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Nature of senior high school chemistry students' alternative conceptions in organic qualitative analysis

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ABSTRACT

Chemical analysis is one of the important areas in learning chemistry as it inculcates in students the spirit of deductive reasoning enabling them to apply theoretical knowledge acquired in practical problems. Organic qualitative analysis (OQA) offers students the opportunity for identification of unknown organic chemicals in substances including toxic substances. Students' alternative conceptions in OQA have been reported in the literature with the nature of the alternative conceptions yet to be investigated. Thus, this study investigated the nature of students' alternative conceptions in OQA using a four-tier diagnostic test instrument. With the use of a cross-sectional survey design, 345 senior high chemistry students were randomly selected to participate in the study. The quantitative data collected were analyzed using descriptive statistics. The findings of the study revealed the nature of students' alternative conceptions in OQA as significant and genuine. The study, therefore, recommended to chemistry teachers and educators to help not only diagnose students' alternative conceptions but also explore the nature of their alternative conceptions as this helps in selecting more effective instructional teaching strategies that cause conceptual changes in students to help improve their conceptualization of abstract chemistry concepts.

Keywords: organic qualitative analysis, functional groups detection, alternative conceptions, four-tier diagnostic test instrument

INTRODUCTION

Chemistry fundamentally deals with the study of matter and the changes it undergoes (Ebbing & Gammon, 2005). Chemical analysis is a vital tool in learning other chemistry-related concepts in the areas of medicine, the chemical industry, government, and academic laboratories throughout the world due to its interdisciplinary nature. Learning chemical analysis in chemistry falls in the area of analytical chemistry. Analytical chemistry consists of a set of powerful ideas and methods that are useful in all fields of science, medicine, and engineering (Skoog et al., 2014). The scope of analytical chemistry continues to be vital and evolve due to its enormous applications in other scientific-related fields such as biology, materials science, ecology, medicine, and forensic science. For instance, analytical concepts are employed to determine the identity and amount of major, minor and traces of elements in substances; concentrations of oxygen and carbon (IV) oxide (CO_2) are determined to diagnose and treat many illnesses; quantities of hydrocarbons (compounds containing carbon and hydrogen only), oxides of nitrogen (such as nitrogen (II) oxide (NO), nitrogen (IV) oxide (NO_2), and carbon (II) oxide (CO) present in exhaust gases from automobiles are determined using chemical analysis (Atkins & Carey, 1990; Fessenden & Fessenden, 1994).

Analytical chemistry is broadly classified into quantitative analysis and qualitative analysis (Ministry of Education [MOE], 2010). Quantitative analysis deals with the estimation of constituents of a substance whereas qualitative analysis deals with the identification and detection of constituents of a substance or mixture of substances in solutions (Dash, 2011). Qualitative analysis is further categorized into inorganic qualitative analysis and organic qualitative analysis (OQA). The inorganic qualitative analysis considers the identification of inorganic ions (cations and anions) and gases, and OQA deals with the detection of functional groups in organic compounds (Fieser & Williamson, 1992).

OQA is a concept in organic chemistry that helps students understand the fundamental concepts of the structure and reactivity of organic compounds (Adu-Gyamfi & Anim-Eduful, 2022). Learning of chemical properties and reactions of organic compounds is abstract, difficult, and complicated (Vishnoi, 2009) for students to learn. Notwithstanding, students with a deep understanding of elemental chemical analysis make it possible to identify functional groups such as

alkenes, alkynes, alkanols, alkanoic (carboxylic) acids, alkylalkanoates (esters), alkanals, alkanones, and amides (MOE, 2010) in solutions. Again, chemical analysis in OQA does not only help students improve their experimental techniques in organic chemistry but also inculcates in students the spirit of deductive reasoning thus enabling students to apply theoretical knowledge acquired in practical problems in their daily lives. To Fieser and Williamson (1992), OQA offers students the opportunity to identify unknown chemicals in substances including toxic substances. Identification of functional group in organic chemistry occurs when there is a chemical reaction between organic solutions and suitable oxidizing and reducing reagents such as acidified potassium heptaoxodichromate (VI), brown bromine solution, ammoniacalsilvernitrate ($AgNO_3/NH_3$), sodium trioxonitrate (IV) (Na_2CO_3) and acidified potassium tetraoxomanganate (VII) (Atkins & Carey, 1990; Ebbing & Gammon, 2005; Fieser & Williamson, 1992). A functional group is a specific combination of bonded atoms that reacts in a characteristic way for easy identification (Silberberg, 2000). Functional group detection is usually the more appropriate way of identifying and recognizing functional groups in organic compounds through chemical reactions and mechanisms. Vishnoi (2009) reports that the three most important and common problems students encounter in OQA concepts are the separation of mixtures of organic compounds; identification of organic compounds, and preparation of organic compounds (in this study, we considered the identification of organic functional groups in compounds.

