers; they direct what is going on in the classroom and guide students based on their knowledge, comprehension, and analysis of the curriculum theory, goals, content, and the prescribed pedagogical approach to its implementation. The success of an educational program correlates with the strength of the teachers in the system. Thus, the quality of teaching organic chemistry in the schools cannot rise above the quality of the chemistry teachers. Therefore, "there's very little doubt in anyone's mind that teachers can, conceivably, have a tremendous impact on students' interest and performance in the sciences" (National Research Council, 2009, p. 9). What would be of concern is conscious effort needs to be made to identify the specific problems the teacher faces in their quest to ensure effective curriculum implementation. Thus, paying attention to teachers' difficulties in assisting students in studying organic chemistry will be a good way of addressing students' weak performance in organic chemistry.

For far too long, research has been directed to students. For instance, research to find out; what students say about teaching and learning chemistry (Donkoh, 2017), the effect of peer-led guided inquiry on students' performance (Ogunleye & Bamidele, 2013), how the use of demonstration and lecture methods enhance students' performance on chemistry (Omwirhiren, 2015), students' misconceptions in chemistry (Omwirhiren & Ubanwa, 2016; Taber, 2002), students' challenges in learning organic chemistry (Salame et al., 2019), and the efficacies of cooperative learning approach, learning activity package, and lecture method on enhancing chemistry students' academic retention (Udu, 2019).

Johnstone (2010) reported that despite the numerous research done over the last 40 years, many of the problems identified in the 1970s are still there. Johnstone (2010) added that we have produced professional teachers, teaching and learning resources, recommended teaching strategies, and elaborate explanations of the psychology of learning, but our students are still leaving us in the 'disappointment' and 'disillusionment' that we had hoped not to see. Hence, teachers' difficulties in teaching cannot be ignored. According to Mudau (2013), where there is a perception of teaching difficulties that hampers meaningful learning, we must find ways of identifying those difficulties to influence meaningful learning of science positively.

Shulman (1986) noted that research tends to ignore the issues that teachers face, and these issues influence students' performance. Shulman (1986) raises several questions including: How does the novice teacher, or even the 'seasoned veteran', make good use of the content in the teaching process? What pedagogical prices are paid when the content of the teacher's competence is itself compromised by a lack of prior education or skills? How do the teachers decide what to teach or how to represent it? Hanson (2017) stated that often, weak performance is blamed on students because of their low retention capabilities, low motivation, low achievement, inappropriate social groups in school, and parental issues, but teachers have a part to play in students' performance. This is because, in the teaching and learning process, the teacher influences students' attitudes towards the study of the content (chemistry). Students' conception of organic chemistry is dependent on the teaching effectiveness measured in terms of the knowledge of what to teach, how to teach it, and when to teach it (Archibong, 2009).

Okorie and Akubuilo (2013) reported that students' poor performance in chemistry has often been related to the teacher's poor knowledge of the curriculum, the foundation upon which students' learning is grounded. The 21st-century teachers are expected to possess pedagogical content knowledge, discipline-based knowledge, and curriculum content and context knowledge. These knowledge dimensions are important for teachers to provide lessons to students effectively and efficiently and the lack of any aspect of this knowledge would bear on the efficiency of teachers (Okorie & Akubuilo, 2013). This perhaps might explain what Donkoh (2017) found that students had an interest in studying chemistry but perceived that their teachers were nervous and afraid of teaching organic chemistry. In other instances, chemistry teachers who taught organic chemistry concepts do not teach the content to students' understanding, and teachers rush through the content. Thus, teachers' posture toward organic chemistry content made it difficult for students.

Although students have misconceptions about organic chemistry, 67% of the students hold that organic chemistry is exciting and simple while 64% like organic chemistry more compared with other branches of chemistry (Omwirhiren & Ubanwa, 2016). However, while some teachers made organic chemistry teaching interesting and fun, helping students develop a positive attitude towards learning organic chemistry, others made it uninteresting and boring making students develop a negative attitude with weak performance in the concept (Omwirhiren & Ubanwa, 2016). Hence, Omwirhiren and Ubanwa recommended that organic chemistry teaching and learning in the SHS should be supported to help provide a good chemistry background for students. Besides, an early introduction of organic chemistry to students will enhance its coverage and, as much as practicable, a separate teacher who has the experience and adequate content knowledge of chemistry should be made to teach organic chemistry. Because a greater percentage (80%) of teachers, although have knowledge about the chemistry curriculum, did not follow the recommended pedagogical strategies in implementing the chemistry curriculum (Okorie & Akubuilo, 2013).

According to Holbrook (2005), chemistry teaching is controversial and meaningless to students, unable to encourage higher-order cognitive abilities, what teachers are teaching, and what students want to know are different and chemistry teaching does not improve because teachers are afraid and therefore, require professional development. Rocard et al. (2007) asserted that challenges and concerns of [chemistry] education is a result of how [chemistry]-related subject and courses are taught in classrooms. This assertion, therefore, leaves us with numerous questions about the where what, and how of the effective teaching of organic chemistry to students.

The key determinants of student success hinge on the teacher quality and quality of instruction (Klieme et al., 2009; Seidel & Shavelson, 2007). The teacher's instructions and students' outcomes (for example, achievement) are influenced by the quality of the teacher which includes their qualifications (such as teacher's educational level, experience, involvement in professional development) and other characteristics (for example the teachers' belief, self-efficacy, and motivation) (Goe, 2007). This professional preparedness and competence (Watson et al., 2007) are essential in forming quality conceptual knowledge in students (Stojanoyska et al., 2020). The lack of qualified teachers in Brazil is one of the major current problems, especially in the case of exact science teachers, such as chemistry (Araujo & Santos, 2018). There is a need for qualified chemistry teachers to be in schools and colleges to offer good teaching and bring about better-quality education (Araujo & Santos, 2018). Teacher quality and the experiences of the teacher have a significant effect on student achievement (Rockoff, 2004). In this regard, Nbina (2012) recommended the need for effective and efficient teachers who are both professionally and academically qualified to help promote chemistry education in schools.

Metz (1997) asserted that improvement of the curriculum is partly dependent on the quality of teaching and the general improvement of the educational process in schools and giving continuous professional development is the key (Abreh, 2018; Watson et al., 2009). To other researchers, using information and communication technology in teaching (Ardac & Akaygun, 2004; Barbour & Reeves, 2009; Carvalho-Knighton & Keen-Rocha, 2007; Keziah, 2011), provision of instructional materials, improvement of textbooks and the working conditions (Vosniadou et al., 2001) are key to effective teaching and learning. Amongst the above, teacher conceptual difficulties have not been sufficiently considered and there was, therefore, the need to find out teacher conceptual difficulties in organic chemistry to inform effective teaching of the concept. Hence, this research examined conceptual difficulties teachers have in teaching organic chemistry to the understanding of SHS students. To achieve this, the research question that guided this research was: What conceptual difficulties do teachers have in teaching a SHS organic chemistry?

RESEARCH METHODS

Research Design

The research design employed in this research was a convergent mixed methods design. This was because first, we needed to collect both quantitative and qualitative data on teacher conceptual difficulties in organic chemistry from all teachers involved in the research. For this reason, the questionnaire variant of convergent mixed methods was, specifically, employed in this research (Creswell & PlanoClark, 2018). Also, it supported the collection of both quantitative and qualitative data on teacher conceptual difficulties in organic chemistry at the same time using a test, structured with open- and closed-ended items. Then, the quantitative data on conceptual difficulties were analyzed independently using means, standard deviations, and percentages. The qualitative data was analyzed using thematic analysis to establish any conceptual difficulties and misconceptions. After the analysis, the quantitative results on conceptual difficulties in organic chemistry were merged with the qualitative results. This was achieved through the direct comparison of the quantitative results on teacher conceptual difficulties to the qualitative results through discussion. Lastly, the findings were related to creating a better picture of teacher conceptual difficulties in teaching organic chemistry to SHS science students.

