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SENIOR HIGH SCHOOL STUDENTS' DIFFICULTIES IN LEARNING HYBRIDISATION IN CHEMISTRY

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Abstract

The concept of hybridisation is one of the most difficult concepts for chemistry students to grasp at all levels of learning. Research showed the students conceptual difficulty ranged from their lack of the pre-requisite knowledge for grasping the topic hybridisation to chemical bond formation and orientations of atomic orbitals. This study investigated the difficulties Senior High School Students face in learning hybridisation. The study adopted a mixed-method approach using the sequential exploratory design. Purposive sampling was used to select six schools that offer elective chemistry subject. Simple random sampling was then used to select 120 Senior High School form 1 students to take part in the study. Convenient sampling was used to interview 24 students from the sample. Hybridisation Achievement Test (HAT) and Semi-structured interviews were self-constructed and used to collect data. Descriptive statistics and Content analysis were used to analyse the data. Results showed that, majority of students had difficulties in explaining the concept of hybrid orbitals, writing the electron configuration of $_6C$, explaining the effect of hybridisation on formation of chemical bonds in $_6C$, and type of hybridisation and shapes of compounds such as NH_3, OF_2, BCl_3, CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4. The study also showed that students had difficulties in explaining and demonstrating the formation of C = C double bond in ethene and other compounds. Equally students were challenged in demonstrating the differences between the formation of sigma and pi bonds in compounds. Students had difficulties in using electron orbital diagrams to explain the shape of CO_2 as linear. The study concluded that Senior High School form 1 chemistry students in the Upper West Region of Ghana lacked the most basic and fundamental concept of hybridisation. Teachers need to use conceptual change instructional approaches to teach hybridisation in order to foster students' understanding and reduce misconceptions.
Keywords: *atomic orbitals, hybrid orbitals, hybridisation, mixed- method approach*, *sigma and pi-bonds*

Introduction

The concept of hybridisation was proposed by Linus Pauling in 1931 to explain the rearrangement of the energy of individual atomic orbitals to produce new orbitals of equivalent energy. These newly formed orbitals, (hybrid orbitals), resulting from the mixing of other same or similar orbitals of different energies and shapes from other similar or same atoms form chemical bonds (Gillespie, 2004). The chemical bonds of compounds formed are either sigma or pi-bonds

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(Gillespie, 2004). The newly hybridised orbitals possess the geometry and bonding properties of the newly formed molecules of chemical compounds (Petrucci, 2007). The new hybrid orbitals formed have some of the properties of the different atomic orbitals which go into forming them (Ameyibor & Wiredu, 1993). Bempong et al., (2009) described hybridisation as the processes of mixing two or more different atomic orbitals of different energies and shapes of the same or different atoms to form new hybrid orbitals which are equivalent in energies and shape. During the mixing of atomic orbitals to form new hybrid orbitals, electrons of the interacting atoms are shared between atomic orbitals and paired in overlapping orbitals of the atoms. In this inter atomic orbital mixing, the shared pair of electrons, share and occupy the same region of space. The orbital overlapping interactions of the atoms balance inter electronic and nuclear repulsions of the interacting atoms. This then results in formation of most stable orbital configurations (Essah & Emmanuel, 2019).

Yet, Senior High School or Upper Secondary School Chemistry students, must have a firm grasp of the concept of hybridisation in order to predict molecular and electrical properties of substances (Essah & Emmanuel, 2019). In Ghana, the Senior High School chemistry syllabus emphasises the need for students to learn how to use models to help them explain molecular shapes and structures, chemical bonds, and their properties (Ministry of Education [MOE], 2010). This aim of the Ministry of Education, (2010) is not different from other African countries.

Research Problem

Recent studies showed that, majority of chemistry students have difficulty understanding and assimilating chemical topics (Essumang & Bentum, 2012). Many of the research studies showed that most Senior High School or Upper Secondary School Chemistry students frequently confuse orbitals, shells, and orbital mixing and are unable to distinguish between atomic and molecular orbitals (Çalış, 2018; Hanson et al., 2012; Koomson et al., 2020), and are therefore unable to comprehend the concept of hybridisation. Some specific students' misconceptions of chemical topics include but not limited to bond angles, shapes of molecules, and their difficulty in understanding concepts of isotopy and allotropy (Schmidt et al., 2003).

Many factors that contribute to students' misconceptions of chemical topics and their subsequent poor academic achievement, including inadequate preparation by teachers, lead to poor instructional techniques employed by chemistry teachers (Okebukola, 2005); the inability of students to understand basic chemistry concepts; teachers inability to explain the sub-microscopic, macroscopic and symbolic learning (Taber, 2001); and the inability of learners to understand basic concepts in chemistry (Taber, 2001). Yet other studies found that students have trouble recognising chemical bonds (Demirci et al., 2016; Harrison & Treaguest, 2000; Kabapinar & Adik, 2006; Şen, & Yilmaz, 2013) and distinguishing chemical bonds from each other (Adik, 2003; Unal et al., 2001).

Koomson et al., (2020) found that, the hybridisation state of central atoms in molecules was a challenge for students to determine. They also reported that students were perplexed by the angles of the bonds in BCl_3 and C_2H_2 chemical compounds and couldn't relate the shape of the molecular species. Other research studies reported that the concept of hybridisation and atomic orbitals is one of the most difficult concepts for students to grasp at all levels of learning (Çalış, 2018; Jian, 2014; Salah & Dumon, 2014). Çalış (2018) reported that majority of students struggled to use atomic and hybrid orbitals to explain the formation of sigma and pi bonds in ethane, ethene and ethyne. Again, Çalış (2018) found that students could not accurately demonstrate how the sp, sp^2, and sp^3 hybrid orbitals are formed.

The research therefore investigated into Senior High School students' difficulties in learning hybridisation in chemistry, especially in the Upper West Region of Ghana. This region is one of the regions in Ghana, in which Senior High School students performed abysmally in West African Senior High Schools' Examinations.

Research Question

This study sought to answer the question: What are the Senior High School students' learning difficulties in hybridisation in chemistry?

Research Methodology

General Background

The study adopted a mixed- method approach using the sequential exploratory mixed-method design. The mixed-method approach enabled the study to gather, analyse, and integrate qualitative and quantitative data of the research (Creswell, 2014). The philosophy that underpinned the study is the pragmatist paradigm.

Sample Procedure

The study targeted Senior High School first year chemistry students in the Upper West Region, Ghana. A multistage sampling technique was used to sample 120 Senior High School first year chemistry students for the study.

The first criterion used in the selection of the schools was Senior High Schools which offer chemistry as an elective subject. Twenty (20) Senior High Schools that offer chemistry as an elective subject were purposively sampled out of 32 Senior High Schools in the Upper West Region of Ghana. The Purposive sampling procedure was used because some of the Senior High Schools do not offer chemistry as an elective subject in their programme of instruction.

The second criterion of the multistage sampling technique was to select schools which were category A Senior High Schools in the classification of Ghana Education Service category, and six schools were purposively selected.

The third criterion of the multistage sampling technique was to select intact classes and six intact classes were simple randomly selected from each of the six category A Senior High Schools. At the fourth stage, twenty-four (24) students comprising of four (4) students each from the six intact classes were conveniently selected to take part in the interview. The selection was based on their performance in the hybridisation achievement test and included those who performed very well and those who performed poorly.

Research Instruments

Two instruments were used to collect data: Hybridisation Achievement Test (HAT) and Semi-structured interviews.