Organic chemistry, which is the study of carbon-containing compounds (Ebbing & Gammon, 2005; Fessenden & Fessenden, 1994; Fieser & Williamson, 1992) consists of many concepts (MOE, 2010) such as nomenclature of structures, physical and chemical properties, separation and purification of compounds, chemical reactions and mechanisms, detections of functional groups (MOE, 2010, p. 46-51). Researchers have revealed that students have difficulties in many of these concepts in organic chemistry. For instance, concepts of nomenclature of organic compounds using IUPAC system by (Adu-Gyamfi et al., 2013, 2017), organic reactions and mechanisms (Bhattacharyya & Bodner 2005; Ferguson & Bodner, 2008; Graulich, 2015; Tang et al., 2010; Wasacz, 2010) functional groups detection (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b). For example, we reported in our study (Anim-Eduful & Adu-Gyamfi 2022b) that senior high school (SHS) chemistry students demonstrated conceptual difficulties at a level of no scientific understanding in the detection of organic functional groups such as hydrocarbons (such as alkenes, alkynes, and benzene), alkanols, alkanoic (carboxylic) acids, alkylalkanoates (esters), alkanals (aldehydes), alkenones (ketones) and amides using a two-tier diagnostic test. The study further revealed that students' conceptual difficulties were categorized as factual difficulties, and alternative conceptions were envisaged in all the functional groups. However, this study did not report on the nature of alternative conceptions held by the students.

In Ghana, chemical analysis is one of the important areas of chemistry that is introduced to students at SHS level (MOE, 2010). One of the major objectives of the chemistry curriculum is for chemistry students not only to acquire a deep understanding of chemical analysis of compounds to stimulate their analytical thinking but also to demonstrate knowledge of characteristic tests for functional groups (MOE, 2010, p. vii). This, perhaps, necessitated the developers of the Ghanaian chemistry curriculum to recommend students acquire analytical skills to help them appreciate and conceptualize chemical analysis of compounds in solutions. Students' deep knowledge of chemical analysis in functional group detection enhances their conceptual understanding of and help improve their scientific reasoning in other chemistry concepts (MOE, 2010). However, notwithstanding the importance of chemical analysis to students, empirical studies (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2022a, 2022b) have reported students' difficulties in learning OQA concepts.

Many studies have revealed students' difficulties in organic chemistry concepts (Adu-Gyamfi & Asaki, 2022, 2023; Adu-Gyamfi et al., 2013, 2017; Bhattacharyya & Bodner, 2005; Childs & Sheehan, 2009; Ferguson & Bodner, 2008; Graulich, 2015; Wasacz, 2010). However, very few focused on OQA concept (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022a, 2022b) in organic chemistry. An examination of literature on students' difficulties in learning OQA have shown that all these studies mainly focused on investigating students' level of understanding and their conceptual difficulties (that is, their factual difficulties and their alternative conceptions) in OQA. However, none of these studies has focused on the nature of students' alternative conceptions in OQA. For instance, Anim-Eduful and Adu-Gyamfi (2022b) investigated students' conceptual difficulties using a two-tier diagnostic test, which consisted of an answer-tier (A-tier) containing four options with three distractions and one correct answer. The answer tier sought for students' content knowledge. The second tier of the instrument was of an open-ended type that sought students' explanations (reasons-tier, R-tier) to the selected answers in the A-tier. In that study, we classified students to have alternative conceptions on the basis that either students scored both tiers incorrectly (no scientific understanding) or scored any of the two-tier correctly (partial scientific understanding), but students who scored both tier correctly were classified to have full scientific understanding.

As science educators, we sought to investigate further about the nature of students alternative conceptions known which has not been reported in the previous studies (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b) in OQA is what is missing (the gap) in the literature about students conceptual difficulties (alternative conceptions) in OQA. There is a need to further investigate students' alternative conceptions to help determine whether their alternative conceptions were genuine or were due to a lack of knowledge in OQA. Again, with respect to students classified to have full scientific understanding (correctly scored both tier), probably their understanding could be due to guessing of answers but not entirely complete understanding of the concept or could also be based on genuine understanding of OQA concepts. These are the gaps previous studies could not report hence, this current study seeks to fill.

Previous studies on OQA could not account for the nature of students' alternative conceptions purposely due to the type of instrument (two-tier diagnostic test) used. This could be the

main limitation of two-tier diagnostic test resulting in a research gap in the literature about the nature of alternative conceptions in OQA held by students. It will be, therefore, appropriate for us to investigate the nature of students' alternative conceptions in OQA using a more robust instrument. For the nature of students' alternative conception in OQA to be investigated and help fill the gap in the literature, a more robust diagnostic test instrument could be developed and tested to overcome these limitations of two-tier instrument.