Sample and Sampling Procedure

The study was conducted in the Upper East Region of Ghana. The Upper East Region was one of the 16 administrative regions of Ghana with a population of 1,301,221 inhabitants (being 4.2%), a land area of 8,842 km^2, density 147.3/$km^{2,}$ and lay between longitude 0° and 1° West, and latitudes 10° 30'N and 11°N (Ghana Statistical Service, 2021). The region shared boundaries with Burkina Faso to the North, Togo to the East, Upper West to the West, and Northeast to the South. Administratively, the region was divided into 15 assemblies as four municipalities and 11 districts, corresponding roughly with the main tribal groupings: the Mole-Dagbon, Grusi, Mande-Busanga, and Gurma. Among the Mole-Dagbon, the Nabdam, Kusasi, Nankani/Gurense, and Builsa were popular. The popular other subgroups were the Kassena among the Grusi, the Busanga among the Mande-Busanga, and the Bimoba among the Gurma. The ethnic group distributions across the districts however varied, depending on the base district of the ethnic groups. Some of the spoken local languages were Gurene (Frafra), Kusaal, Kasem, Bisa, Buili, Taleni, Nankani, Mampruli, and Hausa. Like other regions in Ghana, the English language was used as the official language of communication. In terms of education, there are nine tertiary institutions (three universities, four nursing, and midwifery training institutions, and two colleges of education) and 37 SHS, distributed across the region with every district/municipality having at least one school.

A multi-stage sampling procedure was used to select teachers for the study. Purposive sampling was used to select 31 schools of the 37. Because the 31 schools offered elective chemistry, we were interested in the teachers teaching elective chemistry only. Four schools of the 37 were solely offering technical programs with a different curriculum and the other two schools though SHS with the same curriculum as the 31 schools, did not have any program with chemistry as an elective. In the 2020/2021 academic year, there were 114 teachers consisting of 100 males and 14 females in those 31 schools teaching chemistry. At a confidence level of 95% and 5% confidence interval, 88 teachers of the 114 were considered ideal for this research. Consequently, a simple random sampling technique was used to select 88 teachers from the 31 schools. However, during the data collection phase, 71 of the 88 teachers, representing 80.7% responded to the test and returned them. In all, 5 (7.0%) of the 71 teachers were females and 66 (93.0%) were males. Also, 43 (62.3%) of the teachers had teaching certificates (professional teachers) and 26 (37.7%) did not have professional teaching certificates (non-professional teachers). The teaching experiences of the 71 teachers were varied. Because 32 (45.1%) and 20 (28.2%) of the teachers had been teaching chemistry for the duration of 0-5 years and 6-10 years respectively, and 13 (18.3%) for 11-15 years, 4 (5.6%) for 16-20 years, with only 2 (2.8%) above 21 years.

Data Collection Instruments

A self-developed two-tier diagnostic test was used for data collection; the diagnostic test on organic chemistry for teachers [DTOCT]. DTOCT was organized in two sections. Section A included seven items (items 1-7) centered on the biodata of the teachers, while section B consisted of 25 items (items 8-32) which focused on teachers' conception of hydrocarbons, benzenes, and the derivatives of hydrocarbons. The items in section B were multiple choice for teachers to select the correct option from a given set of four options (that is the first tier). Thereafter, teachers were required to justify the option so selected (that is the second tier). Using a table of specifications, the introduction and classification of carbon compounds formed 16% (four items), the hydrocarbons, 32% (eight items), benzene, 12% (three items), and the derivatives of hydrocarbons, 40% (10 items) of DTOCT. The justification brought out teachers correct scientific conceptions and possible conceptual difficulties in organic chemistry.

In an attempt at validating DTOCT, the test items were compared with similar ones constructed by WAEC for the WASSCE students. Thereafter, three experienced chemistry teachers who were also WAEC examiners reviewed the items. The items on DTOCT were then shown to a science educator and researcher to critique and make suggestions. The expert suggestions were used to improve the quality of the instrument. DTOCT was then pilot tested with 10 chemistry teachers from other schools in the Upper West Region. After the pilot test, the item difficult indices were calculated. Items that were less difficult or extremely difficult were deleted. In all, 21 items (that is, items 9, 10, 12, 14, 15, 16, 19, 20, 24, 25, 26, 30, 32, 33, 36, 40, 41, 42, 46, 47, and 52) were deleted from the initial 53 items. Thereafter, the Kuder-Richardson 20 (KR20) coefficient of reliability was calculated. The KR20 was so used because the test items had varying difficulties. Besides each item was scored correct or wrong (Miller et al., 2009). A reliability coefficient of .86 was obtained and so the items were considered appropriate as they indicated that the DTOCT was reliable.

Data Collection Procedures

Data collection with DTOCT took four weeks as the 31 schools were zoned into four. Author2 visited each zone and interacted with teachers within one week. This became necessary as it was difficult collecting data from teachers using tests. Some teachers were not ready for a test on organic chemistry as they felt they were not students anymore. Even with those who were ready the author2 needed to be patient with them and worked according to their terms and conditions. In some schools, it took hours to have teachers ready to respond to DTOCT in the presence of author2. However, whenever teachers were ready, they responded to DTOCT with all seriousness in the presence of author2. This helped to ensure that the responses were a true reflection of the conceptual difficulties of teachers in organic chemistry.

Data Processing and Analysis

The responses collected with DTOCT were scored using a scoring rubric to help in transforming them into numerical data. The scoring rubric was adapted from Sukarmin et al. (2017). That is, if a teacher failed to choose any option and to provide any reason, or selected a wrong option and provided the wrong reason, a zero score was awarded and the corresponding conceptual classification as **do not understand**; for a correct selection of the option, but wrong reason or wrong selection of the option, but correct reason, a score of one mark was awarded the conceptual classification as **partial understanding with misconception**; and correct selection of option with correct reason was awarded 2 scores with the conceptual classification as **sound understanding**. Hence, a calculated mean of .0 to .49 was considered a demonstration of do not understand; .50 to 1.49 as partial understanding with misconceptions; and 1.50 to 2.00 as sound understanding. Teachers' explanations were examined to establish any misconceptions present. The misconceptions and other conceptual difficulties were analyzed through open coding and constant comparison. The researchers made meaning of the explanations given by teachers to deduce the types of misconceptions and other conceptual difficulties teachers had in organic chemistry.

RESULTS

Teacher's Conceptual Difficulties in Organic Chemistry

The research question sought to examine the conceptual difficulties teachers had in teaching SHS organic chemistry. To be able to achieve this, the selected teachers responded to the diagnostic test (DTOCT). The means scores of teachers on each item are presented in **Table 1** to help establish the level of teacher conceptual understanding of organic chemistry. The results in **Table 1**, generally indicated that the teachers demonstrated partial understanding with misconceptions about organic chemistry. This was because the calculated average means was .82 (Std.=.736). To assess the teachers' conceptual understanding of the concepts under the introduction to carbon compounds, items 8, 10, 19, and 32 were used. On item 8, 56.3% of the 71 teachers at a mean of .82 (Std=.639) demonstrated partial understanding with misconceptions on the idea that organic chemistry basically encompasses studying carbon and its compounds.

Table 1. Proportions of teachers' conceptual understanding of organic chemistry (n=71)

Item	DU		PUM		SU		M	SD
	n	%	n	%	n	%		
Introduction to the study of carbon compounds								
8	22	31.0	40	56.3	9	12.7	.82	.639
10	14	19.7	22	31.0	35	49.3	1.30	.782
19	20	28.2	33	46.5	18	25.4	.97	.736
32	28	39.4	33	46.5	10	14.1	.75	.691
Hydrocarbon								
13	14	19.7	40	56.3	17	23.9	1.04	.664
15	21	29.6	34	47.9	16	22.6	.93	.724
16	16	22.5	28	39.4	27	38.0	1.16	0.768
18	55	77.5	10	14.1	6	8.5	.31	.623
20	39	54.9	9	12.7	23	32.4	.78	.913
21	28	39.4	20	28.2	23	32.4	.93	.851
28	34	47.9	31	43.7	6	8.5	.61	.643
30	20	28.2	34	47.9	17	23.9	.96	.726
Benzenes								
9	32	45.1	21	29.6	18	25.4	.80	.821
12	27	38.0	19	26.8	25	35.2	.97	.861
25	30	42.3	31	43.7	10	14.1	.72	.701
Derivatives of hydrocarbon								
11	27	38.0	27	38.0	17	24.0	.86	.780
14	31	43.7	28	39.4	12	16.9	.73	.736
17	44	62.0	19	26.8	8	11.3	.49	.694
22	27	38.0	42	59.2	2	2.8	.65	.537
23	44	62.0	25	35.2	2	2.8	.41	.550
24	26	36.6	23	32.4	22	31.0	.94	.826
26	41	57.7	14	19.7	16	22.5	.65	.830
27	18	25.4	22	31.0	31	43.7	1.18	.816
29	28	39.4	24	33.8	19	26.8	.87	.809
31	32	45.1	25	35.2	14	19.7	.75	.691
Average mean							**.82**	**.736**