Hybridisation Achievement Test (HAT)

The Hybridisation Achievement Test (HAT) consisted of 15 open-ended questions on the concept of hybridisation. The questions were developed to cover areas such as concept of hybridisation, types and formation of hybrid orbitals and shapes of molecular compounds and formation of sigma and pi bonds. These topics were outsourced in the chemistry curriculum in Ghana (MOE, 2010). The questions were self-constructed to reflect concepts of the topic hybridisation in the chemistry curriculum. This was undertaken to identify major concepts students are supposed to learn. The items were developed based on the profile dimensions outlined in the curriculum, based on the Bloom's taxonomy of learning domains. Works of other researchers from literature on hybridisation also guided in the development of the items (Calis, 2018; Hanson et al., 2012; Koomson et al., 2020). The items were given to experts such as chemistry teachers and lecturers to make inputs and ensure content and face validity.

A rubric for scoring the test was developed and students' responses were put into three categories: Correct Response (CR), Wrong Response (WR) and No Response (NR). A student was categorised under correct response (CR) if all or most of his/her responses to an item were correct. A student was categorised under wrong response (WR) if most of his/her responses to an item were wrong. Students who did not attempt at all to the items were categorised as no response (NR).

The Hybridisation Achievement Test was piloted with 40 SHS students. This was done to determine the reliability and then to ensure that the items were without ambiguity and students understood the items. The Kuder-Richardson formula 21 (KR-21) was used to determine the reliability of the test. The reliability was found to be 0.97 suggesting that the test was reliable.

Semi-Structured Interview

The Semi-structured interview items were self-constructed. To ensure trustworthiness of the interview data, the interview protocol was given to experts to make inputs and pilot tested. The interview transcripts were read to the students to ensure that the responses were exactly what they intended to say. Twenty- four (24) students from the sample were interviewed.

Data Collection Procedure

Permission was sought from the Senior High Schools' administration using an introductory letter from the Science Education Department. A Pre-Test was conducted using the Hybridisation Achievement Test (HAT) to unearth the learning difficulties students have in hybridisation. The students were taught the concept of hybridisation by their teachers for a period of four weeks.

Post-Test was conducted after the instruction using the Hybridisation Achievement Test (HAT) to identify the learning difficulties of students. The items on the Pre-test and Post-test were similar.

Semi-structured interview was conducted to further identify students learning difficulties in hybridisation and to validate the responses from the Hybridisation Achievement Test (HAT). The interview was face to face and lasted between 30-60 minutes. The interview was recorded and transcribed verbatim.

Data Analysis

Data was analysed using Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics such as frequency was used to analyse the data. The frequencies were used to determine the number of students who gave Correct Responses, Wrong Responses or No responses to the items of the test.

Content analysis was used to analyse the interview data. Content analysis is an approach to quantify qualitative information by systematically sorting and comparing items of information in order to summarize them. Often this process entails turning a large set of raw data into useable evidence through data reduction methods (Hawkins, 2013). The data was coded and categories into themes were based on whether students' responses were correct or wrong. The results were presented in tables and figures.

Research Results

Learning difficulties students encounter in hybridisation

Difficulties in the Concept of Hybridisation

Table 1 shows the difficulties students have in the concept of hybridisation. These difficulties were revealed in their responses to items in the Hybridisation Achievement Test.

Table 1
Students' Learning Difficulties on the Concept of Hybridisation

Learning difficulties	Category	Pre-test		Post-test	
		f	%	*f*	%
Explaining the term hybridisation	NR	19	15.8	1	0.8
	WR	55	45.8	45	37.5
	CR	46	38.3	74	61.7
Explaining the term Hybrid orbitals	NR	45	37.5	12	10.0
	WR	67	55.8	87	72.5
	CR	8	6.7	21	17.5
Stating the effect of hybridisation on bonds.	NR	46	38.3	24	20.0
	WR	54	45.0	36	30.0
	CR	20	16.7	60	50.0
Writing the ground state Electron Configuration of $_6C$.	NR	24	20.0	3	2.5
	WR	50	41.7	50	41.7
	CR	46	38.3	67	55.8
Writing the excited state Electron Configuration of $_6C$.	NR	48	40.0	3	2.5
	WR	56	46.7	41	34.2
	CR	16	13.3	76	63.3
Stating the number of hybrid orbitals in $_6C$.	NR	35	29.2	8	6.7
	WR	62	51.7	77	64.2
	CR	23	19.2	35	29.2

(From researchers' data, 2021).
NR – No Response, WR – Wrong Response, CR – Correct Response

The pre-test results revealed that, many of the students gave wrong responses or did not respond to the items on the concept of hybridisation, hybrid orbitals, effect of hybridisation on bonds, ground state and excited state configuration of carbon and stating the number of hybrid orbitals in carbon. This implies that, before the instruction, students had difficulties in the concept of hybridisation.

From the post-test results, 74 of the students representing 61.7% correctly explained the term hybridisation. Also, 45 of the students representing 37.7% gave wrong explanations to the concept of hybridisation while 1 student representing 0.8% did not make an attempt in explaining the term hybridisation. This implies that, students had less difficulty in explaining the term hybridisation.

The post-test results also revealed that, 21 of the students representing 17.5% correctly explained the term hybrid orbitals while 87 students representing 72.5% gave wrong explanations. Also, 12 students representing 10.0% did not respond. This implies that students had difficulty in explaining the term hybrid orbitals.

Results from the interview data also revealed that, students had difficulty in learning the concept of hybridisation. For example, regarding the concept of hybridisation, this is what a student said.

> Researcher*: The hybrid orbitals formed after hybridisation have a higher energy than the individual orbitals mixed. Explain your answer.*
> Student 1*: (Correct response): ''The orbitals mixed always have a higher energy which makes the hybrid orbitals formed to have a lower energy".*
>
> Student 2 *(wrong response): ''The individual orbitals are strong and stable when mixing them due to the type of hybridisation".*
>
> Student 3 *(wrong response): ''Hybrid orbital is the central atom in which hybridisation is formed with the same energy and shape".*
>
> Student 4 *(wrong response): ''Individual orbitals have low energy and when mixed will have orbitals with increasing energy".*

Also, students had difficulty in defining the concept of hybridisation. This was evident in some of their definitions as follows:

> Researcher*: Explain the term hybridisation.*
> Student 20 *(wrong response): ''hybridisation is a mixing of orbital to form the same orbital",*
> Student 15 *(correct response): ''hybridisation is the mixing up of two or more different atoms of the same energy and shape to form a new hybrid orbital of the same energy and shape",*
> Student 8 *(wrong response): '' hybridisation is the mixing of two or more atomic orbitals of different energy and shape to form a new bond"*

Many of the students also had difficulty in explaining the term hybrid orbitals. This is what they had to say:

> Researcher*: Explain the term hybrid orbitals.*
> Student 3 (correct response)*: They are orbitals formed when two or more orbitals of different energies and shapes mix to form new orbitals of equivalent energy and shape*
> Student 12 (wrong response): *'these are point use different the two or more - bond energy all together",*
> Student 8 (wrong response): *''is defined as the covalent molecular atom as the result of the head-on overlap of orbitals", '*
> Student 18 (wrong response): *'is the mixing of two or more orbitals when new orbitals are formed in different energy and shape".*

Students also could not state the effect that hybridisation has on bonds. Example of their responses are seen in the excerpts below:

> Researcher: *what is the effect of hybridization on bonds?*
> Student 5: *''Hybrid orbitals predict equal energy and shape"*
> Student 4: *''The hybridisation has ground state",*
> Student 11: *''The outermost electrons take part in the bonding"*

Students had difficulty in writing the ground and excited-state electron configuration of $_6C$. For example, below are some of the student's responses:

Researcher: write the ground and excited state electron configuration of $_6C$.
Student 3: *s^1, s^2; S^1, s^2; spy spx spz*
Student 5: *$1s^2$ $2s^2$ $2px^2$; $1s^1$ $2s^1$ $2px^1$ $2py^1$ $2pz^1$*
Student 16: *'$1s^2$ spx^2 spy^2; s^2 spx^2 spy^2*

Again, many of the students were not able to state the number of hybrid orbitals in $_6C$. The excerpts below are some of their responses:

Student 1 (wrong response): *4*
Student 9 (wrong response): *four sp^3*
Student 2 (wrong response): *sp^2*
Student17 (wrong response): *one type of hybrid thus sp*

Formation of Sigma and Pi bonds

Table 2 shows the difficulties students had in the concept of formation of sigma and pi bonds. These difficulties are revealed in their responses to items in the hybridisation achievement test.