Sreenivasulu and Subramaniam, (2013) viewed learning as a process that results in a conceptual change. Learning occurs when learners are able to organize and integrate new knowledge acquired into their pre-existing knowledge (Sreenivasulu & Subramaniam, 2013). Students' cognitive structures (misconceptions), which are contrary to scientifically accepted explanations by the scientific community are resistant to conceptual change. Thus, students with alternative conceptions in chemistry concepts could have difficulties learning meaningfully and also understanding the taught concepts (Caleon & Subramaniam, 2010; Mutlu & Sesen, 2016; Palmer, 2001; Treagust, 1995). Students' alternative conceptions greatly interfere with their conceptual understanding of science concepts (Sreenivasulu & Subramaniam, 2013). It is necessary for science educators and researchers to diagnose students' alternative conceptions (misconceptions) to help educators develop and use more efficient and effective instructional teaching strategies that stimulate conceptual change in students in order for them [learners] to facilitate their comprehension of these science concepts. Students can achieve meaningful learning when a multiple choice diagnostic instrument such as the four-tier diagnostic test (Caleon & Subramaniam, 2010; Hoe & Subramaniam, 2016) is used for students' conceptual difficulties to be diagnosed.

The limitations of the two-tier diagnostic test instrument made it difficult for previous studies in OQA (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b) to determine the nature of students' alternative conceptions. The limitation of the two-tier could be addressed significantly by incorporating confidence rating into both tiers (A- and R-tier) to become a four-tier multiple-choice diagnostic test instrument (Caleon & Subramaniam, 2010). The four-tier diagnostic test items consisted of answer tier (A-tier) for students' content knowledge and a reason tier (R-tier) for students explanation knowledge making it a two-tier and confidence rating at each tier making it a four-tier diagnostic test (Caleon & Subramaniam, 2010). The four-tier makes available confidence ratings to students to rate their level of confidence in their selected responses in the A- and R-tier, which measures the accuracy and precision of their selected options in both tier. The confidence ratings ranged from Just guessing (1) to absolutely confident (6).

Myriads of studies (Caleon & Subramaniam, 2010; Hoe & Subramaniam, 2016; Onder-Celikkanli & Tan, 2022; Sreenivasulu & Subramaniam, 2013) have revealed the effectiveness of four-tier diagnostic test in investigating students' alternative conceptions and the nature of those alternative conceptions in other science- related concepts. For instance, a study conducted in Singapore by Sreenivasulu and Subramaniam (2013) explored 296 undergraduate chemistry students' understanding of thermodynamics using four-tier diagnostic instrument. Findings of the study revealed that students harbored as many as 34 alternative conceptions in thermodynamics concepts and the strength of these alternative conceptions held by students were made known. Sreenivasulu and Subramaniam (2013), therefore, suggested that not only do four-tier diagnostic instrument help diagnose students' alternative conceptions in thermodynamics concepts in physics but also has the potential of determining the nature of students' alternative conceptions.

Similarly, in Singapore, Hoe and Subramaniam (2016) explored the alternative conceptions held by grade 9 students in acid-base concepts in chemistry using the four-tier diagnostic instrument. The study revealed that grade 9 students harbored 30 alternative conceptions in acid-base concepts such as properties of acids and bases, strengths of acids and bases, pH, neutralization reactions, indicators and sub-microscopic views of acids and bases. Hoe and Subramaniam (2016) concluded in their study that, the four-tier diagnostic instrument is effective in determining the strength of students' alternative conceptions in acids and bases. Subsequently, a more recent study conducted in Turkey by Onder-Celikkanli and Tan (2022) investigated tenth-grade students' misconceptions about electric charge imbalance using a four-tier diagnostic misconceptions test was administered to 402 students. Findings of the study suggested that the four-tier diagnostic instrument helped determine misconceptions harbored by students in their learning of electric charge imbalance in physics. Due to the effectiveness of the four-tier diagnostic test instrument in diagnosing misconceptions held by students, Onder-Celikkanli and Tan (2022) recommended the use of such an instrument. This is because these tiers help identify what students know (either they know by guessing or are genuine) and what they do not know. Studies above have shown the effectiveness of the four-tier diagnostic test instrument in investigating the nature of students' alternative conceptions of science concepts of which chemistry is not an exception. It is, therefore, appropriate to investigate the nature of chemistry students' alternative conceptions in OQA using a four-tier diagnostic test instrument.