Note. **DU:** Do not understand; **PUM:** Partial understanding with misconception; **SU:** Sound understanding; **M:** Mean; **SD:** Standard deviation; & **n:** number of teachers under a particular conceptual classification

For instance, a teacher who opted for carbon and its derivatives provided the following reason *"other elements or atoms other than hydrogen can be bonded to carbon. E.g., $CH_3CHClCH_3$"* (Teacher 8). A clear demonstration of a lack of understanding of what organic chemistry entails leads to a demonstration of some misconceptions. In most cases, teachers selected the correct option but provided scientifically inaccurate reasons. Some of these scientifically inaccurate reasons were analyzed in relation to the five categories of misconceptions espoused by NRC (1997): preconceived notion, non-scientific belief, vernacular misconception, conceptual misunderstanding, and factual misunderstanding. Of the 30 teachers, (extracted from those who do not have scientific understanding and those with partial understanding with misconceptions who provided reasons for their choice of the options), none of the scientifically inaccurate reasons were found to be from non-scientific beliefs and vernacular misconceptions. That is 40% of the 30 teachers' misconceptions were conceptual misunderstandings as teachers demonstrated that in their school and college days, they could not challenge and overcome their preconceived notions on the meaning of organic chemistry during chemistry lessons. The excerpts are:

> "is a chemistry of carbon and its compounds because oxides are treated as part of inorganic chemistry" (Teacher 31).

> "is a chemistry of carbon and its compounds because they are compounds of C, H, N, O and S" (Teacher 62).

With respect to the preconceived notions where teachers use their everyday experiences as a basis for explaining a chemical concept, 23.3% of the 30 teachers' misconceptions fell in this category. The excerpts are:

> "is a chemistry of carbon and its compounds because carbon or the word carbon is kind of related to life and life or organism tissues or biomolecules contains mainly long chains of carbon" (Teacher 21).

> "is a chemistry of carbon and its compounds because the scientist in the eighteen century believed that organic compounds could only be made by living systems, i.e. plants and animals" (Teacher 53).

Considering factual misconceptions as teachers may had learned false ideas in organic chemistry in their early stages of learning, but had not been challenged to adulthood, 36.7% of the 30 teachers' misconceptions were in this domain. The excerpts are:

> "is carbon and its compounds due to carbon's ability to catenate" (Teacher 1).

> "Carbon has four valence electrons. This means that carbon can form compounds and they achieve this by sharing electrons thus forming covalent bonds" (Teacher 55).

In these excerpts, the teachers demonstrated a clear factual misconception. Because carbon's ability to catenate or form long chains, form bonds with many compounds as well as have four valence electrons only explains why it forms so many compounds, but not organic compounds.

On item 10, 31.0% of the 71 teachers at a mean of 1.30 (Std.=.782) demonstrated partial understanding with misconceptions that the maximum number of bonds carbon can form is four, being the result of its tetravalent nature. As a result, 15 teachers' explanations were extracted from those who do not understand and the partial understanding with misconceptions levels were analyzed for alternative conceptions. Of the 15 teachers' explanations, 33.3% fell under factual misconceptions as teachers may had learned false ideas in tetravalency in their early stages of learning but had not been challenged to adulthood. The excerpts are:

> "Carbon form four bonds around itself because *C* is a sp^3 hybrid that can form four bonds with other elements (Teacher 35).

> "Carbon undergoes sp^3 hybridization to form four hybrid orbitals. Each orbital is capable of forming a sigma bond. Hence four sigma bonds are formed" (Teacher 51).

It is apparent that the teachers could not conceptualize that the maximum number of bonds carbon can form is not explained on the basis of the hybridization state of carbon as well as the number of sigma bonds carbon forms. This is because, in terms of hybridization apart from sp^3 in alkanes, carbon can exhibit sp^2 in alkenes, and *sp* in alkynes. In both alkenes and alkynes, the available number of sigma bonds varies depending on the bonding species involved.

Another factual misconception identified was carbon loses its electrons to have a stable electronic structure. An excerpt is:

> "It will lose all its four valence electrons in order to get to the duplet state and become stable like Helium, He" (Teacher 8).

A clear demonstration of factual misconception because carbon does not loss all its four valence electrons. This is because carbon is a non-metal, and it achieves its stability by sharing its available valence electrons rather than donating as in the case of metals.

Some of the teachers' (60.0%) explanations were in the domain that could be described as conceptual misunderstanding. Excerpts are:

> "Carbon needs four more other electrons to become stable" (Teacher, 36).

> "Carbon ion needs other four electrons outside to complete its electronic configuration" (Teacher, 38).

Some of the teachers' (6.7%) explanations were that of preconceived notions. For instance, teachers mentioned that the maximum number of bonds carbon can form is four because it is in group four. An excerpt is:

> "Carbon forms four bonds because it is in group four" (Teacher, 2).

In this excerpt, the teachers' previous learning of periodicity could have caused their conception. Because in periodicity the number of valence electrons determines the group to which the element belongs and vice versa. This preconceived idea is not analogous to the maximum number of bonds carbon can form. That is, an element's group number does not predict the number of bonds. For instance, we cannot say an element in group seven or eight forms seven or eight bonds, respectively.

Under item 19, which investigated teachers' conceptual difficulties with the classification of organic compounds based on structure, it was apparent that 33 (46.5%) of the 71 teachers at a mean of .97 (Std.=.736) demonstrated partial understanding with misconceptions on identifying the structure of cyclopentane as an alicyclic compound. The explanations of 23 teachers extracted from do not understand and the partial understanding with misconceptions categories were analyzed for the presence of alternative conceptions. Of the 23 teachers' explanations, 39.1% fell under preconceived notions. Evidence of preconceived notions in their explanations is that alicyclic compounds are classified as such because of their shape. Excerpts are:

> "It is in a form of a ring" (Teacher 6).

> "Cyclic shape" (Teachers 26, 37, and 38).

The teachers could not conceptualize fully that alicyclic compounds are hydrocarbons with their carbon atoms arranged in closed rings which may contain single or double bonds. Not all cyclic-shaped structures are alicyclic. For example, heterocyclic and benzenes also have ring shapes but are not alicyclic.

Also, 17.4% of the 23 teachers' explanations were those factual misconceptions. This is because teachers mentioned that the structure of cyclopentane is classified as alicyclic because it looks like a benzene ring in nature. Excerpts are:

> "It is alicyclic being a cycloalkane which resembles benzene" (Teacher, 56).

> "It is alicyclic because it has a benzene ring-like cycle" (Teacher, 40).

Some of the 23 teachers' explanations (43.5%) were that of conceptual misunderstanding. Some of the teachers had difficulty identifying the cycloalkane structure as an alicyclic. To some, the structure is heterocyclic because it contains other elements other than carbon. Evidence of conceptual misunderstanding is that

> "They are cyclic compounds containing other elements like oxygen, nitrogen, and sulphur in the ring but not more than two different elements apart from carbon and hydrogen (Teacher, 30).

> "It is alicyclic because the structure is a ring system with only carbon (Teacher, 62).

Item 32 sought to find the empirical formula of the compound that contains 7.75% hydrogen, 37.21% carbon, and 55.04% chlorine. The results showed that 46.5% of the 71 teachers at a mean of .75 (Std.=.691) had a partial understanding with misconceptions of the composition of an organic compound. That is, teachers could not appreciate that the composition of organic compounds was on the ratio of its moles of atoms present. The teachers only demonstrated procedural knowledge by only following the steps to compute the molar ratios of the atoms present but could not explain the reason for their computations. Hence, the teachers demonstrated procedural knowledge rather than a conceptual understanding of the concept. Thus, with respect to introduction to the study of organic compounds, teachers have conceptual difficulties stemming from a lack of understanding of the concept, or partial understanding with misconceptions in the category of preconceived notions, factual misconception, and conceptual misunderstanding.