Table 2
Learning Difficulty of Students on the Formation of Sigma and Pi Bonds

Learning Difficulty	Response	Pre-test		Post-test	
		f	%	*f*	%
Formation of C = C double bond in ethene.	NR	103	85.8	47	39.2
	WR	17	14.2	70	58.3
	CR	-	-	3	2.5
Formation of pi bond and sigma bond using an electronic diagram.	NR	81	67.5	15	12.5
	WR	38	31.7	81	67.5
	CR	1	0.8	24	20.0
Formation of sigma and pi bonds in Ethyne (H - C≡ C - H).	NR	88	73.3	28	23.3
	WR	32	26.7	86	71.7
	CR	-	-	6	5.0

(From researchers' data, 2021).
NR -No Response, WR - Wrong Response, CR – Correct Response

The pre-test results revealed that, many of the students gave wrong responses or did not respond to the items on the formation of C = C double bond in ethene, formation of pi bond and sigma bond using an electronic diagram and the formation of sigma and pi bonds in ethyne (H - C≡C-H). This implies that, the concept of formation of sigma and pi bonds before the instruction, was difficult for students.

The post-test results revealed that, only 3 students (2.5%) of the students correctly used an appropriate diagram to explain the formation of C = C electron double bond in ethene while 70 students (58.3%) gave wrong explanations, and 47 students (39.2%) did not respond. The high percentage implies that, students had difficulty in explaining the formation of C = C double bond in ethene.

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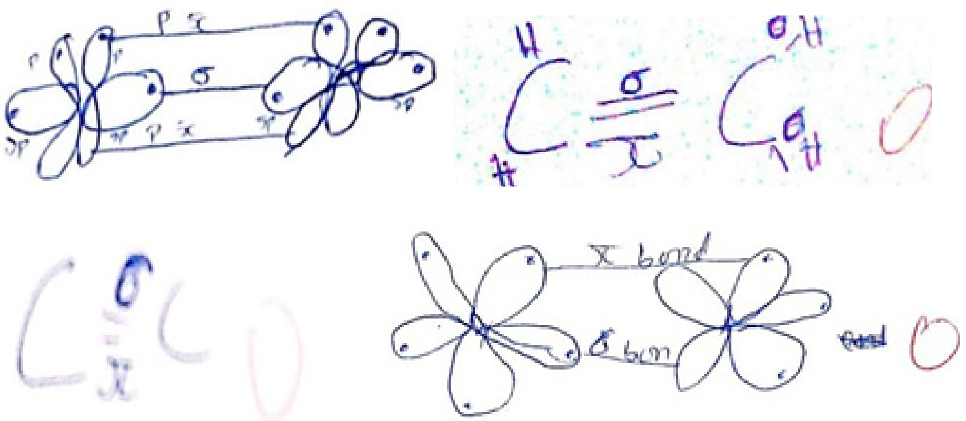
Results from the interview data also revealed that, students had difficulty in learning the concept of formation of sigma and pi bonds in ethene. Some students' responses are presented in Figure 1 below. That is, the majority of students had a difficulty in drawing the trigonal planar shape of Carbon and indicating the unhybridized $2p_z$ orbital for the formation of sigma and pi bonds in ethene.

Figure 1

Students' diagrammatic representation of the C = C bond in an alkene

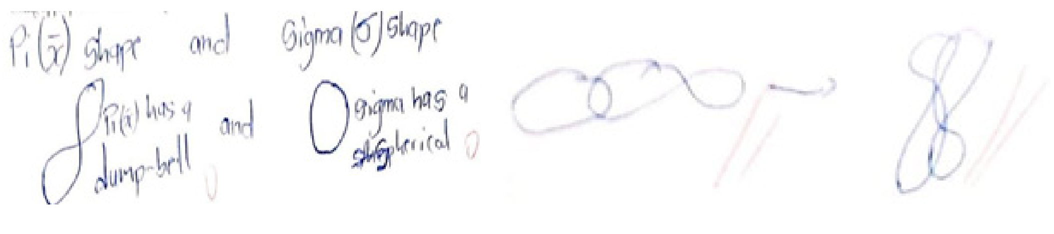


In addition, the post-test results also revealed that, 24 students (20.0%) of students correctly used the appropriate electron diagram to differentiate between the formation of pi bond and sigma bond while 81 students (67.5%) gave wrong explanations, and 15 students (12.5%) did not respond. This implies that, students had difficulty in explaining the formation of pi and sigma bonds in ethene.

Also, students could not use electronic diagrams to differentiate between pi and sigma bonds. The majority of students had difficulty in using s, p, and d hybrid orbitals to differentiate between the formation of pi and sigma bonds. Figure 2 shows a sample of students' drawings.

Figure 2

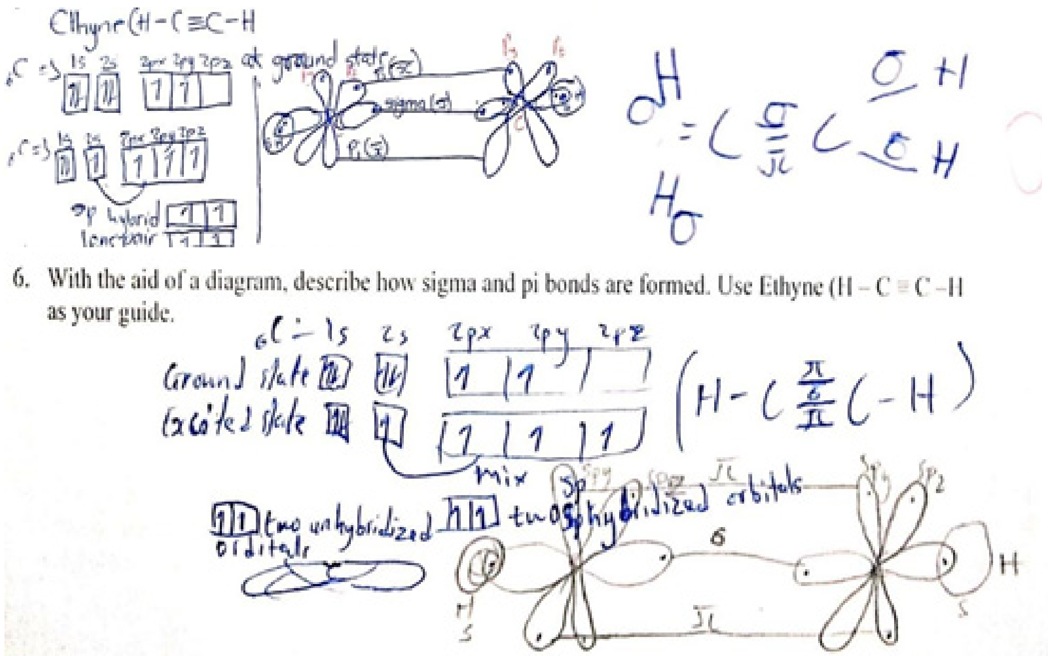
Students' Drawings of pi and sigma Bonds



However, some 6 students (5%) correctly used orbital diagram to describe the formation of sigma and pi bonds in ethyne (H – C ≡ C – H), while 86 students (71.7%) could not describe the bonding in ethyne using orbital diagrams. Moreover, some 28 students (23.3%) did not respond at all. This implies that, majority of students had difficulty in using diagrams to describe the formation of sigma and pi bonds in ethyne. Figure 3 shows samples of students' drawings.