In Ghana, the West African Examination Council (WAEC) chemistry chief examiner's reports (WAEC, 2015, 2016, 2017, 2018, 2019, 2020) have also reported on Ghanaian SHS chemistry students' difficulties in answering standardized test items on OQA (functional group detection) during their examinations. However, chief examiners reports have not indicated the nature of students' alternative conceptions in learning OQA concepts. That is, whether students' alternative conceptions in OQA are significant or otherwise and whether these alternative conceptions are due to students' lack of knowledge or lack of understanding of the concepts. Studies in OQA (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b), were silent on the nature of alternative conceptions shown by students. This is to say that these studies could not report whether students' correct answers provided as explanations to the concepts (suggesting understanding) were due to correct reasoning or due to guessing. Consequently, there is a lack of evidence in the

literature to show that students with incorrect answers (misconceptions) were due to wrong reasoning or lack of knowledge of the concepts but not lack of understanding of the concepts leading to their alternative conceptions. Hence, the need for this study.

As evidence abounds in the literature about the effectiveness of a four-tier diagnostic test instrument in investigating the nature of students' alternative conceptions in other science-related concepts (Hoe & Subramaniam, 2016; Onder-Celikkanli & Tan, 2022; Sreenivasulu & Subramaniam, 2013) but not in OQA. It will, therefore, be appropriate to investigate the nature of students' alternative conceptions in OQA using a four-tier diagnostic test instrument. This study will help to a larger extent, contribute to the body of knowledge, as the findings will expand the boundary of existing literature on students' alternative conceptions in OQA and also contribute to the existing body of knowledge in organic chemistry by accounting for the nature of students' alternative conceptions in OQA. Again, the findings of this study will inform policy and decision-making towards teaching and learning of OQA and organic chemistry as a whole at the high school level and even beyond.

METHODS

Research Design

This study employed a cross-sectional survey design (Creswell, 2014). This design helped to collect quantitative data from a sampled population at the same period.

Sample & Sampling Procedures

This study was carried out in Cape Coast Metropolis in the Central Region of Ghana. There were 10 SHSs in Cape Coast Metropolis for the 2022/2023 academic year. The target population for this study was all SHS 3 chemistry students offering elective chemistry as an elective subject for the 2022/2023 academic year in all the ten schools in the Metropolis. This was because organic chemistry is taught at SHS 2 (MOE, 2010), hence SHS 3 chemistry students had studied the concept in form 2, and hence had covered enough of the concepts. Thus, SHS 3 students were in the position to help obtain data required for this study than those in SHS 1 and SHS 2. Schools in Cape Coast Metropolis were selected for this study because, all three categories (category A, category B, and category C) of schools (MOE, 2010) in Ghana were present within the Metropolis and students in these categories of schools possess similar characteristics as other students in similar schools in other 15 regions in Ghana.

The ten schools were stratified into three strata as category A, category B, and category C (MOE, 2010). There were five category A schools, two category B and three category C schools. Two schools each were randomly selected from two categories (category A and category C) and the two category B schools were purposively selected. In all, six schools out of the ten schools were selected to participate in the study. This was to ensure that every chemistry student in the ten schools had equal chance of being selected to participate in the study. At the time of data collection, only three schools (one each from the three categories) had covered enough in OQA, thus, 345 SHS3 students from three schools within the metropolis participated in the study. This implies that the other three schools had not covered enough content in OQA required of them to respond to the test items appropriately and hence could not participate in the study.

Research Instrument

The instrument used in this study was an achievement test in the form of a diagnostic test (a four-tier-multiple-choice diagnostic test). The diagnostic test based on functional group detection such as hydrocarbons (alkanes, alkenes, alkynes, and benzene), alkanols, alkanoic acids, aldehydes, ketones, and amides consisting of 17 items was adapted from (Adu-Gyamfi & Anim-Eduful, 2022) dubbed organic qualitative analysis diagnostic test (OQADT). The instrument, which was two-tier (content knowledge (A-tier) and open-ended (R-tier) originally, was modified to suit the current study. The modification was done in two phases. In the first phase, the open-ended part (reason-tier, R-tier) was developed by studying available alternative conceptions reported in the literature (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b). These alternative conceptions were used as distractors in the options part of the R-tier. At this point, the instrument had become a complete two-tier with four options for both the A-tier and R-tier. That is, content knowledge (A-tier) and explanation knowledge (R-tier) with four options under each tier. During the second phase, confidence ratings were incorporated at each tier making it a complete four-tier instrument; four-tier organic qualitative analysis test (FTOQAT). The intent of the four-tier multiple-choice diagnostic test was to help measure nature of students' alternative conceptions in OQA. The confidence ratings were incorporated to help measure the certainty level of students' answer selection. That is, to determine both students' correct content conceptions on OQA and whether their reasons were genuine and not guessing, likewise their incorrect responses. In all, the developed FTOQAT had 17 test items.