To find out the teacher's conceptual understanding of the hydrocarbons in terms of nomenclature, reactions, and properties, items 13, 15, 16, 18, 20, 21, 28, and 30 were used. From **Table 1**, it is apparent that teachers had more difficulties with items 18, 28, and 20 than the others. Because they recorded the lowest mean. Item 13 was on the naming of alkanes, and 56.3% of the 71 teachers at a mean of 1.04 (Std.=.664) demonstrated partial understanding of giving the IUPAC name of $CH_3CH_2CHClCH_3$, which was 2-chlorobutane. The explanations of 30 teachers extracted from those who do not understand and those with partial understanding with misconceptions were analyzed for the presence of any misconceptions. It was apparent that 10% of the teachers' explanations were conceptual misunderstandings. For instance, a teacher who selected 1-chlorobutane explained that

> "The methyl is with first carbon" (Teacher, 37).

Of the 30 teachers' explanations, 90.0% were of factual difficulties. This factual difficulty stems from the fact that some gave partial explanations and could not clearly explain the concept. Excerpts are:

> "IUPAC naming convention suggests that we use the lowest number to designate the location of Cl atom" (Teacher, 54).

> "The compound contains an alkyl halide with the chemical formula" (Teacher, 29).

In these excerpts, the teachers could not explain fully that the longest carbon chain is four (root prefix–but) with a functional group showing it is alkane because it is saturated (hence, the suffix–ane). It contains an inorganic substituent, Cl (with prefix chloro) occupying position 2 on the longest carbon chain.

The teacher's conceptual difficulties in naming alkanes with organic substituents were measured with items 28 and 30. On item 28, 43.7% of the 71 teachers at a mean of .61 (Std.=.643) partially understand with misconceptions that the molecule, $CH_3CH(C_6H_5)CH_3$ is 2-phenylpropane. The explanations of 12 teachers were extracted from those who do not understand and those with partial understanding with misconceptions were analyzed to establish the presence of any misconceptions on naming alkane molecules with an organic substituent. Of the 12 teachers' explanations, 16.7% were in the factual misconceptions category. For instance, the teachers explained that the IUPAC name of the structure of 2-phenylpropane is so named because:

> "It has two carbons and three hydrides" (Teacher 32).

> "Hexagonal shape" (Teacher 37).

Also, 16.7% of the 12 teachers' explanations were conceptual misunderstandings. They did not have an appreciation of the concepts, of benzene, and phenyl. They did not know that benzene as a substituent is a phenyl. An excerpt is:

> "The benzene is on the second carbon and there are three carbons, hence it was named as 2-benzenylpropane" (Teacher 6).

In other instances, 66.7% of the 12 teachers' explanations were of factual difficulties. That is, teachers provided incomplete reasons for selecting the right option. An excerpt is:

> "The phenyl group is attached to C-2 (Teacher 58).

However, there was no explanation given regarding why phenyl instead of benzene and why propane among others. Teachers lacked full appreciation of the fact that 2-phenylpropane is so named because the parent structure contains three carbons of which they are all saturated (alkanes family), the substituent is a phenyl (benzene that has lost one hydrogen) and it is attached to carbon 2. Hence, they had a partial understanding with misconceptions being factual misconceptions, conceptual misunderstandings, and factual difficulties.

On item 30, 47.9% of the 71 teachers at a mean of .96 (Std.=.726) showed partial understanding with misconceptions of the IUPAC naming of an alkane with organic substituents, CH_3-CH_2-$CH(CH_3)$-$CH(CH_3)_2$ arranged using the ball-and-stick model. The IUPAC name was 2,3-dimethylpentane. None of the responses were that of five categorization of the NRC (1997) misconceptions. However, all the explanations of the 20 teachers were that of factual difficulties. Excerpts are:

> "It has five carbons in the parent structure" (Teacher 27).

> "In naming alkanes, counting starts from the direction that carbon-bearing substituents are given the least possible carbon number" (Teacher 70).

These explanations though were not misleading did not explain fully why a 2,3-dimethylpentane. Teachers could not appreciate that in naming the 2,3-dimethylpentane, the longest chain contains five carbon atoms (root, prefix; pent), the family was alkane (suffix; ane), and two methyl substituents (CH_3) located on the second and third carbons (dimethyl). Thus, by applying the IUPAC naming system, the substituents are counted from the direction that gives them the least number and the number should be separated from the word by a hyphen, and between two numbers is separated by a comma.

The naming of alkenes was assessed with item 15. The results show that 47.9% of the 71 teachers at a mean of .93 (Std.=.724) had a partial understanding with misconception on the naming of $CH_3CH_2CH{=}CH_2$ as but-1-ene or 1-butene. The explanations of 29 teachers who do not understand and of partial understanding with misconceptions were analyzed to deduce any misconceptions. Of the 29 teachers' explanations, 3.4% were factual misconceptions. An excerpt is:

> "It has geometrical isomers and in alkenes, geometrical isomerism starts from butene" (Teacher, 30).

Of the 29 teachers' explanations, 96.6% were factual difficulties as they were not complete explanations. Excerpts are:

> "The double bond is attached to the first carbon-atom from the left" (Teacher 55).

> "The functional group is on the first carbon from the nearest (right)" (Teacher 58).

In both cases, the teachers could neither explain why the "but" or the suffix "ene" is used nor why "1" is used as well as the hyphen. Hence, the teachers demonstrated factual misconception and factual difficulties in naming unbranched alkene.

On item 18, 55 (77.5%) of the teachers at a mean of .31 (Std.=.623) do not understand the chemical property that differentiates methane from ethene. Hence, the teachers do not understand that saturated hydrocarbons do not undergo addition reactions, but substitution reactions. That is, teachers could not appreciate conceptually that, methane is alkane (a saturated hydrocarbon) and that carbon is completely bonded to other atoms (or hydrogen) or have no unpaired electrons available for accepting any other atom and, therefore, can only react by substituting some of the already bonded hydrogen atoms with the atoms of the other reacting species, but the ethene (an unsaturated hydrocarbon) had carbon atoms that are not fully bonded to other atoms or have an unhybridised unpaired electron available to accept additional atom without substituting any of its bonded atoms. The misconceptions of the teachers so identified were that factual misconception and conceptual misunderstanding. Of the 33 teachers' explanations extracted from the do not understand and those of partial understanding with misconceptions, 21.2% were factual misconceptions. That is, teachers explained that methane cannot react chemically. An excerpt is:

> "Methane cannot react chemically but ethene can still react chemically with other elements" (Teacher, 38).

Some of the teachers' (78.8%) explanations were conceptual misunderstandings. Excerpts are:

> "It is one of the common chemical transformations of a carbon-carbon double bond" (Teacher, 40).

> "Ethene does undergo substitution reaction" (Teacher, 4).

Items 20 and 21 further investigated teachers' conceptual difficulties with the reactions of some of the hydrocarbons. For item 20, of the 71 teachers, 9(12.7%) at a mean of .78 (Std.=.913) have a partial understanding with misconceptions in identifying that only terminal alkynes react with ammonical silver nitrate. Of the nine teachers' explanations, 22.2% were factual misconceptions. That is, the teachers explained that alkynes undergo neutralization reactions by reacting with bases. An excerpt is:

> "This is a reaction between alkyne and base as a result of neutralization" (Teacher, 31).

Also, alkynes react with ammonical silver nitrate because of the presence of van der Waal's forces. An excerpt is:

> "That there are Van der Waal's forces as well as hydrogen bonds" (Teacher, 40).

Of the nine teachers' explanations, 77.8% were of conceptual misunderstanding. In some cases, teachers mentioned that ammonical silver nitrate reacts with alkynes because of the triple bond. An excerpt is:

> "It contains triple bond compound and can react with ammonical silver nitrate" (Teacher 38).

Also, ammonical silver nitrate is a reagent and is used for detecting the presence of alkynes. An excerpt is:

> "This is because ammonical silver nitrate is a reagent used to demonstrate the presence of -C≡C-" (Teacher 25).

This was misleading as not all alkynes give positive results when reacted with ammonical silver nitrate. Only terminal alkynes can be detected using the ammonical silver nitrate. Hence the teachers demonstrated both factual misconceptions and conceptual misunderstandings.

Under item 21, of the 71 teachers, 28.2% at a mean of .93 (Std.=.851) had a partial understanding with misconceptions in identifying the unsaturated hydrocarbons as the class of hydrocarbons that show visible reaction with bromine or carbon tetrachloride. The explanations of nine teachers who do not understand and those who had a partial understanding of misconceptions were analyzed to deduce the presence of any misconceptions. Of the nine teachers' explanations, 33.3% were that conceptual misunderstanding. Excerpts are:

> "is ethene and ethyne as they both have two carbons" (Teachers, 26; 41).