Figure 3

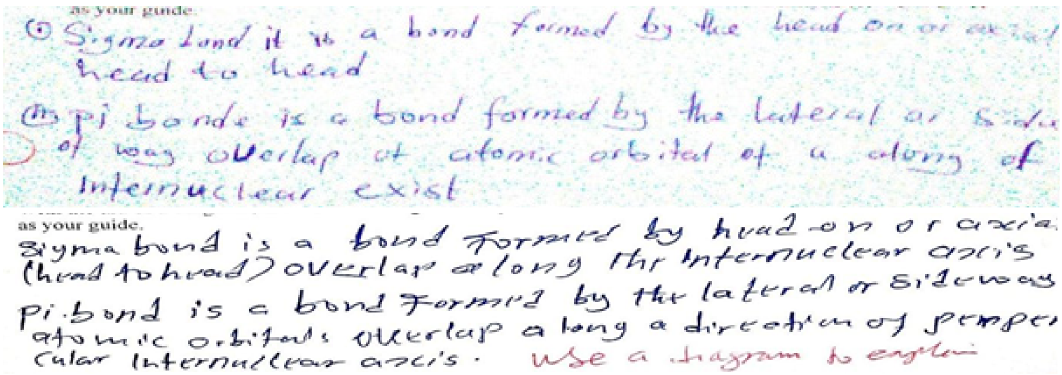
Students' Drawings of the Formation of sigma and pi Bonds in Ethyne



Some other students gave explanations of the formation of sigma and pi bonds without illustrating with orbital diagrams. However, these explanations were wrong. Figure 4 shows samples of students' explanations.

Figure 4

Students' Explanation of the Formation of pi and sigma Bonds



Furthermore, students had difficulty in explaining that a triple bond consists of one sigma bond and two pi bonds. This is what some students had to say:

Researcher: *Explain the type and number of bonds in ethyne.*
Student 1: *ethyne have two pi bonds and one sigma bond*
Student 16*: you can use carbon to explain all the hybridisation – sp, sp^2 and sp^3*
Student 9: *the one sigma and one pi bonds have a small degree of overlap*

Students could not also explain the number of sigma and pi bonds in CO molecule.

Researcher: *How many sigma and pi bonds are in CO? Explain your answer.*
Student 12: *CO has 1 sigma and 1 pi bond because in the excited state is only one electron that is used in the bonding and the one-electron is the sigma bond and the other one is the pi bond*
Student 2: *CO has one sigma, no pi bond…the shape is linear*
Student 18: *CO has one sigma and one pi bond…this is because it is having two lone pair of electrons*
Student 14: *CO has six…because sigma bonds are two and pi bonds are four*

Types and Formation of Hybrid Orbitals

Table 3 shows the results of students' difficulties in the types and formation of hybrid orbitals.

Table 3
Learning Difficulties of Students on the Types and Formation of Hybrid Orbitals

Learning difficulty	Response	Pre-test		Post-test	
		f	%	*F*	%
Describe the formation of sp^3 hybrid orbitals in CCl_4.	NR	83	69.2	32	26.7
	WR	37	30.8	80	66.7
	CR	-	-	8	6.7
Shape and bond angles of sp hybrid orbitals.	NR	73	60.8	7	5.8
	WR	26	21.7	29	24.2
	CR	21	17.5	84	70.0
Type of hybridisation of central atom in NH_3	NR	98	81.7	29	24.2
	WR	19	15.8	42	35.0
	CR	3	2.5	49	40.8
Type of hybridisation of central atoms in OF_2	NR	100	83.3	30	25.0
	WR	20	16.7	47	39.2
	CR	-	-	43	35.8
Type of hybridisation of central atoms in BCl_3	NR	102	85.0	30	25.0
	WR	17	14.2	57	47.5
	CR	1	0.8	33	27.5
Deduction of shape of NH_3	NR	99	82.5	32	26.7
	WR	21	17.5	73	60.8
	CR	-	-	15	12.5
Deduction of the shape of OF_2	NR	101	84.2	32	26.7
	WR	19	15.8	73	60.8
	CR	-	-	15	12.5
Deduction of the shape of BCl_3	NR	102	85.0	37	30.8
	WR	17	14.2	64	53.3
	CR	1	0.8	19	15.8

Type of hybridisation of central atom in CO_2	NR	82	68.3	10	8.3
	WR	28	23.3	40	33.3
	CR	10	8.3	70	58.3
Type of hybridisation of central atom in SiO_2	NR	85	70.8	11	9.2
	WR	35	29.2	78	65.0
	CR			31	25.8
Type of hybridisation of central atom C_2H_2	NR	93	77.5	13	10.8
	WR	26	21.7	70	58.3
	CR	1	0.8	37	30.8
Type of hybridisation of central atom in BeF_2	NR	95	79.2	16	13.3
	WR	20	16.7	60	50.0
	CR	5	4.2	44	36.7
Type of hybridisation of central atom in C_2H_4	NR	95	79.2	17	14.2
	WR	22	18.3	76	63.3
	CR	3	2.5	27	22.5
Shape of CO_2	NR	82	68.3	22	18.3
	WR	31	25.8	44	36.7
	CR	7	5.8	54	45.0
Shape of SiO_2	NR	89	74.2	24	20.0
	WR	31	25.8	80	66.7
	CR	0	0.0	16	13.3
Shape of C_2H_2	NR	94	78.3	23	19.2
	WR	25	20.8	64	53.3
	CR	1	0.8	33	27.5
Shape of BeF_2	NR	94	78.3	27	22.5
	WR	23	19.2	56	46.7
	CR	3	2.5	37	30.8
Shape of C_2H_4	NR	96	80.0	26	21.7
	WR	24	20.0	78	65.0
	CR	-	-	16	13.3

(From researchers' data, 2021).
NR – No Response, WR – Wrong Response, CR – Correct Response

The pre-test results revealed that, many of the students gave wrong responses or did not respond to the items on the formation of sp^3 hybrid orbitals in CCl_4, shape and bond angle of sp hybrid orbitals, the type of hybridisation of the central atoms in and shape of NH_3, OF_2, BCl_3, CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4 molecules. This implies that, before the instruction, students had difficulties in the concept of types and formation of hybrid orbitals.

The post-test results revealed that, 8 students (6.7%) correctly explained the formation of sp^3 hybrid orbitals in CCl_4 while 80 students (66.7%) gave wrong explanations, and 32 students (26.7%) did not respond. The high percentages of wrong and no response implies that, students had difficulty in explaining the formation of sp^3 hybrid orbitals in CCl_4 with diagrams.
The majority of students could not use a diagram to explain the formation of sp^3 hybrid orbitals in CCl_4 given an s and three p orbitals.