Purpose of Study

The purpose of this study was to investigate the nature of students' alternative conceptions using a four-tier diagnostic test instrument. That is, to determine whether students are able to segregate their mistakes resulting from lack of knowledge from mistakes due to genuine alternative conceptions or able to distinguish correct answers based on guessing from correct answers based on genuine understanding. Based on this purpose, the study sought to answer the question: *What is the nature of students' alternative conception in OQA?*

Validity & Reliability of Research Instrument

To ensure face validity of the four-tier diagnostic test instrument, it was shown to two experienced colleague chemistry teachers who were examiners and a science educator for expert advice. Their input helped to fine-tune the instruments before it was pilot-tested. Thereafter, the instrument was pilot-tested with 69 SHS 3 chemistry students from two schools in Abura-Asebu-Kwamankese District, a District in Central Region of Ghana. Students in the pilot-tested schools had similar characteristics as those who participated in the main study. The purpose of the pilot-

testing was to help determine the item difficulty level of the test items and also to establish the reliability coefficient of the instrument. After the pilot-testing, four items (6, 9, 15, and 17) were deleted because they measured the same functional groups hence the deletion. In all, 13 items remained after the deletion. Thereafter, Kuder-Richardson 21 (KR-21) reliability coefficient was calculated to determine the internal consistency of the instrument. The instrument was reliable as the calculated KR-21 value was .81.

Data Collection Procedure

Before the data collection, we had a brief discussion with teachers teaching the third-year students to ascertain whether they (teachers) had covered the concepts of OQA in organic chemistry. Thereafter, we also briefed the students about the relevance and the need for participating in the study as they were preparing to write their final examination conducted by WAEC. Permission was sought from the authorities of the participating schools for smooth data collection. This was to help have data collected without any difficulties and also ensure corporation among participants. In all, we spent two weeks collecting data from 345 SHS 3 chemistry students selected from three schools in Cape Coast Metropolis.

Data Processing & Analysis

Data collected on every item on FTOQAT was analysed according to Caleon and Subramaniam (2010) using descriptive statistics (such as percentages, frequencies, standard deviation, and mean). The answer tier and it corresponding reason tier were scored separately as: '0' and '1' for each incorrect and correct response respectively. Again, a value of '1'was assigned when both (A- and R-tier) were correct and '0' when otherwise (both items been incorrect) (Caleon & Subramaniam, 2010). Some relevant variables were calculated from students' confidence ratings for both tiers, which were mean values of students' confidence ratings for the answer tier and reason tier, and also for the test items: overall mean confidence (CF); (CFC) for confidence of students when correct answers provided; (CFW) confidence of students when wrong answers provided. Confidence discrimination quotient (CDQ) was calculated as CDQ=CFC-CFW/standard deviation of confidence. CDQ indicates whether students discriminate between what they know and what they do not know. Confidence ratings of students' alternative conceptions were further classified as follows:

A significant alternative conception, which refers to a particular option or A-R options, which were chosen by 10% of the sample above the percentage of students who select the option or A-R options by chance. Significant alternative conceptions were further categorized into two: genuine and spurious.

1. **A spurious alternative conception:** It is a type of significant alternative conception that was expressed by students with low confidence ratings below 3.50. This is due to students' lack of knowledge or guessing.
2. **A genuine alternative conception:** A type of significant alternative conception that was expressed with confidence associated with a mean confidence rating of above 3.50. This indicates that students' alternative conceptions were due to a lack of understanding of the concepts (A-tier) and the application of wrong reasoning (R-tier). Genuine alternative conceptions were categorized further into two: moderate and strong. Moderate alternative conceptions is a type of genuine alternative conceptions expressed by students with medium level of mean confident ratings between 3.50 and 4.0 and strong alternative conceptions been a type of genuine alternative conceptions expressed with high level mean confidence ratings of 4.0 and above. **Table 1** shows summary of categorization of students' alternative conceptions as adopted from Caleon and Subramaniam (2010).

Table 1. Categorization of students' alternative conceptions

Alternative conceptions	Question numbers	n
Spurious(M<3.50)	3 & 8	2
Genuine (M>3.50)	1, 2, 4-7, & 9-13	11
Genuine (moderate) (M=3.50-3.99)	5-7 & 9-13	8
Genuine (strong) (M>3.99	1, 2, & 4	3