> "is ethene and ethyne as they both have two parent carbon" (Teacher 38).

Of the nine teachers' explanations, 66.7% were factual difficulties as the teachers could not explain the exact chemistry. Excerpts are:

> "The double bond of ethene breaks and the bromine atom becomes attached to each carbon" (Teacher, 57)

> "They contain double bonds which can easily be broken at room temperature" (Teacher, 54).

Item 16 sought the teachers' conceptual difficulties on saturated and unsaturated hydrocarbons from the IUPAC name of a given molecule. Of the 71 teachers, 39.4% at a mean of 1.16 (Std.=.768) had a partial understanding with misconceptions of an example of saturated hydrocarbons from the IUPAC name. The explanations of 12 teachers who do not understand and those who had a partial understanding with misconceptions were further analyzed to deduce the presence of any misconceptions. Of the 12 teachers' explanations, 45.0% were factual misconceptions. For instance, the teachers explained that benzene is not a saturated hydrocarbon. An excerpt is:

> "Benzene is not saturated hydrocarbon as it possesses double and triple bonds" (Teacher 36).

> "Benzene is not saturated because it has hydrogen and chlorine" (Teacher 34).

Of the 12 teachers' explanations, 10% were conceptual misunderstandings. That is, teachers explained that 2,2,4-trimethylpentane is not a saturated hydrocarbon. An excerpt is:

> "2,2,4-trimethylpentane is not a saturated hydrocarbon because it can still take more molecules" (Teacher, 41).

Another teacher explained that ethane is not a saturated hydrocarbon though it can undergo substitution reaction, but not addition. An excerpt is:

> "Ethane is not a saturated hydrocarbon though it cannot undergo additional reaction but can undergo substitution reaction" (Teacher 12).

Of the 12 teachers' explanations, 45% were that to factual difficulties as they could not clearly explain the concept. For example, a teacher explained that ethane contains single bonds.

> "Ethane contains only single bonds between carbon atoms" (Teacher, 54).

Hence, in hydrocarbons, conceptual difficulties also exist. Their misconceptions exist as factual misconceptions, conceptual misunderstandings, and factual difficulties.

For the benzenes, items 9, 12, and 25 were used to investigate teachers' conceptual difficulties. Item 25 appeared difficult to the teachers. This was because it recorded the lowest mean score of .72 (Std.=.701) as compared with item 9 (M=.80, Std.=.821), and item 12 (M = .92, Std.=.861). On item 9, 29.6% of the 71 teachers showed partial understanding with misconceptions on the concept that benzenes are with high stability compared to alkenes. The explanations of 22 teachers who do not understand and those with partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions. Of the 22 teachers' explanations, 18.2% were factual misconceptions. Excerpts are:

> "Benzenes have single and double bonds" (Teacher, 32).

> "They do not show unsaturation unlike alkenes and therefore less reactive" (Teacher, 21).

Of the 22 teachers' explanations, 81.8% were factual difficulties. These included instances where some provided incomplete explanations for the options they selected. Excerpts are:

> "Because of the structural arrangement between them" (Teacher, 23).

> "It has C=C bonds which rotate to form a ring. The C=C bond cannot easily be broken" (Teacher, 62).

The teachers could not conceptualize fully that benzenes have extra stability than the alkenes though both contain double bonds as a result of the presence of delocalized pi bond electron system or the resonance structure. Hence, the teachers' conceptual difficulties were factual misconceptions and factual difficulties.

On item 12, 26.8% of the 71 teachers had a partial understanding with misconception on identifying examples of aromatic compounds. The explanations of 19 teachers who do not understand and those who had a partial understanding with misconceptions were analyzed for the presence of any misconceptions. Of the 19 teachers' explanations, 15.8% were preconceived notions. The teachers tried to make inferences from the aromatic to mean 'aroma', implying something that smells good. Excerpts are:

> "The aromatic compound has a sweet swelling" (Teacher 37).

> "It smells because of the aroma" (Teacher 26).

Of the 19 teachers' explanations, 26.3% were of conceptual misunderstanding. This was demonstrated in the fact that they provided correct explanations for aromatic compounds but opted for the wrong option. Excerpts are:

> "This $CH_3CH{=}CHCH_3$ is the answer … as it has one or more benzene rings" (Teacher, 31, 36, and 40).

> "The answer is $CH_3CH{=}CHCH_3$. Because aromatic compounds contain delocalized pie electrons" (Teacher, 51).

Of the 19 teachers' explanations, 57.9% were of factual difficulties. This was demonstrated on the ground that teachers could not provide clear explanations to the selected aromatic compound though in most instances they got the right example. Excerpts are:

> "is methylbenzene which is toluene ($C_6H_5CH_3$) an aromatic hydrocarbon" (Teacher, 54).

> "Toluene is an aromatic compound" (Teacher, 58).

The teachers could not appreciate fully that $C_6H_5CH_3$ is a methylbenzene (Toluene) because it contains conjugated planar ring systems with delocalized pi electron clouds instead of discrete single and double bonds.

On item 25, 43.7% of the 71 teachers demonstrated partial understanding with misconceptions on identifying that benzene was resistant to addition reaction. All 31 teachers' explanations under do not understand and partial understanding with misconceptions were factual misconceptions. For instance, Benzene is ring-like and cannot undergo addition reactions. The excerpts are:

> "Because C_6H_6 belongs to ring compounds, it cannot undergo addition reactions" (Teacher, 36).

> "It is benzene because is a ring form cannot undergo addition reactions" (Teacher, 12).

Benzene is saturated and a coated compound. The excerpts are:

> "Benzene is the answer. This is because its surface is coated with silver" (Teacher, 37).

> "Benzene is the answer as it is saturated" (Teacher, 56).

Benzene is a multiple bond compound that will not undergo addition reactions. An excerpt is:

> "It contains at least a double or triple bond … it prevents addition reactions" (Teacher 31).

Some of the teachers could not conceptualize that the compound C_6H_6 *is benzene* and that benzenes have low resonance energy and the presence of a delocalized pi bonding system making them more stable and resistant to addition reaction. Hence, the conceptual difficulties the teachers had were that of factual misconceptions on reasons why benzenes do not undergo addition reactions.

To examine teachers' conceptual difficulties on the derivatives of hydrocarbons - carboxylic acids (alkanoic acids), alcohols (alkanols), and esters (alkyl alkanoates)-, items 11, 14, 17, 22, 23, 24, 26, 27, 29, and 31 were used. Items 23, 17, 22, and 26 recorded the lowest mean values among them, implying they were the items teachers demonstrated no conceptual understanding or partial understanding with misconceptions. On item 17, 62.0% of the 71 teachers at a mean of .49 (Std.=.694) do not understand the concept, identifying the class of organic compound that shea-butter belongs to, which was alkanoic acids (carboxylic acids). The explanations of 25 teachers extracted from those who do not understand and those with partial misunderstanding with misconceptions were analyzed for the presence of any misconceptions. Of the 25 teachers' explanations, 20.0% were preconceived notions. Teachers mentioned that shea-butter has a smell and, therefore, it should be an ester. Excerpts are:

> "Alkyl alkanoates are esters with a fruity smell and they occur naturally mostly in plants. The shea-butter has a smell, it has no sour taste and cannot be alkanoic acid" (Teacher, 8).

> "Fats and oils contain one, two or three alkanoates groups which usually do not have pleasant odors" (Teacher, 54).

Of the 25 teachers' explanations, 52.0% were factual misconceptions. Excerpts are:

> "Sheabutter is an amine because its functional group is $-NH_2$" (Teacher, 40).

> "Sheabutter is amine because it is an example of alkanols" (Teacher, 70).

Also, 8.0% of the 25 teachers' explanations were conceptual misunderstanding. An excerpt is:

> "When you react a base with oil or fats you get salt derivative. This is saponification reaction" (Teacher, 35).

Of the 25 teachers' explanations 20.0% were factual difficulties. Excerpts are:

> "Alkanoic acids occur naturally in plants and animals" (Teacher, 55).

> "Shea-butter are very long chains of fatty acids" (Teacher, 21).