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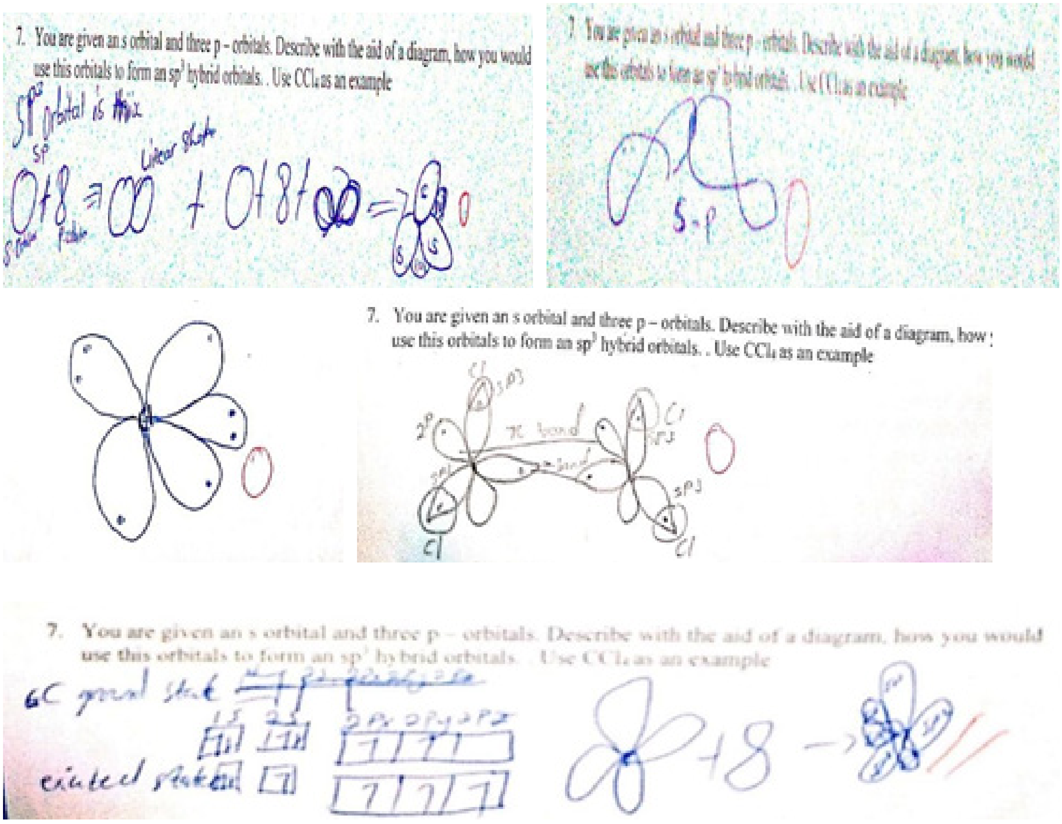
In addition, some of the students drew the electron configuration of C but could not mix the s and p orbitals to draw the tetrahedral shape of the sp^3 hybrid orbital. Some samples of students' responses are presented in Figure 5.

Figure 5

Students' Responses on the Formation of sp^3 Hybrid Orbitals in CCl_4



It was also revealed in the post-test that, 84 students representing 70.0% correctly used diagrams to explain the shape and bond angle of sp hybrid orbitals. Also, 29 students representing 24.2% gave wrong explanations while 7 students (5.8%) did not respond. This implies that most of the students had less difficulty in explaining the shape and bond angle of sp hybrid orbitals.

Also, the post-test results showed that, 49 students (40.8%) correctly stated the type of hybridisation of the central atom in NH_3 while 42 students (35.0%) stated wrongly and 29 students (24.2%) not answering. Also, 43 students (35.8%) correctly stated the type of hybridisation of central atom in OF_2 while 47 students (39.2%) gave wrong responses, and 30 students (25.0%) did not respond. With the type of hybridisation of the central atom in BCl_3, 33 students (27.5%) gave correct response while 57 (47.5%) gave wrong responses, and 30 students (25.0%) did not respond. This implies that, students had difficulties in stating the type of hybridisation of the central atoms in NH_3, OF_2 and BCl_3.

Furthermore, post-test results revealed that, 15 students representing 12.5% deduced the shape of NH_3 correctly while 73 students (60.3%) provided wrong responses, and 32 students (26.7%) did not respond. Also, with the shape of OF_2, 15 students (12.5%) correctly deduced the shape while 64 students (53.3%) gave wrong response, and 32 students (26.7%) did not respond. For BCl_3 molecule, 19 students (15.8%) deduced the shape correctly while 64 students

(53.3%) gave wrong responses, and 37 students (30.8%) provided no response. This implies that, students had difficulty in deducing the shape of NH_3, OF_2 and BCl_3.

The results further revealed that, 70 (58.3%), 31 (25.8%), 37 (30.8%), 44 (36.7%) and 27 (22.5%) students provided correct responses on the type of hybridisation of the central atoms in CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4 respectively. Also, 40 (33.3%), 78 (65.0%), 70 (58.3%), 60 (50.0%) and 76 (63.3%) students gave wrong responses on the type of hybridisation of the central atoms in CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4 respectively.

The post-test results also revealed that, 54 (45.0%), 16 (13.3%), 33 (27.5%), 37 (30.8%) and 16 (13.3%) of students stated correctly the shapes of CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4 respectively. Also, 44 (36.7%), 80 (66.7%), 64 (53.3%), 56 (46.7%) and 78 (65.0%) gave wrong responses on the shapes of CO_2, SiO_2, C_2H_2, BeF_2 and C_2H_4 respectively.

Interview responses from students also revealed students' difficulties in the concept types and formation of hybrid orbitals.

Researcher: *The central atom C in CH_4 is sp^3 hybridised. Explain your answer.*
Student 3: *"the core atom of CH_4 is sp orbital";*
Student 16: *"because C in CH_4 has two lone pair of electrons and is bent in the form";*
Student 7: *"because the lone pair of electrons on C in CH_4 will move them down"*

Also, on the type of hybridisation on the carbon atoms in ethyne, students had this to say.

Researcher: *All the carbon atoms in ethyne are sp^2 hybridised. Explain your answer.*
Student 1: *''In Ethyne there is one pi bond and two sigma bonds which join together to form sp^3 in carbon''.*
Student 2*:''Because all the carbon atoms are having one angle of 109.5 and a shape of trigonal''*
Student 3:*'' You can use carbon to explain all the hybridisation – sp, $sp^{2,}$ and sp^3 ''*

Shapes of Molecular Compounds

Table 4 shows the difficulties students have in shapes of molecular compounds. These difficulties are revealed in their responses to items in the Hybridisation Achievement Test.