Note. Source: Caleon and Subramaniam (2010) & n: Number of items

RESULTS & DISCUSSION

This study sought to investigate the nature of students' alternative conceptions in OQA using four-tier diagnostic test items. To achieve the purpose of this study, mean confidence ratings for A-tier, R-tier, and both tiers were calculated. Mean values for confidence ratings for all tiers helped to answer the research question raised. Even though students' response to items measuring their content knowledge (A-tier) and explanation knowledge (R-tier) revealed that students harbored alternative conceptions, such alternative conceptions were not reported. This was because students' alternative conceptions on OQA had already been reported in authors' previous studies. Generally, all the alternative conceptions harbored by students on OQA in this study were significant. That is, the options for (either answer-tier or reason-tier) or answer-tier and reason-tier (A-R) were chosen by 10% of the students sample, which was above the percentage of students who selected that particular option or A-R options by chance. Of the 13 items of which students harbored significant alternative conceptions, only two items (3 and 8) were spurious (that is, had mean values to be less than 3.50) and the remaining 11 were genuine (mean values been greater than 3.50). This implies that the alternative conceptions exhibited by students in the two items (3 and 8) were due to students' lack of knowledge in OQA. Although students' alternative conceptions were all significant, they were classified as spurious alternative conceptions because they were as a result of lack of knowledge of the concepts but not alternative conceptions that exist within students' cognitive structures due to lack of understanding. Such alternative conception could be subjected to conceptual change with effective conceptual change teaching instructional strategy. However, the rest of the alternative conceptions expressed by students in the other eleven were classified as genuine. Students' alternative conceptions classified as genuine indicate that those conceptions were due to a lack of understanding of the concepts and application of

Table 2. Proportion of students' relevant confidence variables per question (n=345)

Item	Prop. correct			A-tier				R-tier				B-tier			
	A-tier	R-tier	B-tier	CF	CFC	CFW	CDQ	CF	CFC	CFW	CDQ	CF	CFC	CFW	CDQ
Q1	.77	.77	.77	4.64	4.73	4.40	0.19	4.26	4.25	4.19	0.06	4.34	4.22	4.45	-0.14
Q2	.68	.65	.68	4.03	4.17	3.71	0.27	4.17	4.12	4.30	-0.17	4.34	4.03	4.65	-0.39
Q3	.81	.65	.81	4.09	4.14	3.82	0.19	3.64	3.78	3.50	0.26	3.80	3.81	3.78	0.02
Q4	.52	.54	.52	3.94	3.92	3.97	-0.03	3.81	3.69	3.97	-0.26	4.04	3.53	4.55	-0.64
Q5	.73	.67	.72	4.00	3.80	4.56	-0.44	3.74	3.65	3.91	-0.24	3.95	3.78	4.15	-0.23
Q6	.54	.51	.54	3.46	3.38	3.57	-0.11	3.51	3.43	3.78	-0.32	3.72	3.50	3.94	-0.28
Q7	.70	.74	.70	3.67	3.81	3.33	0.28	3.68	3.77	4.05	-0.26	4.58	4.87	4.29	0.36
Q8	.23	.23	.23	3.42	3.53	3.51	0.01	3.57	3.58	3.80	-0.20	3.59	3.29	3.89	-0.38
Q9	.67	.68	.67	3.64	3.81	3.27	0.32	3.41	3.69	2.76	0.85	3.42	3.74	3.10	0.40
Q10	.67	.70	.70	3.30	3.44	3.24	0.12	3.16	3.19	3.64	-0.41	3.54	3.26	3.82	-0.35
Q11	.78	.78	.78	3.49	3.34	4.00	-0.39	3.52	3.17	4.59	-1.30	3.87	3.15	4.59	-0.91
Q12	.59	.55	.59	3.51	3.62	3.46	0.09	3.65	3.83	3.61	0.20	3.75	3.83	3.67	0.10
Q13	.61	.59	.61	3.51	3.50	3.34	0.09	3.55	3.50	3.62	-0.11	3.55	3.55	3.55	0.00
M	.64	.62	.64	3.75	3.78	3.70	0.05	3.66	3.67	3.83	-0.07	3.61	3.74	4.04	-0.19
SD	.48	.45	.46	1.71	1.65	1.77		1.09	0.48	1.69		1.59	1.61	1.57	

Note. M: Mean & SD: Standard deviation

wrong reasoning to their correctly answered A-tier. This implies that students' alternative conception in 11 items were due to students' lack of understanding of concepts (**Table 1**).

As seen in **Table 1**, three items (item 1, item 2, and item 4) of the eleven genuine alternative conceptions were strong alternative conceptions (M=3.50-3.99). This implies that students had a mean confidence rating in those three items to be above 3.99 and eight of the alternative conceptions being moderate had a mean confidence rating between 3.50 to 3.99. Students exhibiting eleven out of the thirteen test items on OQA to be genuine indicate that students' conceptual difficulties in learning OQA concepts were accompanied by alternative conceptions. This means that even when students correctly answered the content knowledge (A-tier), they selected wrong reasoning to justify their correct answers. This shows that students show little awareness of their conceptual difficulties, implying they do not know that they do not understand the concepts of OQA.

It is worth noting that students' alternative conceptions in OQA were significant (M>3.50) and this could be deep-rooted within their cognitive structures. With students' alternative conceptions been significant in all the items, this could impede their further learning of chemistry concepts related to OQA. It could be seen in **Table 1** that the nature of students' alternative conceptions was significant as all mean values for students' alternative conceptions were greater than 3.50.