Hence, the teachers demonstrated preconceived notions, factual misconception, conceptual misunderstanding, and factual difficulties in identifying shea butter as an example of alkanoic acids.

Item 11, also, looked at the class of organic compounds in an unripe orange. Of the 71 teachers, 38.0% at a mean of .86 (Std.=.780) had a partial understanding with misconceptions in detecting the class of organic compound in an unripe orange. The explanations of 12 teachers were extracted and analyzed to deduce the presence of misconceptions. Of the 12 teachers' explanations, 8.3% were of factual misconceptions. An excerpt is:

> "Citric acid found in all citrus fruits adds the sour taste to orange" (Teacher 19).

Also, of the 12 teachers' explanations, 91.7% were that of conceptual misunderstandings. For instance, the teachers selected the functional group present in an unripe orange as $R\text{-}CO_2R$ (which is the esters).

> Because of the functional group–$COOR^I$ present makes it acid" (Teacher, 36).

> "Because $R\text{-}CO_2R$ is functional group of acid which has a sour taste" (Teacher, 38).

This may probably be because they might have been taught in their lessons that esters have a characteristic "fruity" smell.

Others were selected -C=C- as the functional group present in an unripe orange. Excerpts are:

> "The functional group for unripe orange is *-C=C-* … an example of acid" (Teachers, 26; 40)

> "This is the compound *-C=C-* responsible for the chemical characteristic reaction of the unripe orange" (Teacher, 29).

Hence, the teachers' misconceptions on identifying the functional group present in unripe orange are factual misconceptions and conceptual misunderstandings.

On item 22, of the 71 teachers, 59.2% at a mean of .65 (Std.=.537) had a partial understanding with misconception on the reaction between methanoic acid and methanol to methyl methanoate. The explanations of 29 teachers from do not understand and partial understanding with misconceptions levels were analyzed to deduce the presence of any misconceptions. Of the 29 teachers' explanations, 69.0% were factual difficulties as they could not explain the exact ester formed from the reaction between methanoic acid and methanol. Excerpts are:

> "Carboxylic acids and alcohols react to produce an ester" (Teacher, 1).

> "CH_3OH and HCOOH react to form an ester" (Teacher, 4).

Of the 29 teachers' explanations, 27.6% were of conceptual misunderstanding that the formation of an ester is by neutralization reaction. An excerpt is:

> "The reaction will form ester by neutralization of ethanoic acid with the methanol" (Teacher, 6).

Thus, the teacher took the methanol as a base and the methanoic acid as the acid. This is a clear demonstration of a conceptual misunderstanding (NRC, 1997).

Also, of the 29 teachers' explanations, 3.4% were preconceived notions. An excerpt is:

> "The organic product of a reaction between CH_3OH and $HCOOH$ is $HCOOCH_3$ … because the reaction takes place in front and not at the back side of the carbon and already H is the backside, so the substitution will be on the product" (Teacher, 8).

The teacher only knows that whenever carboxylic acids react with alcohols, they give esters but could not explain that both methanol (CH_3OH) and methanoic acid ($HCOOH$) in solution dissociates to give methyl cation (CH_3^+) and a hydroxide (OH^-) and methanoate ion ($HCOO^-$)- and a proton (H^+), respectively. The methyl ion reacts with the methanoate ion to form the methyl methanoate. Hence, the teachers demonstrated preconceived notions, conceptual misunderstanding, and factual difficulties in the reaction between alkanoic acids and alkanols, resulting in the formation of ester (alkyl alkanoate).

Item 14 was on the detection of alcohol. Of the 71 teachers, 39.4% at a mean of .73 (Std.=.736) had a partial understanding with misconceptions in detecting the presence of alcohol using potassium dichromate reagent. The explanations of 18 teachers were extracted from those who do not understand and those who had a partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions. Of the 18 teachers' explanations, 27.0% were factual misconceptions. Excerpts are:

> "It is used to test the presence of alcohol in one's blood" (Teacher, 32).

> "Potassium is present" (Teacher, 40).

Also, of the 18 teachers' explanations, 72.2% were factual difficulties. Excerpts are:

> "When the breath analyzer is used on a drunk motorist, the potassium dichromate in it reacts with the alcohol particles from the drunk motorist hence changing the color from yellow to green" (Teacher, 7).

> "Yellow-orange is the color of potassium dichromate so when alcohol vapor changes from the yellow to green" (Teacher, 19).

The teachers could not appreciate that the alcohol will reduce the dichromate (Cr^{6+}) (yellow color) to chromium ions (Cr^{3+}) which is green in color hence the color change.

On item 23, of the 71 teachers, 62.0% at a mean of .41 (Std.=.550) do not understand $CH_3COOHC_2H_5(l) + NaOH(aq) \longrightarrow CH_3COONa(aq) + C_2H_5OH(aq)$ was an example of hydrolysis reaction. The explanations of 27 teachers were extracted and analyzed to deduce the presence of any misconceptions. Of the 27 teachers' explanations, 29.6% were that of preconceived notions. They hold the conception that any reaction involving a strong acid or base is a neutralization reaction as such the reaction involving an ester and the strong base ($NaOH$) was conceived by the teachers as a neutralization. Excerpts are:

> "The first compound ($CH_3COOC_2H_5$) is an acid and NaOH is a base which reacted to yield an acidic salt (CH_3COONa), aside that the reaction is not reversible" (Teacher, 53).

> "It is a reaction between a strong acid and a strong base to form salt and water" (Teachers 3 and 6).

Also, teachers conceived that any reaction that forms salt is a neutralization reaction. An excerpt is:

> "It has salt e.g., $CH_3COONa(aq)$ and it is neutralization" (Teacher, 40).

Of the 27 teachers' explanations, 18.5% were conceptual misunderstanding. They conceptualized esterification as an ester reacting with a strong base. An excerpt is:

> "The process where a base reacts with an ester to form salt and alcohol is esterification" (Teacher, 35).

In addition, teachers conceptualized saponification for esterification explaining that an ester reacting with a base produces soap. An excerpt is:

> "The reaction $CH_3COOHC_2H_5(l) + NaOH\ (aq) \longrightarrow CH_3COONa(aq) + C_2H_5OH(aq)$ is production of soap" (Teacher 2).

Of the 27 teachers' explanations, 51.9% were factual difficulties. Most of the explanations offered for this item indicated that the teachers do not fully understand the concept of hydrolysis in organic reactions. They rightly selected that the reaction of ethyl ethanoate with sodium hydroxide is an example of a hydrolysis reaction. They gave their explanations as:

> "It is an ester reacting with base. It is saponification" (Teacher, 16)

> "Saponification is under hydrolysis and the equation is saponification" (Teacher, 8).

Most of the teachers could not conceptualize that the $NaOH$ (alkaline) dissociated such that the OH^- ion separated (hydrolyses) and that of the alkyl alkanoate (CH_3COO^-). Thus, the OH^- reacts with the ethyl, $C_2H_5^+$ ion to form ethanol and the ethanoate ion reacts with the Na^+ to form the sodium ethanoate.

On item 24, of the 71 teachers at a mean of .94 (Std.=.826) had a partial understanding with misconceptions of identification of a tertiary alcohol. The explanations of 17 teachers who do not understand and those who had a partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions. Of the 17 teachers' explanations, 29.4% were preconceived notions. That is, teachers, conceptualizing that tertiary should correspond to a longest or biggest chain of carbon atoms. Excerpts are:

> "It is the biggest molecule among them" (Teacher, 26).

> "It has the longest chain among the given molecules" (Teacher, 41).

Also, teachers conceptualized that the tertiary means three. An excerpt is:

> "The carbons are three for a tertiary alcohol" (Teacher 27).

Of the 17 teachers' explanations, 52.9% were factual difficulties. Excerpts are:

> "The functional group –OH is attached to carbons in a tertiary alcohol" (Teacher, 31).

> "For tertiary alcohols, the central carbon atom with the –OH group is attached to methyl group" (Teacher, 35).

Of the 17 teachers' explanations, 17.6% were conceptual misunderstanding. Excerpts are:

> "All the CH_3 are bonded to the carbon with the OH group for tertiary alcohols" (Teacher, 10).

"… the functional group of alkanols has occurred on the middle and not on the tail end carbons of the tertiary alcohols" (Teacher, 12).

Hence, the conceptual difficulties the teachers had in the identification of tertiary alcohols are that of preconceived notions, factual misconception, conceptual misunderstanding, and factual difficulties.