Table 4
Students' Learning Difficulties in Shapes of Molecular Compounds

Learning difficulty	Response	Pre-test		Post-test	
		f	%	*f*	%
Explain why H_2O is not a linear molecule using hybridisation.	NR	59	49.2	19	15.8
	WR	59	49.2	50	41.7
	CR	2	1.7	51	42.5
Explain why CO_2 is a linear molecule using hybridisation.	NR	69	57.5	17	14.2
	WR	51	42.5	50	41.7
	CR	-	-	53	44.2
Explain why NH_3 and H_2O have bond angles of 107^0 and 104.5^0 respectively.	NR	92	76.7	40	33.3
	WR	28	23.3	70	58.3
	CR	-	-	10	8.3

Draw an orbital overlap diagram to represent the bonding in the methyl (CH_3) group.	NR	92	76.7	17	14.2
	WR	28	23.3	95	79.2
	CR	-	-	8	6.7
Matching sp, sp^2 and sp^3 hybrid orbitals with shapes of molecules and compounds.	NR	63	52.5	9	7.5
	WR	26	21.7	25	20.8
	CR	31	25.8	86	71.7
With the aid of electron bonded diagrams show the lone pair of electrons and bond pair of electrons present around Al and P in $AlCl_3$ and PCl_3 molecules?	NR	93	77.5	63	52.5
	WR	27	22.5	56	46.7
	CR	-	-	1	0.8
With the help of a diagram show the electron bonding in CO molecule.	NR	10	90.0	56	46.7
	WR	12	10.0	64	53.3

(From researchers' data, 2021).

NR – No Response, WR – Wrong Response, CR – Correct Response

The post-test results showed that, 51 students (42.5%) correctly explained why H_2O is not a linear molecule while 50 students (41.7%) explained wrongly, and 19 students (15.8%) did not respond. This implies that, students had difficulty in using hybridisation to explain why H_2O is not a linear molecule.

Also, 53 students (44.2%) used hybridisation to explain correctly that, CO_2 is a linear molecule while 50 students (41.7%) provided wrong responses, and 17 students (14.2%) did not respond. This also implies that students had difficulty in using hybridisation to explain that CO_2 is a linear molecule.

The post-test results further revealed that, 10 students (8.3%) correctly accounted for the difference in bond angles between NH_3 and H_2O using diagrams while 70 students (58.3%) gave wrong explanations, and 40 students (33.3%) did not respond. This implies that, students had difficulty in using diagrams to account for the difference between NH_3 and H_2O with bond angles of 107^0 and 104^0 respectively.

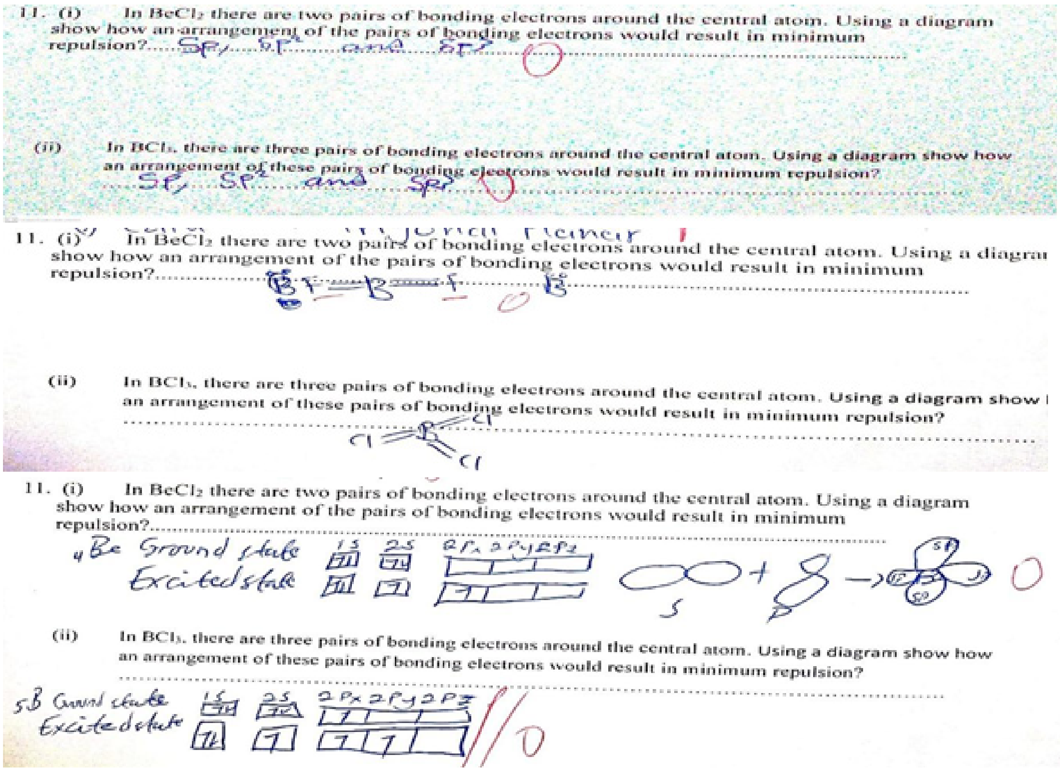
In addition, the post-test results indicated that, 8 students (6.7%) correctly used orbital overlap diagrams to represent the bonding in methyl (CH_3), while 95 students representing 79.2% gave wrong responses, and 17 students (14.2%) did not respond. This implies that, majority of the students had difficulty in using orbital overlap diagrams to represent the bonding in methyl (CH_3).

The results from the post-test show that, none of the students could use a diagram to show the bonding in CO molecule while 64 students (53.3%) gave wrong response, and 56 students (46.7%) did not respond. This implies that, students had a difficulty in using diagrams to show the bonding in CO molecule.

The results revealed that majority of students were not able to use diagrams to show the arrangement of bonding electrons in $BeCl_2$ and BCl_3. Figure 6 shows samples of students' responses.

Figure 6

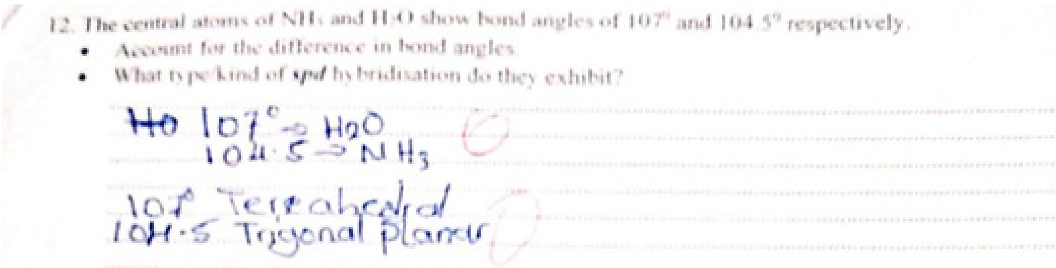
Student's Drawings of the Bonding in $BeCl_2$ and BCl_3



Students could not account for the difference in bond angles in NH_3 and H_2O. Figure 7 shows samples of students' responses.