The four-tier diagnostic test with confidence ratings embedded in a two-tier (answer-tier and reason-tier) instrument was able to measure veracity of students confident regarding their answer response selections in both A- and R-tiers. Confidence ratings for each of the 13 test items were summarized as seen in **Table 2**.

The average mean confidence (CF) for A-tier and R- tier were (M=3.75) and (M=3.66) respectively whereas that of each tier was (M=3.61). The mean CFC for the A-tier was 3.78 while that of CFW was 3.70. These CFC and CFW values for the A-tier suggest what confidence ratings students assign to their selection whether their selection is correctly scored or otherwise.

CFC and CFW values for all tiers suggest that when the value is less than (M=4.0), it implies that students were unable to assign the highest confidence rating when the test item is answered correctly. This also indicates that students also fail to assign lowest confidence rating when the test item is wrongly answered. As seen in **Table 2**, only three A-tier items (item 1, item 2, and item 3) had CFC value to be above 4.0 and the rest of the ten item values were less than 4.0. This implies that for the ten items, although students' scores were correct, they failed to assign the highest confidence rating for the certainty of their responses. This suggests that even when students conceptually understood the concepts with correct score, still had low confidents regarding accuracy of their responses. This is interesting and could be that students do not know that they conceptually understand OQA concepts. With regards to the three items, students confidently assigned highest confidents ratings to correctly scored items.

On the other hand, three items (1, 5, and 11) had CFW value to be less than 4.0, and the remaining ten of the items value were above 4.0. This suggests that although students' scores were wrong, yet they failed to assign lowest possible confidence rating. This suggest that while students exhibit alternative conceptions in those items, they still assigned high confident rating indicating that students were oblivious of their difficulties in OQA (that is, students do not know that they do not conceptually understand the concepts in OQA). This makes students alternative conceptions to be due to their lack of understanding of the concepts but not due to students lack of knowledge.

For the R-tier, only two items (1 and 2) had CFC values to be above 4.0, and the remaining eleven items had CFC values to be below 4.0. This seems to suggest that when students' scores in the explanation knowledge (R-tier) were wrong, they were unable to assign the lowest confidence rating but rather assigned high confidence rating. This seems to suggest that more of the students' correct responses were due to a lack of understanding of concepts but unlikely to be due to a lack of knowledge of the concepts.

As seen in **Table 2**, CFW for four items (1, 2, 7, and 11) on the reason tier had their values to be above 4.0 and the remaining nine items had CFW values to be below 4.0. This

implies that even when students were wrong in their explanation, continued not to assign the lowest possible confident ratings. Once again, students' responses in justifying their A-tier were purely alternative conceptions due to their lack of understanding of the concepts in OQA but not due to lack of knowledge. This means students express high confidence ratings for their wrong explanations when their [students] explanations presented are scientifically unaccepted.

Furthermore, on both tiers, three items (1, 2, and 7) had CFC values to be higher than 4.0 and ten of the items CFC values were below 4.0. This implies that students assigned highest confidence ratings to their incorrect responses. Little over half (53.8%) of the students' responses had CFW value to be below 4.0. This indicates that students assigned lowest confidence ratings when their scores were incorrect. This seems to suggest that majority of the students were able to know that they had conceptual difficulties in OQA concepts.

CDQ values were calculated to help determine students' discrimination power, that is, how well they are able to discriminate what they know from what they do not know. Students exhibit low discriminating power when CDQ values for the item is negative. This implies that students fail to discriminate well between what they know and what they do not know. However, students exhibit high discriminating power when CDQ values for the items are positive. This implies that students strongly discriminate well between what they know and what they do not know.

For instance, students' responses regarding A-tier had four items (4, 5, 6, and 11); that of R-tier had nine items (2, 4, 5, 6, 7, 8, 10, 11, and 13) and eight items (1, 2, 4, 5, 6, 8, 10, and 11) for both-tier had negative CDQ values. This implies that A-tier recorded the lowest number of items students showing highest discriminating power (were able to discriminate what they know from what they do not know). Students' responses to both-tier items recorded the lower discriminating power of eight items (were able to discriminate what they know from what they do not know) with students' response to the R-tier recording the highest number of items students showed lowest discriminating power (were unable to discriminate what they know from what they do not know). This seems to suggest that many students failed to discriminate well between what they know and what they do not know with more seen in the R-tier followed by both-tier with A-tier being the least.

Findings of this study suggest that nature of alternative conceptions harbored by students' in OQA were significant (spurious and genuine). This implies that students' alternative conceptions were due to lack of understanding of the concepts but not due to lack of knowledge. This study has not only confirmed previous studies (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b) that students have conceptual difficulties accompanied with alternative conceptions in OQA but has shown the nature of students' alternative conception to be significant and genuine, which are due to their lack of understanding of the concept. Students' alternative conceptions were not only due to lack of understanding of the concepts but also due to application of wrong reasoning in their quest of explaining or providing reasons to justify their content knowledge. With few of students' alternative conceptions been genuine perhaps, could also be due to students been oblivious of the difficult nature of organic functional group detection concepts. Again, with few of students' alternative conceptions been spurious indicates that students' difficulties in learning of OQA could be due to lack of knowledge of the concepts or guessing but not necessarily due to their lack of understanding of the concepts.