On iem 26, 19.7% of the 71 teachers at a mean of .65 (Std.=.830) had a partial understanding with misconceptions of the test of alcohol in a solution of iodine in aqueous sodium hydroxide. The explanations of nine teachers who do not understand and those who had a partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions. Of the nine teachers' explanations, 55.6% were factual difficulties. Excerpts are:

"Because of the presence of sodium and iodine" (Teacher, 36)

"CH_3CH_2OH is present" (Teacher, 41).

Also, of the nine teachers' explanations, 44.4% were factual misconceptions. Excerpts are:

"If the solution is evaporated carefully to dryness after the reaction between the ethanol with sodium hydroxide, a white solid is obtained" (Teacher, 19).

"The same yellow ppt. or solution is seen meaning there is no observable reaction" (Teacher, 60).

The teachers could not conceptualize fully that the CH_3CH_2OH with its structural units bonded to a C or H atom was oxidized to give a solid triiodomethane (CHI_3) on warming with the iodine in aqueous $NaOH$. The yellow color seen was a result of the formation of triiodomethane, which had precipitated out of the reaction mixture. Hence, the conceptual difficulties the teachers had were of factual misconception, conceptual misunderstanding, and factual difficulties.

On item 27, 31.0% of the 71 teachers at a mean of 1.18 (Std.=0.816) have a partial understanding with misconceptions in the identification of a derivative of hydrocarbon given its formula, $CH_3(CH_2)_2CO_2H$ as an alkanoic acid. The explanations of 12 teachers who do not understand and those who had a partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions. Of the 12 teachers' explanations, 33.3% were conceptual misunderstandings. The teachers lacked the appreciation of the concept of the functional group of an organic compound and thus, in some cases identified $CH_3(CH_2)_2CO_2H$ as alkanoic acid on the basis of its molecular formula. Excerpts are:

"They have the general formula $C_nH(2nH)COOH$" (Teacher, 6).

"Because it has the general molecular formula, RCOOH" (Teacher, 1).

In other instances, the teachers identified the $CH_3(CH_2)_2CO_2H$ on the basis of how it is written. Excerpts are:

"is an alkanoic acid because it can also be written as $CH_3CH_2CH_2COOH$ which is known as butanoic acid" (Teacher, 12)

"*R-COOH* is attached to the alkyl group" (Teacher, 27).

Of the 12 teachers' explanations, 66.7% were factual difficulties. Excerpts are:

"Because of *COOH*" (Teacher, 36).

"*COOH* is an alkanoic acid" (Teacher, 55).

Hence the teachers' conceptual difficulties in the identification of organic compounds as an alkanoic acids were conceptual misunderstanding and factual difficulties.

On item 29, 33.8% of the 71 teachers at a mean of .87 (Std.=.809) had a partial understanding with misconceptions of the fact that the boiling points of alkanoic acids (CH_3COOH) should be higher compare to an alkanol (CH_3CH_2OH), alkene (CH_2CH_2), and alkane (CH_3CH_3). The explanations of 15 teachers were extracted from those who do not understand and those who had a partial understanding with misconceptions were analyzed to deduce the presence of any misconceptions and factual difficulties. Of the 15 teachers' explanations, 26.7% were conceptual misunderstandings. For instance, teachers explained the reasons for the higher boiling point on the basis of the functional groups. An excerpt is:

"It is an alkanol will have the highest boiling point because of –OH functional group" (Teacher, 31).

Also, teachers conceptualized the boiling of organic compounds based on unsaturation. An excerpt is:

"It is an unsaturated hydrocarbon that will have the highest boiling point" (Teacher, 12).

In other instances, teachers conceptualized the boiling point of derivatives of hydrocarbons on the basis of the states of matter. An excerpt is:

"C_1 to C_8 are mostly liquids. Therefore, have higher boiling points" (Teacher, 33).

Of the 15 teachers' explanations, 73.3% were of factual difficulties. Though teachers identified that the boiling points of a compound can be explained on the basis of its bonding, they could not explain clearly how the bonding in each compound is. Thus, in the presence of alkanol and alkanoic acids they could not distinguish between the two which have higher boiling points. Some of the teachers who selected alkanol instead of alkanoic acid explained that:

"This is because of intermolecular hydrogen bonding that may occur in the compound" (Teacher, 52).

"CH_3CH_2OH contains hydroxyl group which is capable of hydrogen bonding" (Teacher, 30).

The teachers could not appreciate that alkanoic acids have two hydrogen bond associations, whereas alkanols have only one hydrogen bond association. Therefore, alkanoic acid (CH_3COOH) unlike the alkanol (CH_3CH_2OH) selected should have a higher boiling point.

On item 31, 35.2% of the 71 teachers at a mean of .75 (Std.=.691) had a partial understanding with misconceptions on the reactions of likely derivatives of hydrocarbons (such as an alkanol, alkanoic acid, and alkyl alkanoate) with sodium metal. The sodium metal will react with the derivative that can donate a proton (such as alkanol and alkanoic acid). The explanations of 18 teachers were extracted and analyzed to deduce presence of misconceptions. Of the 18 teachers' explanations, 27.7% were factual misconceptions. For instance, a teacher who selected alkanol and alkanoic acids explained that both will release hydrogen gas because they have hydrogen in them. An excerpt is:

> "They both alkanol and alkanoic acid contain hydrogen" (Teacher, 26).

Another teacher who selected alkanol, alkanoic acids, and alkyl alkanoate explained that they give hydrogen gas because they are hydrocarbons. An excerpt is:

> "For alkyl alkanoate, alkanol, and alkanoic acid are hydrocarbons, and react with sodium" (Teachers 41).

Of the 18 teachers' explanations, 33.3% were those conceptual misunderstandings. An excerpt is:

> "Sodium metal ion can attach in front of [CH_3COOH] and [CH_3COOCH_3] to form CH_3COONa and CH_3COOCH_2Na, respectively" (Teacher, 8).

Some teachers explained that compounds that release hydrogen gas are those that can undergo neutralization reaction. An excerpt is:

> "The compounds that will react to liberate hydrogen gas is a neutralization reaction" (Teacher, 31).

Of the 18 teachers' explanations, 38.9% were of factual difficulties. Excerpts are:

> "Both alkanols and alkanoic acids react with metals to produce hydrogen atoms" (Teachers, 15).

> "CH_3COOCH_3 will not react with Na to produce H_2" (Teacher, 58).

The teachers could not conceptualize that alkanol (slightly weaker acids than water) and alkanoic acid, both are capable of releasing their hydrogen attached to their functional groups to form hydrogen gas, and the ions left in the specie react with sodium to form alkoxide (ethoxide for the alkanol) and metal ethanoate (sodium ethanoate for the alkanoic acids), but esters do not exhibit this property.

DISCUSSION

The finding that the teachers have a partial scientific conceptual understanding with misconceptions of the concept of organic chemistry confirms the findings of Anim-Eduful and Adu-Gyamfi (2021) that teachers have a partial understanding of functional group detections. Because the concept of functional group is an aspect of organic chemistry that this current study covered. Then teachers teaching organic chemistry indeed have conceptual difficulties in organic chemistry they teach to SHS students. There could be underlying factors accounting for these conceptual difficulties. That is, it could be teachers' interest in organic chemistry, their SHS chemistry education, their university chemistry education, or how challenging the content they are currently teaching accounting for their conceptual difficulties in organic chemistry. Teacher's partial understanding of organic chemistry implies that those teachers lack the needed content knowledge (Kind, 2009) to effectively teach it to students in the Ghanaian SHS even if they (teachers) have knowledge of pedagogy or if at all teachers have the content knowledge, it is an incorrect one. Because Smith and Banilower (2015) explain that PCK can be incorrect, especially when it incorporates incorrect science content knowledge. This shortfall in the teacher professionalism may have informed Engida (2014) to develop the ICTeTD as a TPACK model for effective teaching of chemical concepts in the 21st century. Because in the 21st century teacher's knowledge of the content of chemistry is embedded with the context of pedagogical and technological knowledge as well as the content knowledge (Anci et al., 2021). Teachers' lack of sound scientific conceptual understanding could also be looked at as 'bad chemistry' explained by Kay and Yiin (2010) as when the teachers do not have a sound understanding of the chemical principles as well as not being aware of their own misconceptions. If teachers are not aware of their own misconceptions, which they have acquired through learning and experience, then how could they overcome those misconceptions to avoid transfer to students they teach. This finding goes to confirm earlier findings of Valanides (2000) that the teachers exhibit great prevalence and diversity of conceptual difficulties and advanced that the teachers are a more likely reflection of the students they teach as their conception has a bearing on the endorsement of misconceptions.