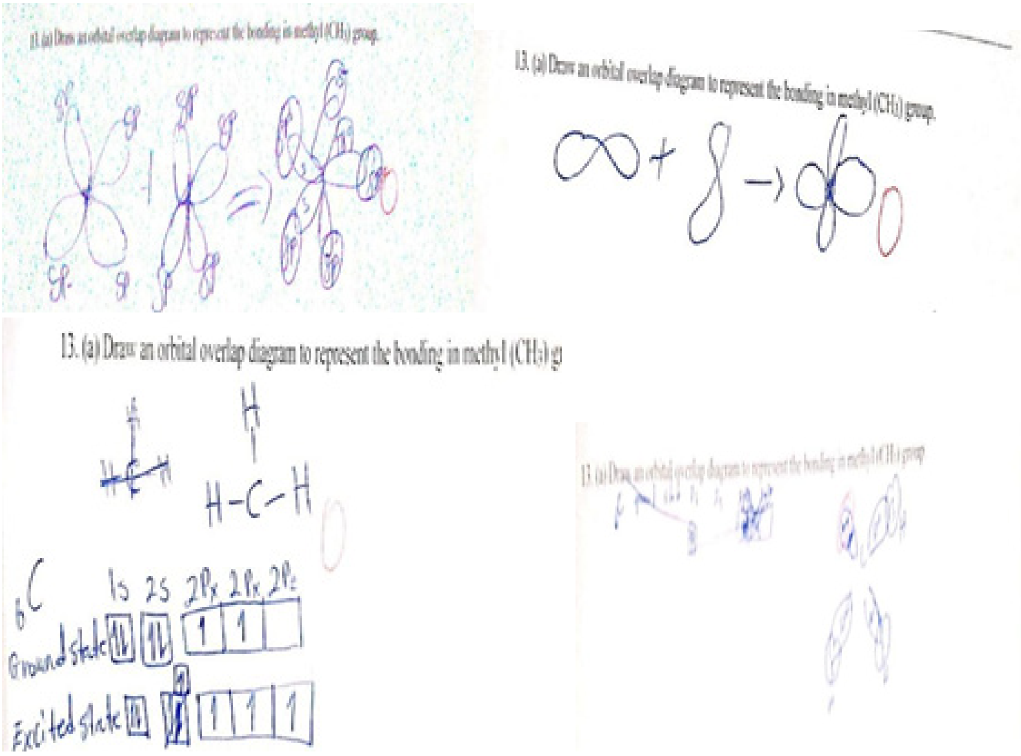
Figure 7

Students' Responses on Bond Angles of NH_3 and H_2O



In addition, students could not draw an orbital overlap diagram to represent the bonding in methyl (CH_3). Majority of students failed to understand that the central atoms in CH_3 and CH_4 are sp^3 with the only difference being the number of Hydrogen atoms in the tetrahedral structure. The difficulty of students is seen in some of their responses as shown in Figure 8.

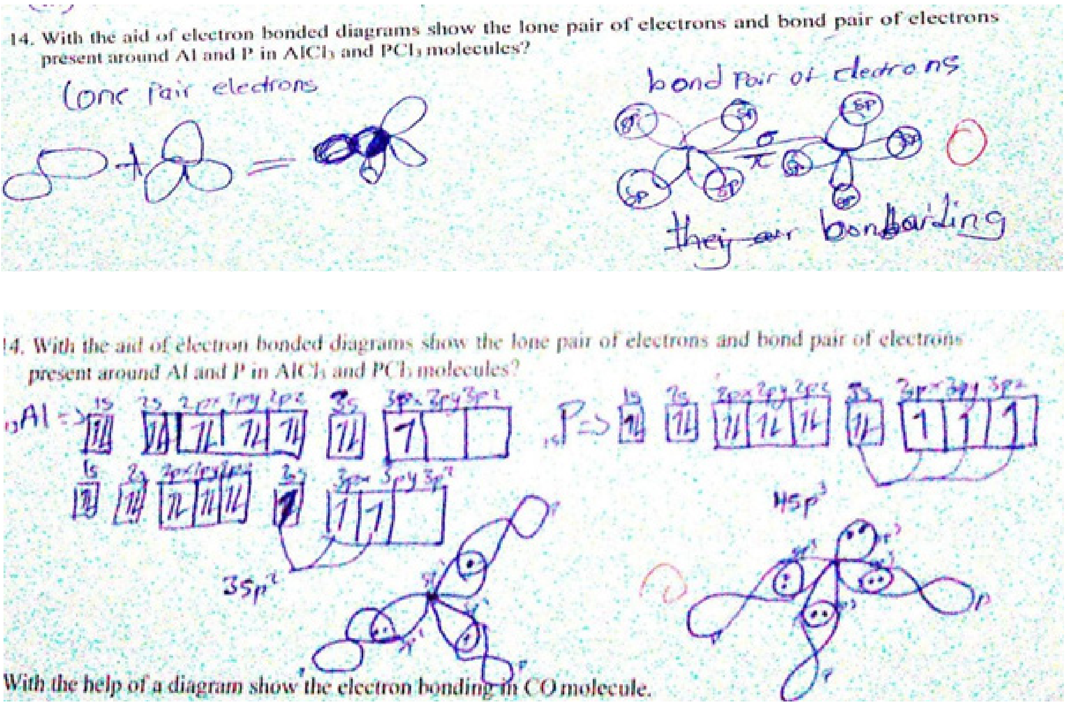
Figure 8
Students' Drawings on Bonding in Methyl (CH_3)



Furthermore, students were not able to use orbital diagrams to show the number of lone pair and bond pair electrons of Al and P in $AlCl_3$ and PCl_3 molecules. Majority of the students could not draw the orbital diagrams and identify the bond pair and lone pair electrons in $AlCl_3$ and PCl_3.

Figure 9

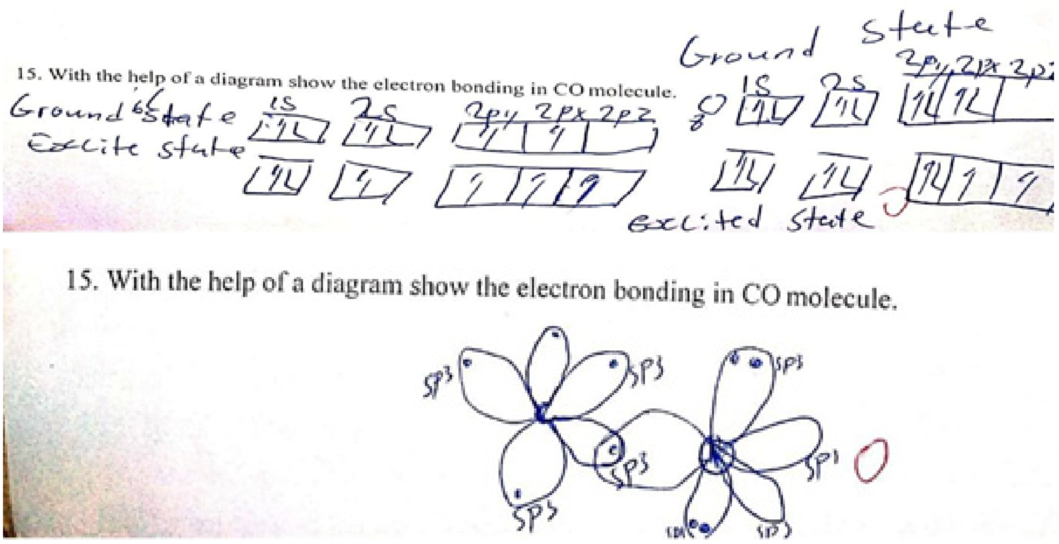
Students' Drawings of Bonding in $AlCl_3$ and PCl_3 Molecules

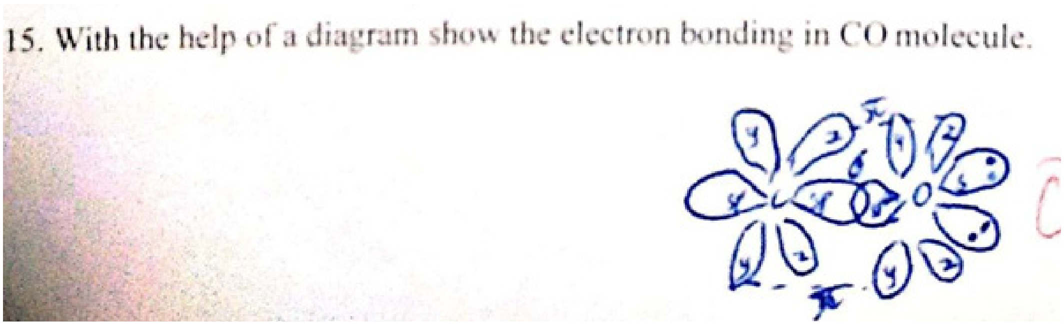


Students had difficulty in showing the bonding in CO. Some of the responses from students are shown in Figure 10.