This study has shown that not all incorrect answer responses from students could be a genuine alternative conception, as this could also be mistakes in students' selections of answer options. This was seen as students assigned high confidence rating to their incorrect answers. In the same vein, this study has shown that not all correct answers from students are due to conceptual understanding of the concepts but could be due to guessing yielding correct answers. This was envisaged in the study as students assigned lowest confidence ratings when they had scored correctly. These findings seem to suggest that students were uncertain of their understanding of OQA concepts as they failed to assign high confident rating to their selected options regarding correct responses. Not only were students oblivious to the difficult nature of OQA concepts but they also doubted their understanding of the concepts with little or no confidence. Students doubting their understanding could also be due to their weak content knowledge in OQA. Students were with low confidence ratings with correct responses, especially to both A-tier and R-tier. This could be the reason students failed to assign the highest confidence rating when their responses to the concepts were even correct.

Furthermore, this study has shown that students exhibited low discrimination power to most of the items. That is, they were unable to discriminate well between what they do know and what they do not know. Students exhibited low discrimination power for the explanation of concepts (R-tier) followed by both tiers, but the answer (A-tier) had high discrimination power. This implies that students were able to distinguish between what they know and what they do not know for the A-tier. This could be that students were good at answering questions that required a response in declarative learning ('what is') much better than answering questions that required explanatory responses found in explicative learning ('why'). The findings of this study suggest that students have more conceptual difficulties in assigning reasons or explanations to a particular phenomenon than to indicate what the phenomenon is. This could be the reasons students harbored alternatives conceptions in OQA (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022b)

Furthermore, the study has shown that students' lack of conceptual understanding in OQA concepts could influence their learning of chemical analysis not only in OQA concepts but also in other chemistry concepts such as organic reactions. This could be the reason why students exhibit difficulties in understanding organic reactions and mechanisms regarding all functional groups. With students having conceptual difficulties in explanation knowledge (R-tier) than in content knowledge (A-tier) indicate that students have more difficulties providing scientifically accepted explanations in justifying and explaining chemical analysis phenomenon. This indicates that students are more interested in declarative learning ('what is') much more than explicative learning ('why').

With regards to the effectiveness of four-tier diagnostic test, findings of this study have shown that not only is the four-tier diagnostic test effective in investigating students' alternative conceptions (Caleon & Subramaniam, 2010; Sreenivasulu & Subramaniam, 2013) but is also effective and efficient in investigating nature of students' alternative conceptions as well. The four-tier diagnostic test instrument was also effective in determining students' confidence ratings that is, the certainty of their selected responses.

CONCLUSIONS

This study sought to investigate the nature of students' alternative conceptions in OQA using a four-tier diagnostic test instrument. The study has revealed the nature of students' alternative conceptions of OQA to be significant and genuine indicating students' alternative conceptions were due to students' lack of understanding but not lack of knowledge of OQA concepts. On one hand, students assigned low confident ratings when they scored items correctly, and on the other hand, students assigned high confident ratings when their scores were incorrect. These findings indicate that students were more oblivious to the difficult nature of OQA. Again, this study has revealed that students perform better in A-tier than in R-tier, that is, they [students] scored more correctly in A-tier than in R-tier and assigned high confident ratings to A-tier responses when they were correct than when they were incorrect. Additionally, students exhibited low discrimination power to most of the items indicating their inability to discriminate between what they do know and what they do not know especially in the A-tier and R-tier, but more were seen in the latter.

Consequently, this study has showed that not all alternative conceptions exhibited and harbored by students are due to a lack of understanding of the concepts but could also be due to their lack of knowledge in the concepts. Students are good at answering questions that require a response in declarative learning ('what is') much better than answering questions that require explanatory responses in explicative learning (why).

Conclusively, the four-tier diagnostic test has been found in this study not only effective in diagnosing students' alternative conceptions but also efficient in investigating nature of students' alternative conceptions in OQA.

Recommendations

This current study investigated the nature of SHS students' alternative conceptions in OQA using a four-tier diagnostic test instrument. However, the study did not consider using an intervention to help improve students' conceptual understanding of OQA.

Studies in OQA have employed either a mixed-method research approach or a quantitative research approach using paper-test mode diagnosing students' alternative conceptions as seen in previous and current studies. However, no study on OQA has employed a qualitative research approach to obtain an in-depth understanding of the students' perspectives without limitation to writing. Hence, further studies should employ a qualitative research approach to explore students' conceptual understanding of OQA qualitatively.

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Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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