The conceptual difficulties demonstrated by teachers in this study are not only limited to introduction to organic chemistry where nature, tetravalency, and hybridization of the carbon atom are introduced to students, but the IUPAC nomenclature, structural formula, functional group, and reactions of hydrocarbons, aromatics, and derivatives of hydrocarbons. This implies that teachers' conceptual difficulties in organic chemistry cut across most concepts confirming that organic chemistry is difficult (Chang & Goldsby, 2016; Childs & Sheehan, 2009; Miheso & Mavhunga, 2020; Salame et al., 2019). These teachers' difficulties in most concepts of SHS organic chemistry could be a major block to an effective transformation of the content (PCK) to students (Van Driel et al., 1998). The transformation of organic chemistry by the teacher to benefit the student is dependent on teacher's TPACK (Engida, 2014) as well. What is revealing in the teachers' conceptual difficulties is their inability to correctly conceptualize that organic chemistry is chemistry of carbon compounds. This could be the reason behind the teachers' partial understanding of carbon's ability to catenate or form single and multiple bonds with itself and other atoms or form long chains. A sound scientific understanding of hydrocarbons is a good ground for developing a sound scientific understanding of derivatives of hydrocarbons, but teachers in this study have conceptual difficulties in hydrocarbons and hence, their difficulties in derivatives of hydrocarbons. Reactions of organic compounds are difficult for teachers. That is, teachers are unable to conceptualize the unique reactions of certain families of organic compounds with respect to their functional group. For instance, substitution reactions are ideal for alkanes and benzenes, but not addition reactions, which are ideal for saturated hydrocarbons (Anim-Eduful & Adu-Gyamfi, 2021). This implies teachers have problems with their content knowledge in organic chemistry. Reagents are chemical substances that are used to show distinction among the families of organic compounds (Chang & Goldsby, 2016). For instance, ammonical silver nitrate reacts with terminal alkynes and alcohol reduces the dichromate (Cr^{6+}) (yellow color) to chromium ions (Cr^{3+}) (green color). In the everyday application of organic chemistry, teachers have partial understanding. That is, teachers could not identify the family of organic compounds (alkanoic acids) to which shea-butter or unripe orange belongs. This could mean that teachers cannot relate organic chemistry to real-life experiences (Duda et al., 2020) to help their students develop sound scientific understanding leading to the abstract nature of chemistry. However, teachers need to help their students to relate abstract concepts to everyday life experiences (Margunayasa et al., 2019) and one of the means of achieving this is emerging TPACK in teaching organic chemistry where variety of technological tools are used by teachers to transform the content (Engida, 2014; Utami & Muhtadi, 2020) of organic chemistry to students in the SHS. The finding that teachers have a partial understanding of IUPAC nomenclature, and the structural formula of organic compounds cannot go unnoticed. This is because the concept of IUPAC nomenclature and structural formula cuts across all families of organic compounds. They could not identify the structure of a given IUPAC name and vice versa. This is due to the teachers' inability to identify the longest continuous carbon chain, substituted chains, branched chains, and that of the family or the functional group of as given molecule. Though Adu-Gyamfi et al. (2012, 2017) report on similar conceptual difficulties in IUPAC nomenclature and structural formula of organic compounds among SHS students in Ghana it could be inferred that one of the courses of the problem is the teacher transforming this concept to students. Because teachers have conceptual difficulties, and the conceptual difficulties of students are a direct reflection of their teachers. For teachers to be well-equipped to handle IUPAC nomenclature of organic compounds with less or no difficulty, there is the need for some professional development programs targeting their PCK and TPACK. Because teacher's content knowledge will be enriched as well as the application of their pedagogical and technological knowledge to affect students' naming and writing structural formula of organic compounds through teachers' emerging TPACK (Engida (2014) in teaching IUPAC nomenclature of organic compounds.

The finding that the teachers have preconceived notions, conceptual misunderstanding, and factual misconceptions in organic chemistry are in line with earlier claims that misconceptions are not only peculiar to students but teachers (Von Aufschnaiter & Rogge, 2010). Like students, the misconceptions teachers have, are those they carried from previous learning in schools and everyday life experiences, which remained unchallenged by classroom instruction (Adu-Gyamfi & Ampiah, 2019; NRC, 1997; Woldeamanuel et al., 2014). It could, also, be seen that misconceptions such as nonscientific beliefs and vernacular misconceptions are absent in relation to teachers' conceptual difficulties in organic chemistry. That is, teachers' misconceptions are not influenced by the usage of everyday language and religion to explain organic chemistry. Indeed, conceptual misunderstanding is becoming one of the common issues in teaching and learning chemistry (Mubarak & Yahdi, 2020), and teachers in this study have misunderstandings in another known difficult concept (Burrows & Mooring, 2015) like organic chemistry. Teachers' conceptual misunderstanding is an indication that they are misapplying basic principles (NRC, 1997) such as the number of bonds formed by each carbon atom in a chain, hybridization of the carbon atom, IUPAC nomenclature, structural formula, and chemical reactions. The misconceptions teachers demonstrate are one of the reasons for teachers' weak PCK (Swati et al., 2019) in organic chemistry. It could be that (science) teacher education institutions are not putting the right interventions in place to identify teachers' misconceptions (NRC, 1997) in organic chemistry to help them deal with their misconceptions (Kartal et al., 2011).

The finding that teachers demonstrate factual difficulties in organic chemistry cannot go unnoticed. Because teachers though in some instances have no misconceptions, could not explicitly bring out their conception of organic chemistry. The idea of factual difficulties was reported by Anim-Eduful and Adu-Gyamfi (2021) who attributed it to the weak content knowledge of teachers in functional group detection. Maybe it is about time teachers teaching organic chemistry reflect on their learning activities (as a component of their TPACK) (Anci et al., 2021) to have sound understanding of the content they teach to their students. This could be attributed to teachers' confidence in expressing their knowledge (Chen & Wei, 2015) of organic chemistry. It could, also, be that teachers barely participate in professional development programs on the content of organic chemistry to help update and deepen their sound scientific knowledge (Desimone et al., 2002; Supovitz et al., 2000) of organic chemistry and develop the confidence needed to soundly explain (Stein et al., 1999) organic chemistry.

CONCLUSION AND IMPLICATIONS

The results of this convergent mixed methods study showed that the 71 teachers, selected through a multi-stage sampling procedure, have conceptual difficulties in teaching SHS organic chemistry. These conceptual difficulties are the result of the teachers having a partial understanding with misconceptions in organic chemistry. In examining this, there has been an addition to the literature that not only are teachers having conceptual difficulties in functional group detection, but that of IUPAC nomenclature, structural formula, reactions of hydrocarbons, aromatics, and derivatives of hydrocarbons. Therefore, the Ministry of Education should collaborate with the Teacher Education Universities to organize short courses focusing on content knowledge to help in-service teachers update their knowledge in organic chemistry leading elimination of their misconceptions. The teachers' misconceptions are preconceived notions, factual misconceptions, and conceptual misunderstandings, but not non-scientific beliefs and vernacular misconceptions. This is an indication that teachers' misconceptions are science classroom related. Consequently, this study has categorised the misconceptions teachers have in organic chemistry into preconceived notions, factual misconceptions, and conceptual misunderstandings. Hence, in order to deal with factual misconceptions and conceptual misunderstandings with few preconceived notions, chemistry educators should adopt instructional approaches that will help pre-service teachers challenge and deal with their misconceptions in organic chemistry. In addition, the teachers' partial understanding with misconceptions is partly due to some factual difficulties. Because there are instances teachers could not fully express their conceptual understanding of the chemistry behind the various aspects of organic chemicals used in this study. It is, therefore, not out of place to conclude that teachers have conceptual difficulties in SHS organic chemistry because of misconceptions and factual difficulties they have. Hence, the management of schools should organize professional development programs, such as workshops and seminars, for chemistry educators and researchers to share their research findings and solutions to overcoming misconceptions in organic chemistry with in-service teachers.

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