Figure 10

Students' Drawings on the Bonding in CO Molecule





Discussion

The results revealed that, 61.7% of the students were able to correctly define the concept of hybridisation while 37.5% gave incorrect definitions. The findings are consistent with that of Çalış (2018) who reported that the number of students who correctly explain the definition of the hybridisation concept with their own census is 35%. Çalış (2018) identified that 20% of the students considered the bonds made by the carbon atom as hybridisation, while 25% of the students define hybridisation as bringing orbitals in different energy levels to the same energy level. The findings supported that the misconceptions in the definitions reported by Çalış (2018) since 37.5% of students could not define hybridisation. In a study about hybridisation and atomic orbitals, Nakiboğlu (2003) stated that the students could not identify hybrid types or define the hybridisation concept. In his study, Zoller (1990) stated that the students confused the hybridisation concept with electronic orbitals and could not really define it. Taber (2001) revealed that the students thought that electrons in hybrid orbitals were the s, p, d atomic orbitals and they stated that hybrid orbitals were similar to atomic orbitals.

Fifty percent (50%) of students stated correctly the effect of hybridisation on bonds while 30% gave wrong responses. Many of the students (55.8%) were able to write the ground state configuration of carbon, while 41.2% of them could not. Also, majority of the students (63.3%) were able to write the excited state configuration of carbon, while 34.2% of them could not. Majority of the students (64.2%) could not state the number of hybrid orbitals of carbon.

However, Hanson et al., (2012) in their study found that more than half of the participants did not understand the meaning of the term, hybridisation. They reported that 72 of the participants (93.2%) failed to respond correctly to the set question on the hybridisation or did not answer it at all. The study also found that 72.5% of students gave wrong definitions of hybrid orbitals. This finding agrees with the work of Hanson et al., (2012) who reported that students had a better conceptual understanding of the concept of atomic orbitals.

The majority of students had difficulty in stating the type of hybridisation in and shapes of NH_3, OF_2, BCl_3, CO_2, SiO_2, C_2H_2, BeF_2, and C_2H_4. Koomson et al., (2020) also found that, students struggled to identify the hybridisation of central atoms in molecules. Students could not also state the bond angle of BCl_3 and C_2H_2, and they could not relate bond angles to the shape of molecules. They reported that some students struggled to identify the hybridisation state of central atoms in molecules, that others were perplexed by the bond angles of BCl_3 and C_2H_2 and couldn't relate the shape of the molecular species, that students couldn't define hybridisation, that students had a poor understanding of hybridisation's contributing effect on bonds, and that student's diagrammatic poor representation of why water is not a linear molecule.

Again, students could not explain why the central atom in CH_4 is sp^3 hybridised. Furthermore, many of the students failed to explain correctly why all the carbon atoms in ethene are sp^2 hybridised and why the carbon atoms in ethyne are sp hybridised. Majority of the students could not explain the bond angles of molecules such as NH_3 and H_2O. Hanson et al.,

(2012) reported that students experience conceptual difficulty as a result of understanding the meaning of s, p, d and f orbitals and how they are oriented in space. Again, the results confirmed the findings of 2. Nakiboğlu (2003) and Hanson et al., (2012) that, pre-service teachers they used for their study displayed major misconceptions about atomic orbitals and hybridisation and students were unaware of the role hybridisation played in the formation of covalent bonds. Çalış (2018) supported with his findings that, 75% of students could not accurately demonstrate how sp, $sp^{2,}$ and sp^3 hybrid orbitals were formed while 25% could.

Tilahun, and Tirfu (2016) reported that students had poor knowledge in the concept of hybridisation orbital like sp, sp^2, and sp^3 which are the bases of chemical bonding. They did not recognize the importance of sp, sp^2 and sp^3 in determining single, double, and triple bonds respectively. Çalış (2018) further found that 25% of the students were able to show the sp, sp^2 and sp^3 hybrid orbital formations correctly and recognize these orbitals. These students also did not specify how many identical hybrid orbits were formed, although they could show the formation of sp^3, sp^2 and sp hybrid orbital from the p orbital with s orbital. Also, most of the students did not show the hybrid orbital formation correctly. This result is also seen as a result of students' tendency to learn by memorizing the hybridisation phenomenon.

The majority of students were not able to use diagrams to show the arrangement of bonding electrons in $BeCl_2$ and BCl_3. Also, most of the students (57.5%) in the post test results had difficulty in explaining why H_2O is not a linear molecule. This supports the findings of Koomson et al., (2020) that students could not draw and represent with diagrams explanations of why water is not a linear molecule.

The results also showed that students could not correctly state the hybridisation of the central atoms in NH_3, H_2O, OF_2, CO_2 and SiO_2. This is consistent with other findings. For example, Uyulgan and Akkuzu (2016) in a study on conceptual understanding of the molecular structures of compounds found that 49.6% of students were not able to give the hybrid type of the central atom in the molecules while other students (31.6%) gave mostly incorrect answers, showing that the students had difficulty in identifying the hybrid type. Also, students had misconceptions about hybridisation. The students were not able to state that hybrid orbitals occur as a result of overlapping of orbitals.

Conclusions

In general, from the study most of the students had difficulty in understanding the concept of hybridisation. However, the concept of hybridisation is one of the key topics science students need to have adequate understanding to progress in the field of chemistry. This is because knowledge of hybridisation is pre-requisite to learning other topics in chemistry such as chemical bonding and organic chemistry. Unfortunately, research found that hybridisation is difficult to understand by most students at all levels of schooling. In order to find ways of minimizing the difficulties students encounter in learning hybridisation, the root cause as well as the specific areas of the concept students find to be more problematic must be known.

It is therefore important to detect and take into consideration students' prior conceptions when planning chemistry lessons. Understanding the concept of hybridisation requires the connection of different abstract concepts such as atomic orbitals, chemical bonding, and molecular compounds. This work found out the peculiar hindrances that impede senior high school science students understanding of the concept of hybridisation.

The major areas of difficulties in learning hybridisation identified from the study included the inability of students to:

- define the concept of hybridisation,
- explain the types and formation of hybrid orbitals,
- explain the formation of sigma and pi bonds in ethene and ethyne,

- draw electron orbital diagrams of some molecules, and
- draw the shapes of molecules.

There is the need for chemistry teachers to use student-cantered teaching approaches that will foster understanding of students in hybridisation. Again, teachers should use teaching and learning materials such as molecular/atomic models to teach hybridisation for conceptual understanding. In addition, conceptual methods and analogies should be used to teach shapes of hybrid orbitals and their orientations. Emphasis should be placed on the relationship the type of hybridisation of the central atom has on the molecular geometry of a molecule. For students to gain conceptual competency on the covalency of hybrid orbitals in bond formation, they must be introduced to more worked examples.

It is therefore suggested that further research on using cutting-edge instructional technology or teaching learning materials should be conducted to minimize if not eliminate the learning difficulties associated with the findings of the research.

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Declaration of Interest

The authors declare no competing interest.

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